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Intertidal shellfish monitoring in the northern North Island region, 2018–19

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Berkenbusch, K.; Neubauer, P. (2019). Intertidal shellfish monitoring in the northern North Island region, 2018–19.

***New Zealand Fisheries Assessment Report 2019/32*. 106 p.**

Coastal bivalve species such as cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*) are widely distributed throughout New Zealand, where they support recreational and customary fisheries in different coastal environments. In northern North Island, regular monitoring of cockle and pipi populations that are targeted in non-commercial fisheries provides data on their abundance and population size structure. This monitoring programme assesses bivalve population across different northern sites each year, including estuaries, bays and large inlets in Northland, Waikato, Bay of Plenty and the wider Auckland region. These surveys collect data on the population status of cockle and pipi populations, and allow temporal comparisons of population trends across the northern North Island region.

This study presents the most recent survey findings, based on data from the 2018–19 fishing year. Northern sites included in this survey were (in alphabetical order): Aotea Harbour, Hokianga Harbour, Kawakawa Bay (West), Mangawhai Harbour, Mill Bay, Ngunguru Estuary, Ohiwa Harbour, Otumoetai (Tauranga Harbour), Ruakaka Estuary, Te Haumi Bay, Whangamatā Harbour and Whangapoua Harbour.

All of the 2018–19 survey sites contained cockle populations, with most sites supporting notable population sizes. Abundance estimates ranged from 3.46 million (CV: 12.25%) cockles at Ruakaka Estuary to 222.41 million (CV: 17.52%) cockles at Kawakawa Bay (West). The corresponding density estimates were between 88 cockles per m^2 at Ruakaka Estuary and 1997 cockles per m^2 at Ngunguru Estuary. Density estimates were also high (>1000 individuals per m^2) at Whangapoua, Mangawhai and Whangamatā harbours.

None of the northern sites contained notable numbers of large cockles (≥30 mm shell length), and this size class consistently contributed few individuals to the total population. The highest density estimates of large cockles were just over 30 individuals per m^2 at Mangawhai, Ohiwa and Whangamatā harbours and Te Haumi Beach. This size class was near-absent at Otumoetai (Tauranga Harbour) and Ruakaka Estuary, and the remaining sites had small abundance and density estimates (frequently with high uncertainty) for this size class.

Nine of the current survey sites supported pipi populations, with population sizes varying from an estimated 1.97 million (CV: 13.89%) pipi at Mangawhai Harbour to 91.64 million (CV: 17.84%) pipi at Ruakaka Estuary. Population densities for this species included a low estimate of 27 individuals per m^2 at Mangawhai Harbour to the highest density of 2333 pipi per m^2 at Ruakaka Estuary.

Large-sized individuals (≥50 mm shell length) were absent at two of the sites that supported pipi populations, namely Hokianga and Mangawhai harbours. At the remaining sites, large pipi were scarce, and density estimates varied from 0.45 million (CV: 24.34%) large pipi per m^2 at Te Haumi to 1.44 million (CV: 13.32%) pipi per m^2 at Whangapoua Harbour. Most of the estimates for large pipi had high uncertainty, with a coefficient of variation exceeding 20%.

Sediment sampling at each site documented that cockle strata were generally characterised by a low organic content and a small proportion of sediment fines (silt and clay; grain size <63 µm). Grain size compositions showed some variation across sites, but fine and/or medium sands (grain sizes >125 to >250 µm) made up the bulk of sediment across sites.

1. INTRODUCTION

Marine invertebrate communities in coastal environments include species that are important for commercial, recreational and customary fisheries, such as crustaceans, echinoderms and bivalves (Murray-Jones

& Steffe 2000, Caddy & Defeo 2003, Kinch et al. 2008). In New Zealand, the latter group contains several intertidal bivalve species such as endemic littleneck clam (tuangi/tuaki; *Austrovenus stuchburyi*) and pipi (*Paphies australis*), which occur across a range of sheltered and semi-enclosed embayments, estuaries and harbours throughout the country (Morton & Miller 1973). Both species are valued in recreational and customary fisheries, and their widespread distribution in the intertidal zone and propensity to form high-density beds make them easily accessible to shellfish gathering (Hauraki Māori Trust Board 2003, Hartill et al. 2005, King & Lake 2013).

Population studies of cockles and pipi have revealed variable growth rates for each species, dependent on life stage and environmental conditions (Larcombe 1971, Hooker 1995). Cockles generally attain a maximum size of around 40 mm shell length, although larger sizes have also been recorded. They reach sexual maturity at 18 mm shell length within the second year of growth, growing to 30 mm shell length within two to five years (Larcombe 1971). For pipi, the maximum shell length is 60 mm after three to four years of growth, and this species reaches sexual maturity at about 30 to 40 mm shell length (Hooker 1995).

Both species are suspension feeders and rely on water movement and submergence for the provision of food. As such, they are susceptible to changes in sediment dynamics, including increases in sediment fines (silt and clay, <63 micron grain size), which can impact on their feeding efficiency. Different tolerances for sediment fines mean that cockles and pip occupy distinctly different habitat types, even though both species frequently co-occur in soft-sediment environments.

Cockles have a broad distribution and occur throughout the intertidal zone of New Zealand's mud and sand flats. They tolerate a range of sediment grain sizes, including sediments that contain up to 60% mud; however, their highest densities are usually in sediments that contain less than 11% in this grain size fraction. In comparison, pipi have a more restricted distribution and a lower tolerance of sediment fines. They form high-density beds close to mean low water and in the proximity of tidal channels, with their populations frequently extending into shallow subtidal waters. This species usually prefers coarse and clean sands with a mud content of less than 3%.

The occurrence of cockles and pipi in coastal environments makes them vulnerable to human impacts, such as physical disturbance, overfishing, contaminants and sediment runoff (Grant & Hay 2003).Concerns about overexploitation of shellfish resources in the Auckland area led to the implementation of a regular (usually annual) shellfish monitoring programme in this area in 1994, commissioned by the predecessor of Fisheries New Zealand (e.g., see Morrison & Browne 1999, Morrison et al. 1999). The Auckland monitoring area was subsequently expanded to the northern North Island region (Fishery Management Areas FMA 1 and FMA 9), with sites in Northland, Waikato and Bay of Plenty.

Across the northern region, the monitoring is focused on particular shellfish populations that are considered to be targeted by non-commercial fisheries. Since 1999–2000, the survey methodology has remained largely consistent, obtaining data on the population abundance, density and size structure of cockle and pipi populations (most recently in 2017–18, see Berkenbusch & Neubauer 2018). Recent surveys have also collected sediment data (organic content and grain size composition) to gain an understanding of habitat variables that may determine the distribution and abundance of cockles at the survey sites (Neubauer et al. 2015).

The current report presents the most recent findings of the northern bivalve monitoring programme. Survey results include data on the abundance and population structure of cockles and pipi at 12 selected northern North Island sites. The overall objective of this study was "to determine the distribution, abundance and size frequency of cockles and pipi for 2018/19". Northern sites included in the current survey were (in alphabetical order): Aotea Harbour, Hokianga Harbour, Kawakawa Bay (West), Mangawhai Harbour, Mill Bay, Ngunguru Estuary, Ohiwa Harbour, Otūmoetai (Tauranga Harbour), Ruakaka Estuary, Te Haumi Bay, Whangamatā Harbour and Whangapoua Harbour (Figure 1).

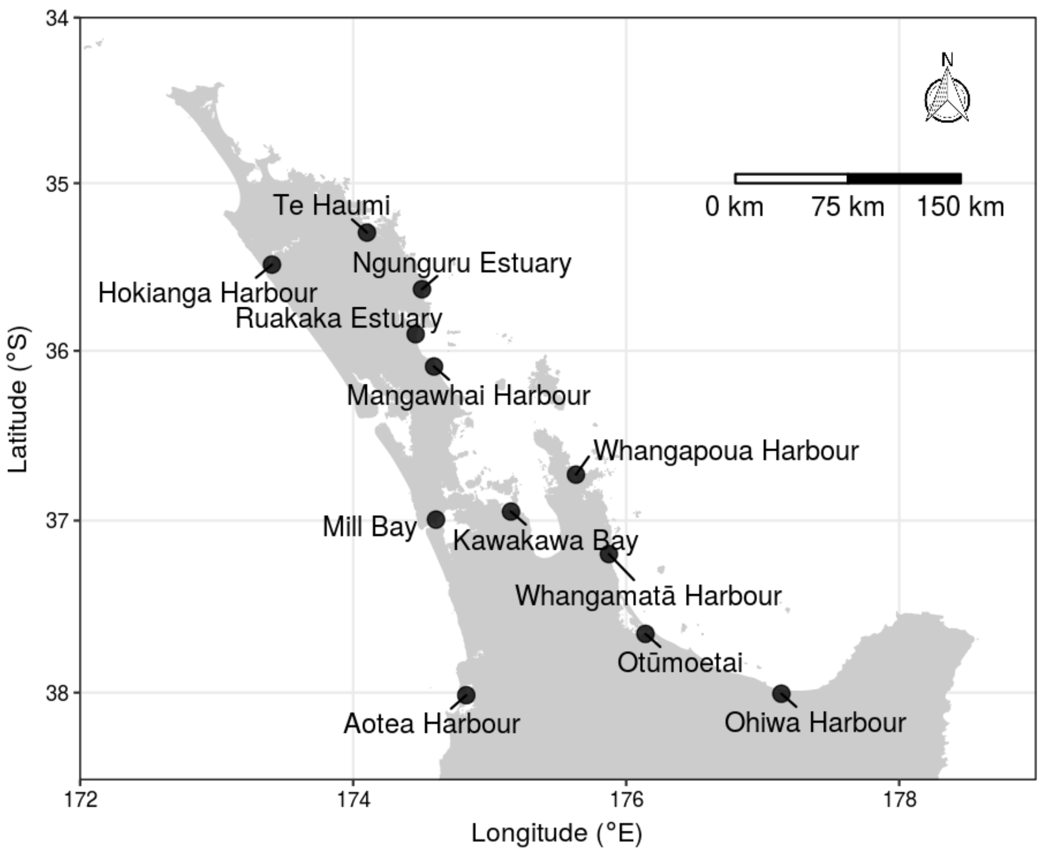


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2018–19.

2. METHODS

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

The methods used in recent surveys are described in detail by Berkenbusch & Neubauer (2016, 2017). For completeness, the methods are included here, following updates to reflect the 2018–19 survey.

2.1 Survey methods

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

Preliminary analyses of cockle density data from previous surveys (2013–14 to 2016–17) using GPS-referenced samples indicated that the previous stratification at individual sites rarely delimited areas of similar characteristics (e.g., homogenous densities) and, therefore, did not necessarily lead to reductions in variance in the estimation of cockle population sizes and densities. For this reason, the high-resolution spatial data (GPS-referenced samples) from previous surveys were used to re-define cockle strata based on the spatial distribution and variability of previous samples (see Berkenbusch & Neubauer 2016).

The number of sampling points for each bivalve population was determined by the population size and variability within each stratum, informed by data from previous surveys. For each stratum, a regular grid was generated, with the size and shape of the grid cells reflecting the desired sampling density and the orientation of the stratum. The intersection of the grid with the boundary of the stratum was taken. For strata with odd shapes, the number of grid cells did not necessarily reflect the number of desired samples; if there were more grid cells than sampling points, not all cells had sampling points allocated to them. In this case, sampling points were allocated across all cells with a probability proportional to the area of the cells.

The position of the point within a cell was randomly allocated. All sampling points were pre-calculated for two phases before the sampling began. All phase-1 points were sampled, whereas sampling of phase-2 points was only carried out when the coefficient of variation (CV) of the total abundance estimate after first-phase sampling exceeded the target value of 20% for either cockle or pipi (i.e., at four sites in 2017–18). The number of required phase-2 samples was calculated using the method of Francis (1984).

Owing to the importance of sediment properties for infaunal bivalves, recent previous surveys included a sediment sampling programme to determine the sediment organic content and grain size at each site (see Berkenbusch et al. 2015, Berkenbusch & Neubauer 2015). The 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 (but the current survey sampled 20 points in the designated cockle stratum at Hokianga Harbour, so that the corresponding number of sediment samples was also 20 at this site). The sediment sampling point allocation was based on a subset of at least six sediment sampling points that was randomly allocated within each cockle stratum, corresponding with a randomly-allocated cockle sampling point. Data from the sediment sampling were used to provide baseline information of current sediment properties, and to build a data set that allows spatial and temporal comparisons in future analyses.

2.2 Field sampling–bivalves

The field survey of the northern North Island sites was conducted in January and February 2019. Over this time, bivalve populations at each site were sampled during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

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

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

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 through a stack of sieves to determine the proportion in each sediment grain size fraction (i.e., >63, >125, >250, >500, and >2000 µm). Sediment retained on each sieve was subsequently dried to constant weight at 60°C before weighing it (accuracy $\pm$ 0.0001 g).

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

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

2.4 Data analysis–bivalves

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

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

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

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

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

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

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

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

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

To estimate the length-frequency distributions at each site, measured individuals were allocated to 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

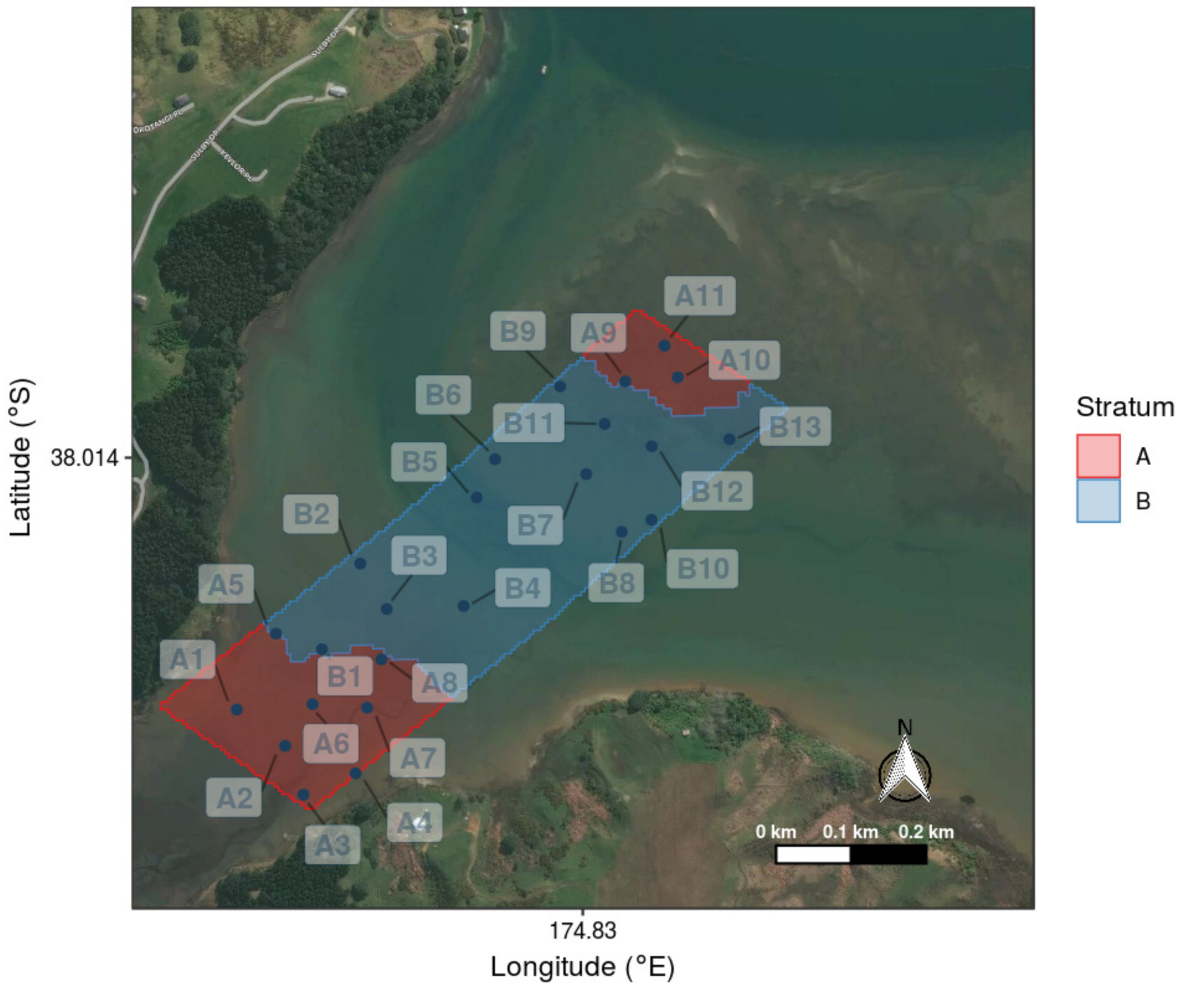
Aotea Harbour is a large tidal inlet on the Waikato west coast. It was first included in the monitoring programme in 2005–06, with four subsequent surveys since then, including the present study (see Appendix A, Tables A-1, A-2). These surveys have solely targeted cockles, as there have been no discernible pipi populations at this site since the start of the survey programme.

Throughout the survey series, the sampling has included the cockle population on the intertidal mudflat south of the main harbour channel; since 2014–15, the sampling has focused on this population only and the sampling extent has remained unchanged. Within this sampling extent, the current assessment sampled a total of 90 points across two strata (Table 1).

The sediment at Aotea Harbour had a low organic content of less than 2.5% (Figure 2, and see details in Appendix B, Table B-3). The grain size composition was dominated by fine (>125 µm grain size) and very fine (>63 µm grain size) sands, with these two fractions making up the bulk of the sediment (54 and 21%, respectively). The proportion of fines (<63 µm grain size) was variable, ranging between 0 and 23%. Similarly, the proportion of gravel (>2000 µm grain size) varied from a low proportion of 0.3% to a maximum of 12.8%.

The cockle population at Aotea Harbour was concentrated in the mid-shore region, in stratum B, which spanned across a side channel and a seagrass area in its lower part (Figure 3). The total population size in 2018–19 was an estimated 82.34 million (CV: 11.06%) cockles, and the density of the total population was 423 cockles per m^2 (Table 2). These values documented an increase in the total population, which was also reflected in an increase in the number of large individuals ($\geq$30 mm shell length): there were 0.96 million (CV: 32.86%) large cockles in 2018–19, after this size class was absent in 2016–17. Within the current population, large cockles occurred at a mean density of two individuals per m^2.

The small number of large cockles meant that this size class only made up a small proportion (1.17%) of the total population in 2018–19 (Table 3). Instead, recruits ($\leq$15 mm shell length) and small-sized individuals dominated the population in recent surveys, with the former size class constituting 22.44% of all individuals in 2018–19 (Table 3, Figure 4). Current mean and modal sizes of 18.64-mm and 20-mm shell lengths were consistent with the prevalence of small and medium-sized cockles. Individuals at these sizes constituted a strong single cohort in the unimodal population, showing little growth to larger sizes over time. While large cockles were scarce, recruits made up a quarter to a third of the population in recent assessments, indicating regular recruitment at this site.



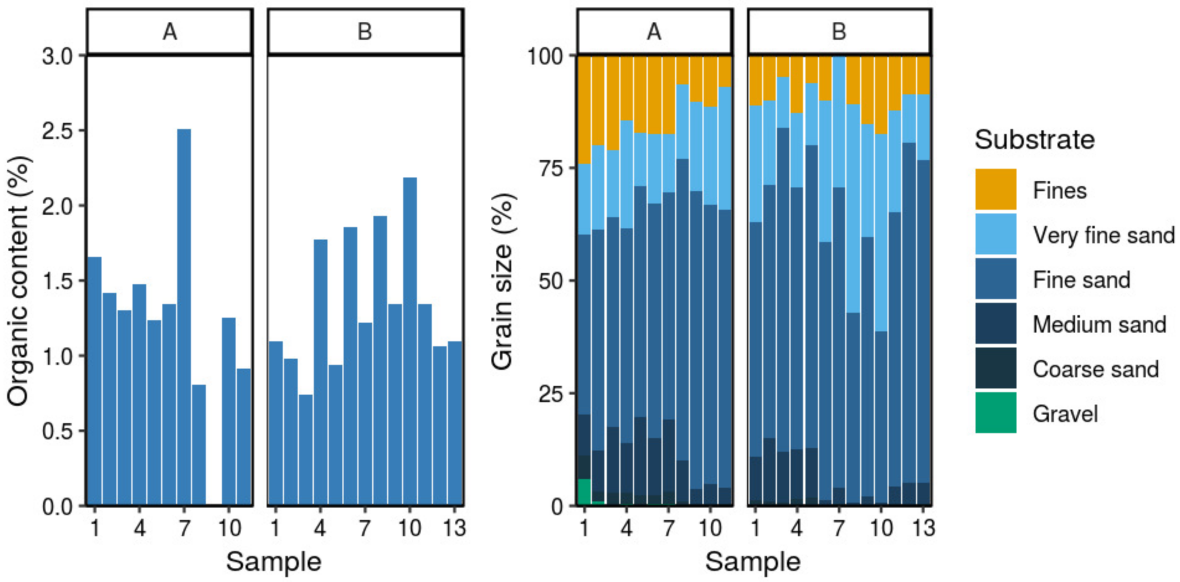


Figure 2: Sediment sample locations and characteristics at Aotea Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Aotea Harbour

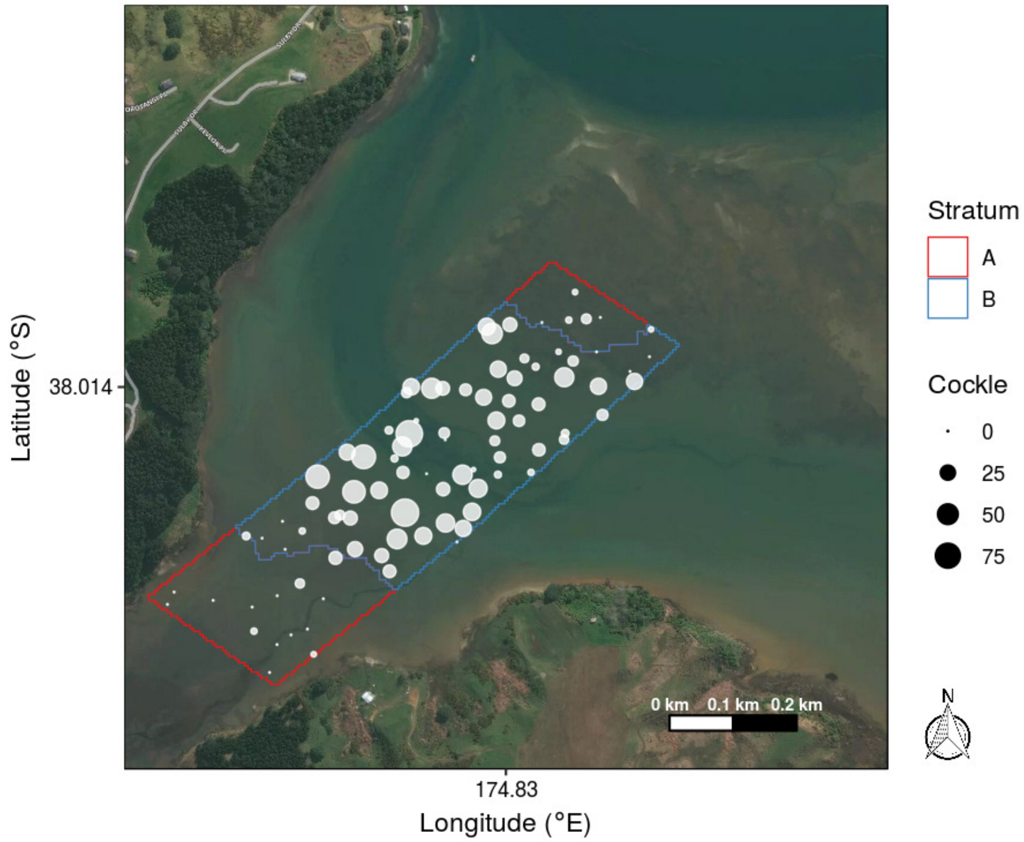


Figure 3: Map of sample strata and individual sample locations for cockles at Aotea Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Aotea Harbour, by stratum, for 2018–19. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	6.7	20	50	4.79	71	40.78
B	12.8	70	1 489	77.55	608	11.47

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	6	17.18
2009–10	28.1	140.78	501	10.54	3.46	4	27.88
2014–15	19.5	74.20	381	13.37	0.55	1	45.13
2016–17	19.5	76.41	393	11.05	0.00	0	
2018–19	19.5	82.34	423	11.06	0.96	2	32.86

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 (%)
2014–15	18.40	19	6–32	24.91	0.74
2016–17	17.06	17	2–29	32.93	0.00
2018–19	18.64	20	5–34	22.44	1.17

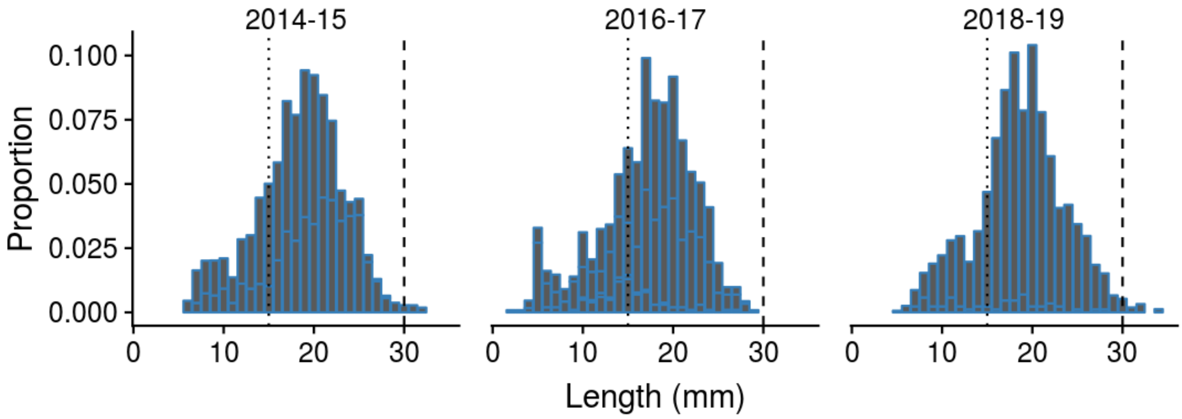


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Aotea Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Hokianga Harbour

Hokianga Harbour is a large tidal inlet in northern Northland, on the west coast of this region. It was added to the bivalve monitoring in the present study, with the field sampling focused on two areas that were identified by local iwi as being targeted in intertidal shellfish gathering (see map in Appendix C). Both areas, Pākanae and Koutu Beach, were on the southern side of the harbour and close to its entrance. At Pākanae, the intertidal sampling area consisted of relatively coarse sediment, interspersed with rocks and cobbles (Appendix C, Figure C-2); here, cockles and pipi were assessed in two small separate beds. At Koutu Beach, the sampling encompassed a more extensive intertidal sandflat area inhabited by a pipi bed (Figure C-3). The bivalve beds and their boundaries were identified and delineated based on local knowledge and on-site reconnaissance, resulting in three separate strata (Table 4). Across this sampling extent, cockles and pipi were assessed at a total of 90 points.

Sediment samples from the cockle stratum in Hokianga Harbour were characterised by a low organic content (<3%) and a varying proportion of sediment fines (grain size <63 µm): the latter ranged from 0.5 to 18.2% across all samples (Figure 5, and see details in Appendix B, Table B-3). Overall, the sediment grain size composition was evenly spread across the fine and medium sand fractions (grain sizes >125 µm and >250 µm), with a small proportion of coarse sand (grain size >500 µm). All of the samples contained some gravel (grain size >2000 µm), including samples that contained a large proportion of sediment in this grain size (i.e., over 40% to a maximum of 64%).

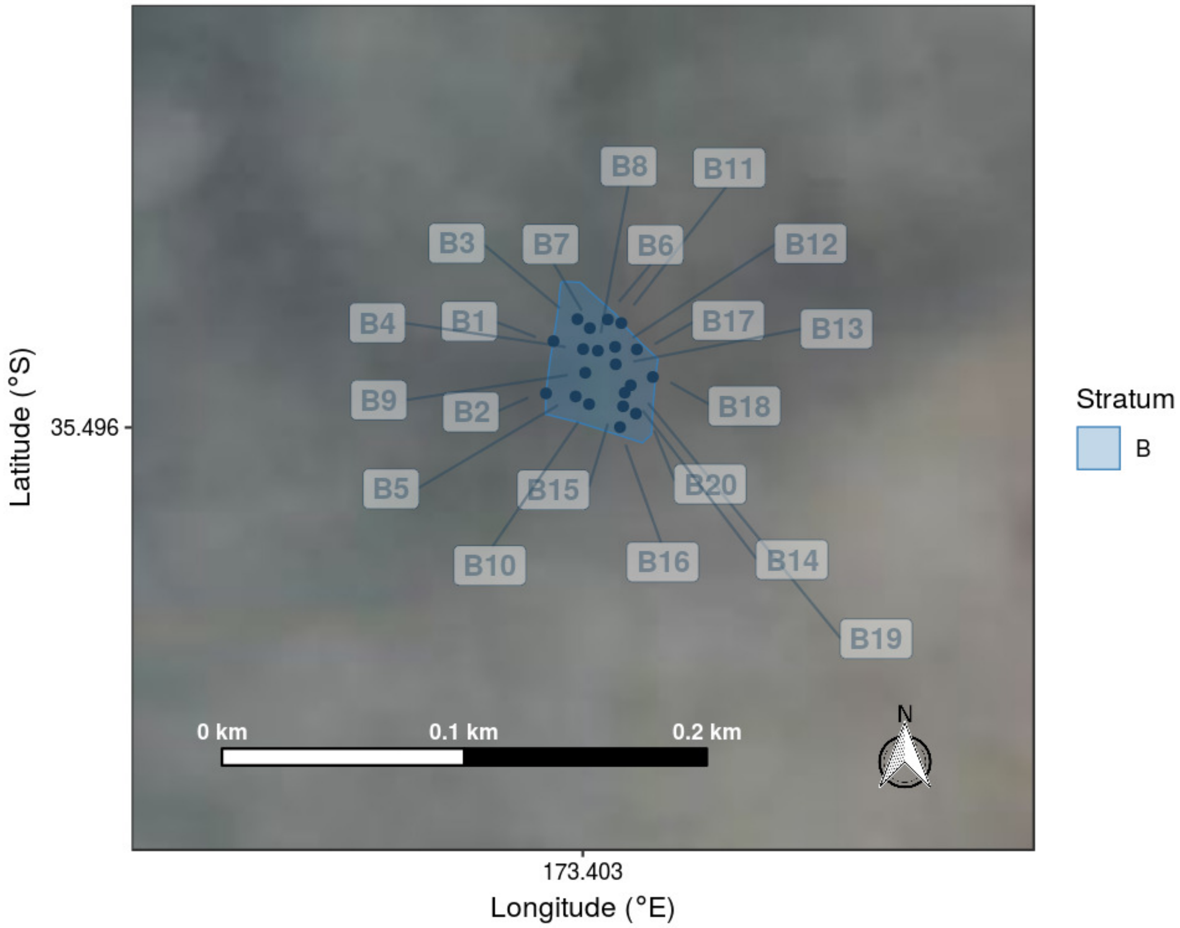
Cockles at Hokianga Harbour were sampled in a small area at Pākanae, where this species was concentrated in stratum B; cockles were also distributed throughout most of the intertidal pipi bed at Koutu Beach, in stratum C (Figure 6, Table 4). Based on the field sampling, the abundance and density of cockles at this site were estimated at a total of 25.54 million (CV: 11.88%) individuals and 254 cockles per m^2 (Table 5). There were few large cockles ($\geq$30 mm shell length) in this population, with an estimated 0.32 million (CV: 49.47%) individuals in this size class. The corresponding mean density was one large cockle per m^2, but the uncertainty of these latter estimates was high (i.e., the CV exceeded 40%).

The low number of large cockles meant that only 1.25% of the population were in this size class (Table 6, Figure 7). Most of the cockles were at small or medium sizes, although recruits ($\leq$15 mm shell length) made up about a third (34.06%) of the population. The high proportion of recruits indicated a significant recruitment event preceding the current field sampling. The influence of recruits and small-sized individuals was reflected in the population size structure: the unimodal population was determined by a modal shell length of 18 mm.

The pipi population at Hokianga Harbour was distributed throughout stratum A at Pākanae and stratum C at Koutu Beach (Table 7, Figure 8). The total abundance estimate of pipi was 87.39 million (CV: 10.87%) individuals, and this species occurred at a mean density of 868 pipi per m^2 (Table 8). The population included few large pipi ($\geq$50 mm shell length), with estimates that indicated a general absence of this size class (and high uncertainty).

Instead, the majority of pipi were small and medium-sized individuals (Table 9, Figure 9). The prevalence of these size classes was evident in the modal shell length of 22 mm. This size parameter also reflected the strong influence of large numbers of recruits ($\leq$20 mm shell length), which constituted 36.17% of the pipi population. The unimodal population was dominated by small-sized individuals.

In summary, both cockle and pipi populations at Hokianga Harbour were dominated by small and medium-sized individuals, whereas large cockles and pipi were scarce. The high proportion of recruits in both populations indicated strong recruitment events prior to the field sampling. Future surveys will help determine whether recruits and small-sized individuals contribute to the adult populations, and if the general absence of large-sized individuals is characteristic of the sampling areas at Hokianga Harbour.



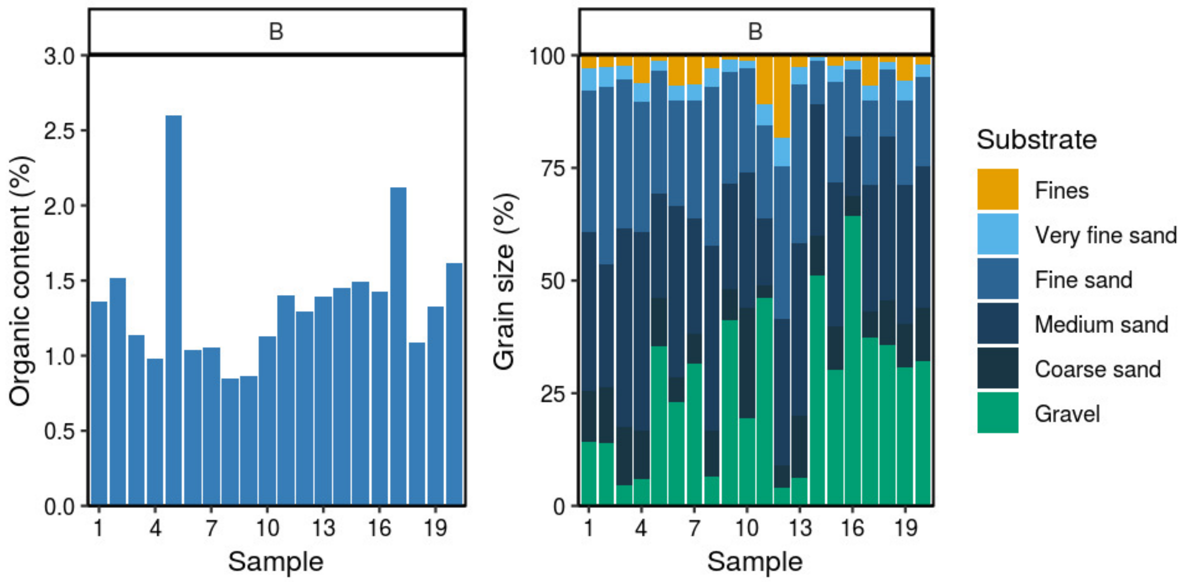


Figure 5: Sediment sample locations and characteristics at Hokianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.2.1 Cockles at Hokianga Harbour

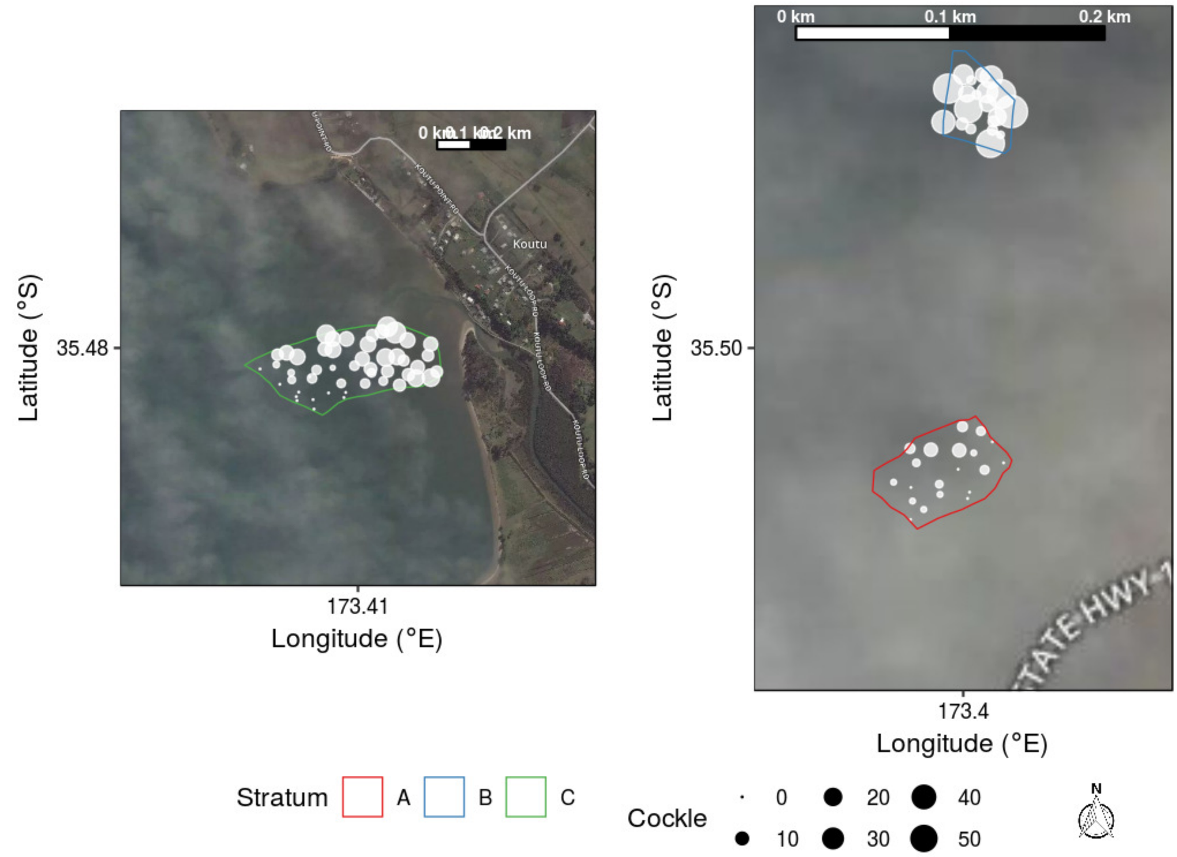


Figure 6: Map of sample strata and individual sample locations for cockles at Hokianga Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of cockle abundance at Hokianga Harbour, by stratum, for 2018–19. 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	0.4	20	39	0.22	56	28.21
B	0.2	20	396	1.20	566	19.09
C	9.5	50	446	24.12	255	12.54

Table 5: Estimates of cockle abundance at Hokianga 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 (%)
2018–19	10.1	25.54	254	11.88	0.32	1	49.47

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2018–19	18.13	18	5–34	34.06	1.25

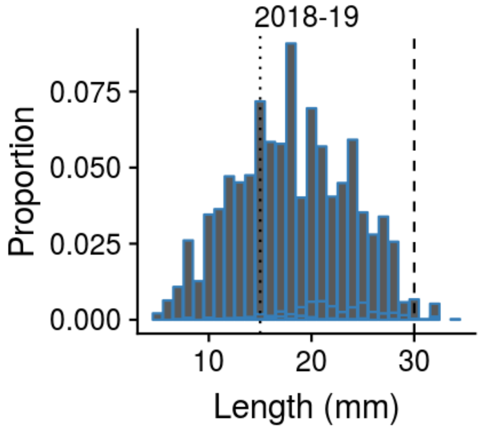


Figure 7: Weighted length-frequency (LF) distribution of cockles for the present survey at Hokianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2.2 Pipi at Hokianga Harbour

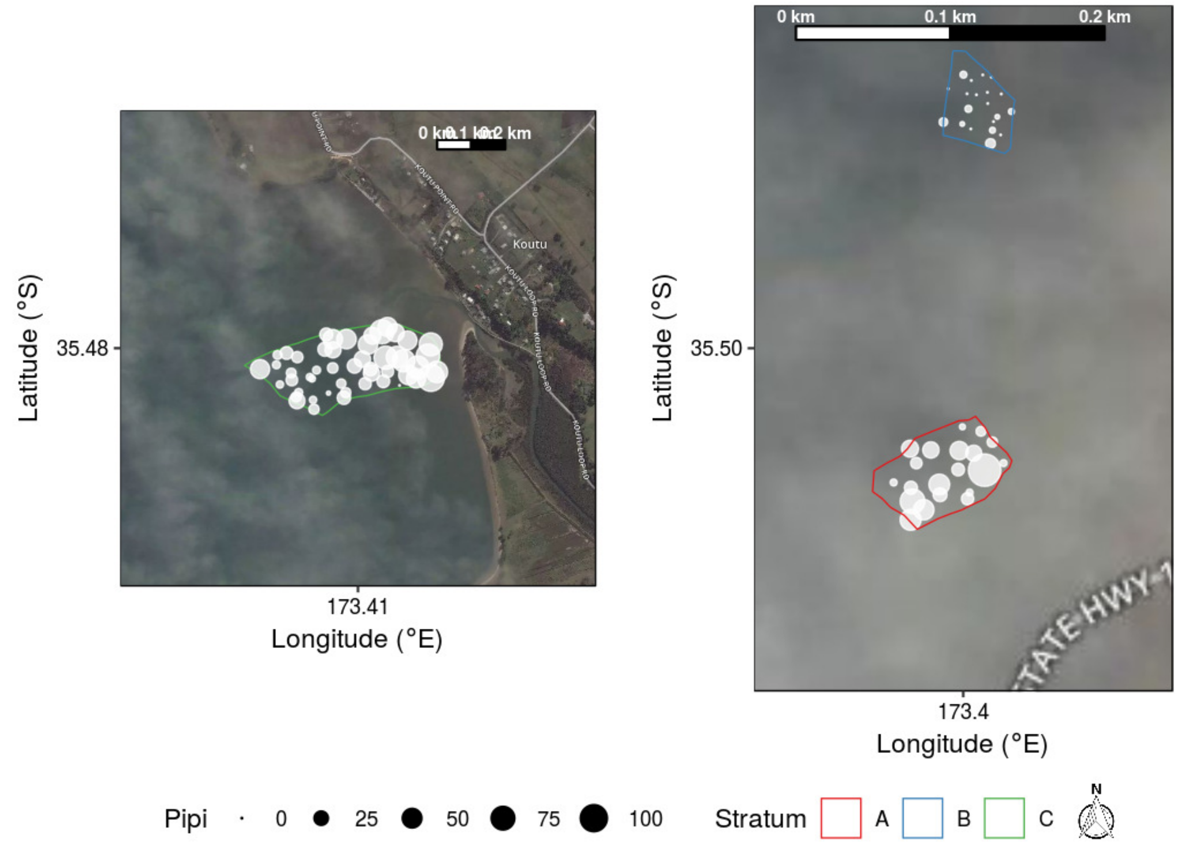


Figure 8: Map of sample strata and individual sample locations for pipi at Hokianga Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of pipi abundance at Hokianga Harbour, by stratum, for 2018–19. 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	0.4	20	467	2.61	667	22.90
B	0.2	20	24	0.07	34	36.57
C	9.5	50	1 566	84.70	895	11.19

Table 8: Estimates of pipi abundance at Hokianga 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 (%)
2018–19	10.1	87.39	868	10.87	0.00	<1	>100

Table 9: Summary statistics of the length-frequency (LF) distribution of pipi at Hokianga 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 (%)
2018–19	24.09	22	7–54	36.17	0.00

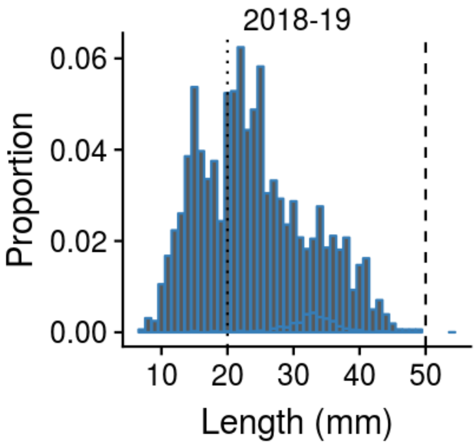


Figure 9: Weighted length-frequency (LF) distribution of pipi for the present survey at Hokianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Kawakawa Bay (West)

Kawakawa Bay (West) is a large bay within Hauraki Gulf, within the wider Auckland region. This bay was part of four previous surveys, starting in 2004–05, with the most recent preceding survey in 2016–17 (see Appendix A, Tables A-1, A-2). Surveys at this site have sampled bivalves across the entire bay, with a consistent spatial extent of the sampling area across all surveys, including the current study (Figure 10). The field sampling in 2018–19 was based on three strata, which contained a total of 108 sampling points, including 14 points in phase 2 (Table 10).

This site does not support a pipi population, although the field sampling usually includes a few individuals (predominantly recruits, $\leq$20 mm shell length). The current survey only sampled 14 pipi, and this small sample size precluded further analysis of this species at Kawakawa Bay (West).

The sediment organic content at this site was less than 2%, with a variable proportion of fines (grain size $<$63 µm), varying between $<$1 and 20% (Figure 10, and see details in Appendix B, Table B-3). While most of the sediment consisted of very fine and fine sands (grain sizes $>$63 µm and $>$125 µm), some samples also contained a relatively high proportion (over 15%) of coarser grain size fractions, including coarse sand and gravel (grain sizes $>$500 µm and $>$2000 µm).

The cockle population at Kawakawa Bay (West) was spread across most of the sampling extent, excepting the western area, stratum C (Figure 11, Table 10). Highest cockle abundance and density were in stratum B, with a total population estimate of 222.41 million (CV: 17.52%) cockles in 2018–19 (Table 11). The population density was estimated at 365 individuals per m^2 (Table 11). Both estimates were decreases from the preceding survey, when both abundance and density had increased to 261.21 million (CV: 13.84%) cockles and 429 cockles per m^2 from comparatively low estimates in previous surveys (i.e., $<$90 million individuals and population densities of $<$150 individuals per m^2). In 2018–19, there was a concomitant reduction in the population of large cockles ($\geq$30 mm shell length), with 50% decreases in their abundance and density to 9.34 million (CV: 28.81%) large individuals and five large individuals per m^2.

The marked population increase in the preceding survey was in part explained by an influx of recruits ($\leq$15 mm shell length), as 45.05% of the 2016–17 population were recruits, compared with 18.04% in 2014–15 (Table 12). At the same time, the contribution of the large size class to the total population continued to decrease, from over a quarter of the population in 2014–15 to 4.20% in 2018–19. Over the same period, the mean and modal sizes of the unimodal population declined from 26 mm and 24.05 mm in 2014–15 to 17 mm and 18.40 mm shell length in the current study.

The time series of the three most recent length-frequency distributions confirmed the shift towards recruits and small individuals in the population size structure, accompanied by the decline of large cockles since 2014–15 (Figure 12). Although small individuals appeared to grow to medium sizes, only few cockles exceeded the 30-mm cut-off length of the large size class in recent studies.

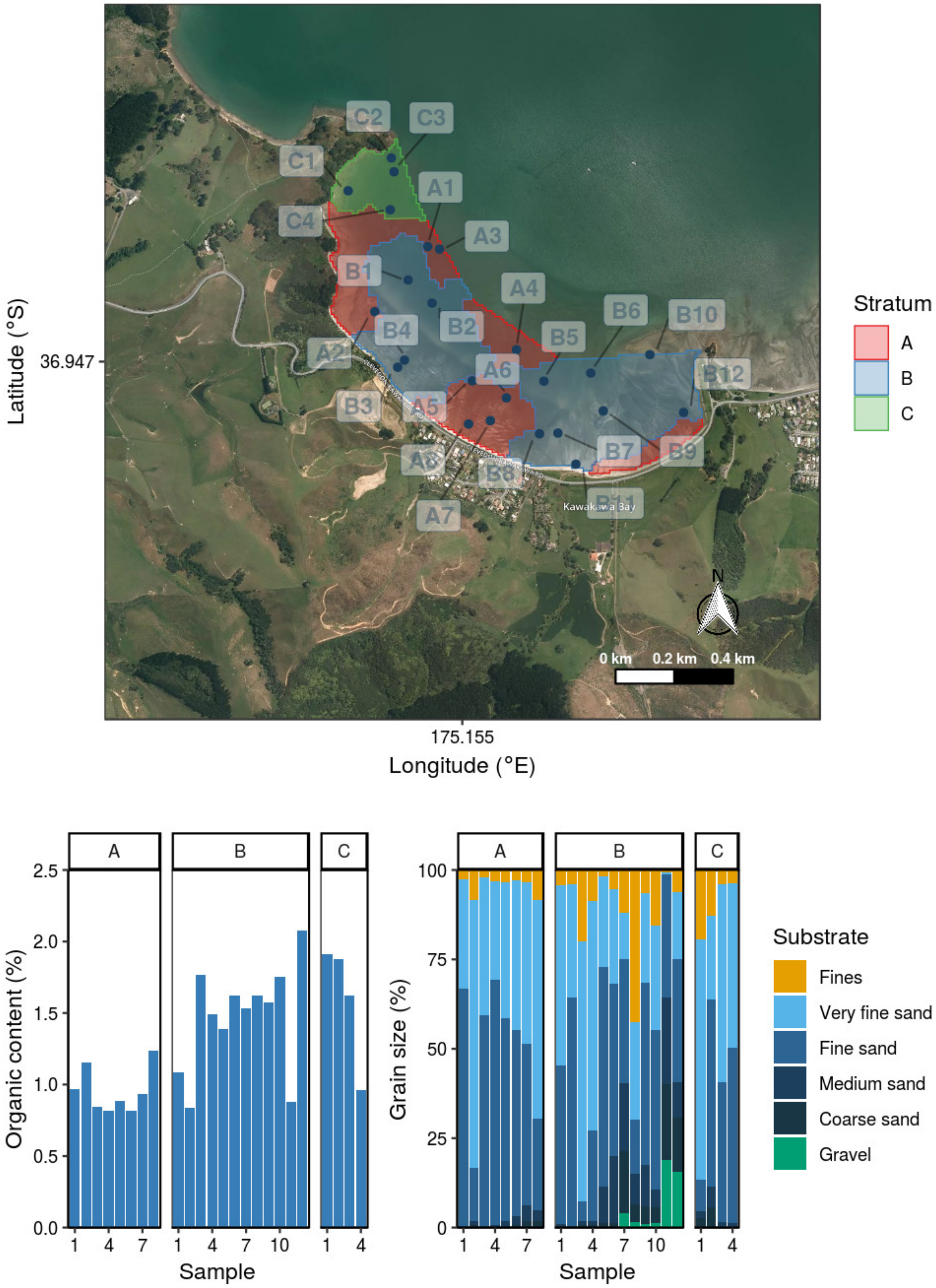


Figure 10: Sediment sample locations and characteristics at Kawakawa Bay (West). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.3.1 Cockles at Kawakawa Bay (West)

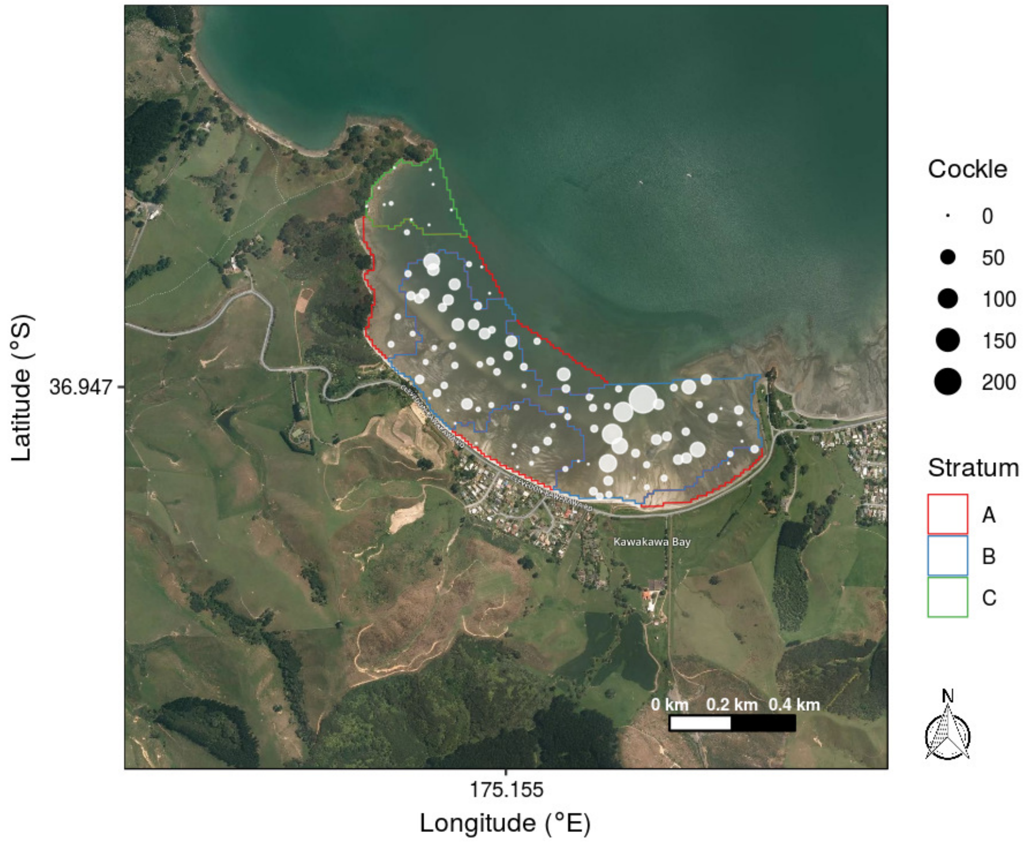


Figure 11: Map of sample strata and individual sample locations for cockles at Kawakawa Bay (West), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of cockle abundance at Kawakawa Bay, by stratum, for 2018–19. 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	20.0	20	99	28.29	141	39.34
B	35.6	78	1 487	193.97	545	19.25
C	5.3	10	1	0.15	3	>100

Table 11: 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	4	17.55
2006–07	62.9	86.39	137	10.54	21.23	7	22.75
2014–15	60.9	74.44	122	9.69	19.80	7	15.80
2016–17	60.9	261.21	429	13.84	18.33	10	36.42
2018–19	60.9	222.41	365	17.52	9.34	5	28.81

Table 12: 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 (%)
2014–15	24.05	26	6–46	18.04	26.64
2016–17	17.75	15	6–46	45.05	7.02
2018–19	18.40	17	6–41	33.33	4.20

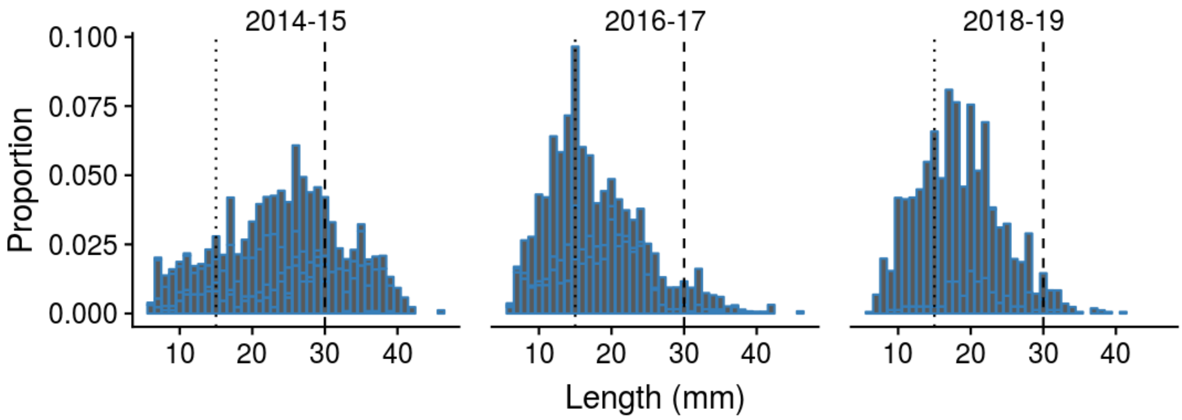


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Kawakawa Bay (West). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Mangawhai Harbour

Mangawhai Harbour is one of the Northland monitoring sites. This large estuary has been included in eight previous surveys, with the 2016–17 assessment directly preceding the present study (see Appendix A, Tables A-1, A-2). The survey effort at Mangawhai Harbour has been consistently split across three general areas, with cockles sampled at the harbour entrance and on a mudflat in the lower harbour (Figure 13), whereas the sampling focus on pipi has been in southern channel areas in the upper harbour. Owing to changes in the location and size of the pipi population, there have been some changes in the sampling extent over time; however, the current field sampling was based on a similar extent as the survey in 2016–17. The current study was based on a total of 150 ampling points that were spread across five strata (Table 13).

The sediment samples from the cockle strata indicated an organic content of a maximum 7.6% (Figure 13, and see details in Appendix B, Table B-3). Similarly, the proportion of fines (grain size <63 µm) was generally small at less than about 3%, with several samples lacking this grain size fraction. Most of the sediment was fine sand (grain size >125 µm), followed by medium sand (>250 µm), with small proportions (i.e., $<5\%$) of other grain size fractions.

The cockle population at Mangawhai Harbour was distributed throughout all five strata, with high numbers in strata A and D (Figure 14, Table 13). Based on field data, estimates for the current cockle population were 78.89 million (CV: 8.56%) cockles and a mean density of 1091 cockles per m^2 (Table 14). These estimates signified an increase in the cockle population, and were the highest population estimates since 1999–2000, the first year of the survey series. Population increases were also evident in the abundance and density of large cockles ($\geq$30 mm shell length). This size class has fluctuated over the monitoring series, with an overall decline in its abundance and density since 2010–11. In 2018–19, there were an estimated 2.48 million (CV: 17.36%) large individuals, which occurred at a density of seven large cockles per m^2.

Although abundance and density estimates increased in 2018–19, the proportion of large cockles within the population remained small; this size class contributed only 3.14% of all individuals (Table 15). This finding was similar to the two preceding surveys, whereas recruits ($\leq$15 mm shell length) consistently contributed over a quarter of the total population, including in 2018–19 when their proportion was 29.01%.

Considering the length-frequency distributions in the three most recent surveys, the initial second cohort of recruits in 2014–15 shifted into the small and medium size classes over time, resulting in the current unimodal population structure (Figure 15). Mean and modal sizes confirmed the influence of medium-sized cockles, e.g., the current modal shell length was 20 mm. Although recruits appeared to be growing to medium sizes, there was little evidence of further growth towards the large size class.

Recent assessments of the pipi population at Mangawhai Harbour have focused on beds associated with the main channel, including an area of recruits in stratum E (Figure 16, Table 16). Pipi were also distributed throughout stratum A, close to the harbour entrance. The current abundance estimate for this species was 1.97 million (CV: 13.89%) pipi across all strata, reflecting a decrease from previous estimates, including the 2016–17 survey when the population consisted of 2.51 million (CV: 16.18%) individuals (Table 17). The continuing population decline was also evident in the current density estimate of 27 pipi per m^2 (cf. 34 pipi per m^2 in 2016–17). In addition, there were few large pipi ($\geq$50 mm shell length) at Mangawhai Harbour, with the current estimates indicating the absence of this size class (and high uncertainty).

Most of the population consisted of recruits ($\leq$20 mm shell length), with 85.55% and 76.58% of individuals in this size class in 2016–17 and 2018–19, respectively (Table 18, Figure 17). Their high proportion in recent surveys highlighted the influence of strong recruitment events that accompanied a general scarcity of medium-sized and large pipi. The mean and modal sizes in the two recent surveys were similar, representing a unimodal size structure of a cohort at 10 mm modal shell length in 2018–19. There were few individuals at larger sizes in the three recent assessments.

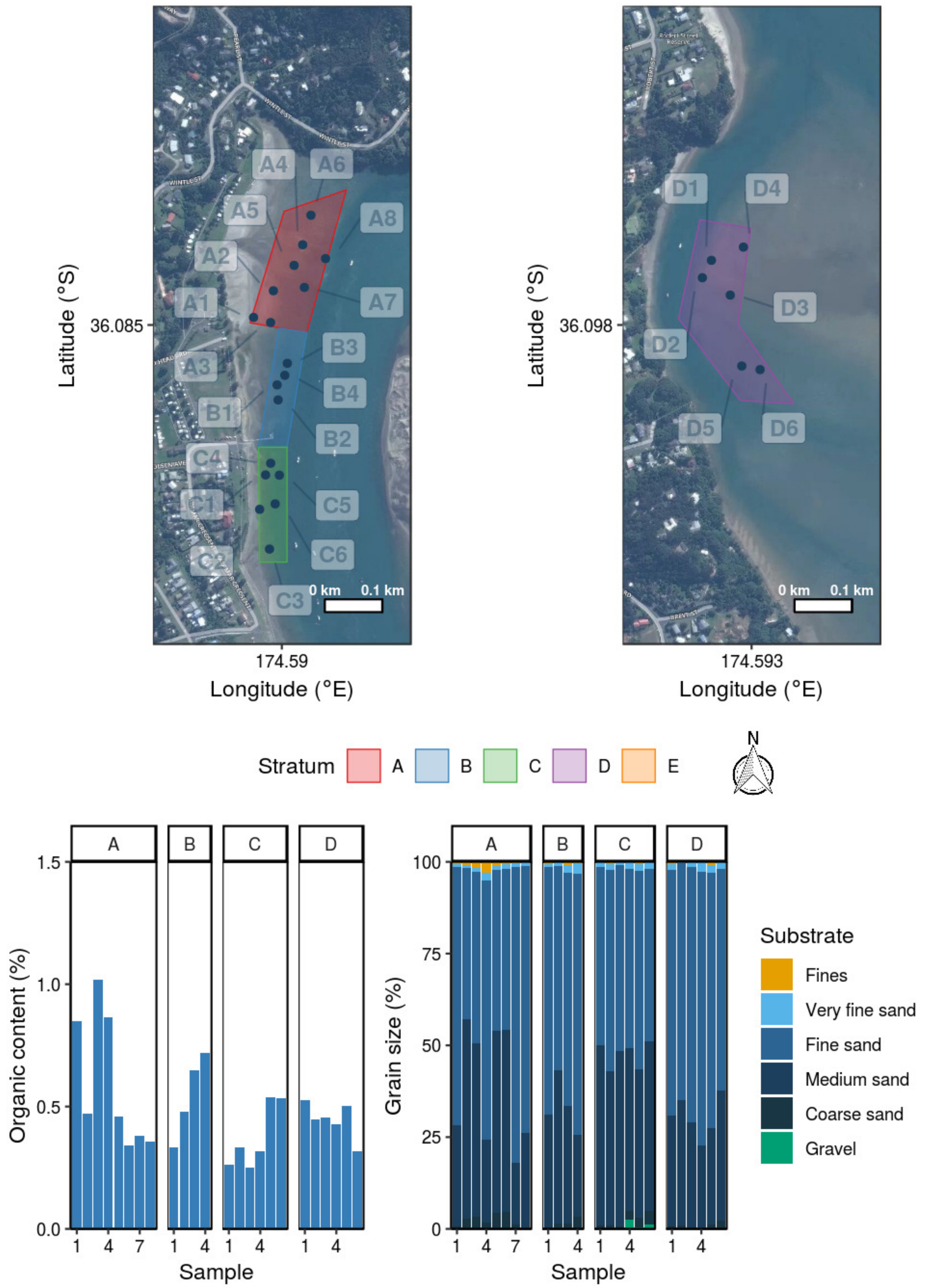


Figure 13: Sediment sample locations and characteristics at Mangawhai Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.4.1 Cockles at Mangawhai Harbour

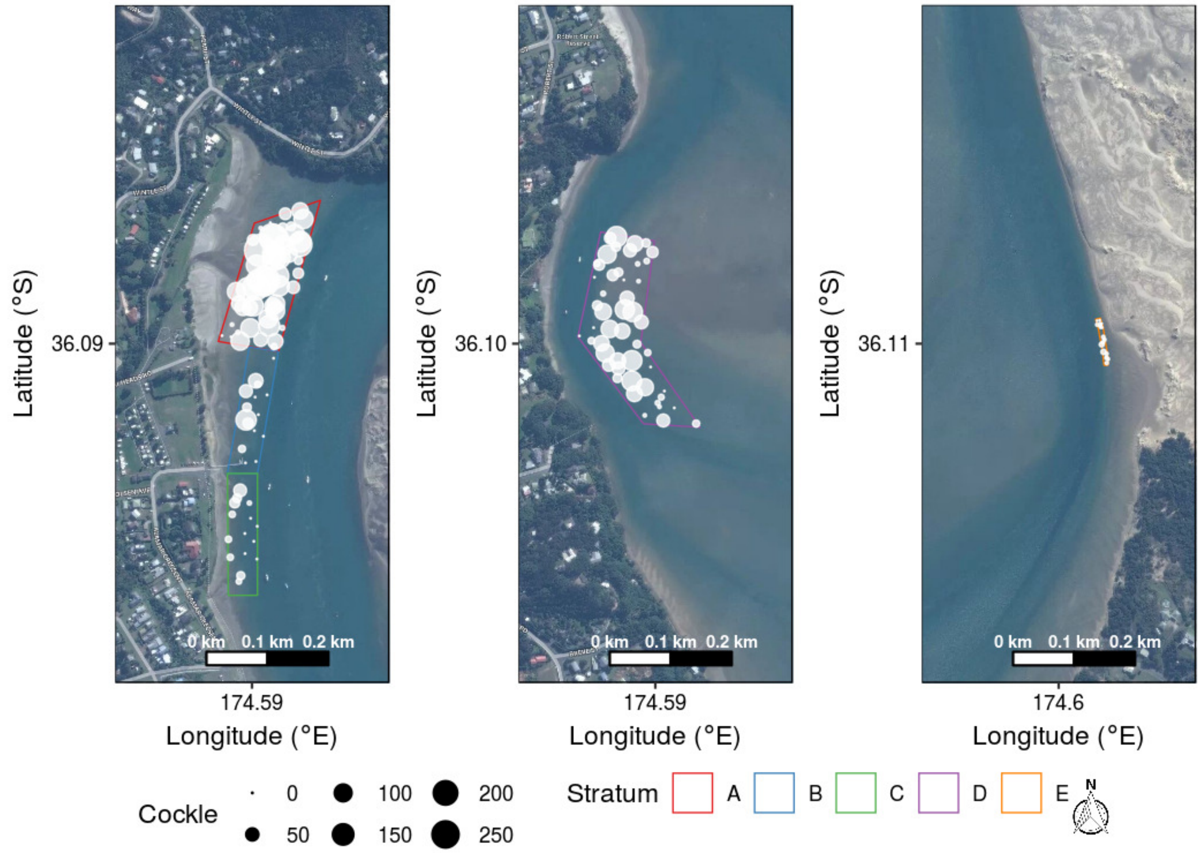


Figure 14: Map of sample strata and individual sample locations for cockles at Mangawhai Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Mangawhai Harbour, by stratum, for 2018–19. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	2.2	50	3 763	47.88	2 150	11.24
B	1.0	15	218	4.17	415	45.65
C	1.0	15	100	1.86	190	35.88
D	3.0	50	1 473	24.97	842	14.18
E	0.1	20	18	0.02	26	33.14

Table 14: 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	61	7.17
2000–01	8.4	76.61	912	4.35	45.27	108	4.35
2001–02	8.4	28.54	340	5.80	8.75	21	7.48
2002–03	8.4	46.14	549	5.46	20.46	61	6.47
2003–04	8.4	50.77	604	4.71	17.43	41	6.24
2010–11	9.0	61.78	686	9.15	8.28	18	17.41
2014–15	8.6	52.73	617	7.58	2.05	4	15.95
2016–17	7.4	58.97	794	13.89	1.46	4	28.67
2018–19	7.2	78.89	1 091	8.56	2.48	7	17.36

Table 15: 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 (%)
2014–15	19.68	25	4–37	25.45	3.89
2016–17	19.19	22	5–47	29.01	2.48
2018–19	18.55	20	5–36	33.73	3.14

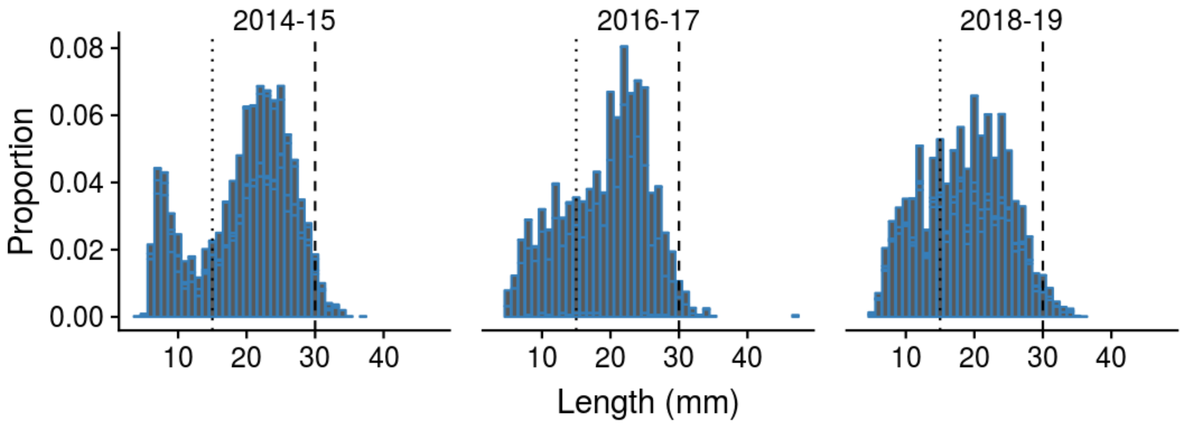


Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4.2 Pipi at Mangawhai Harbour

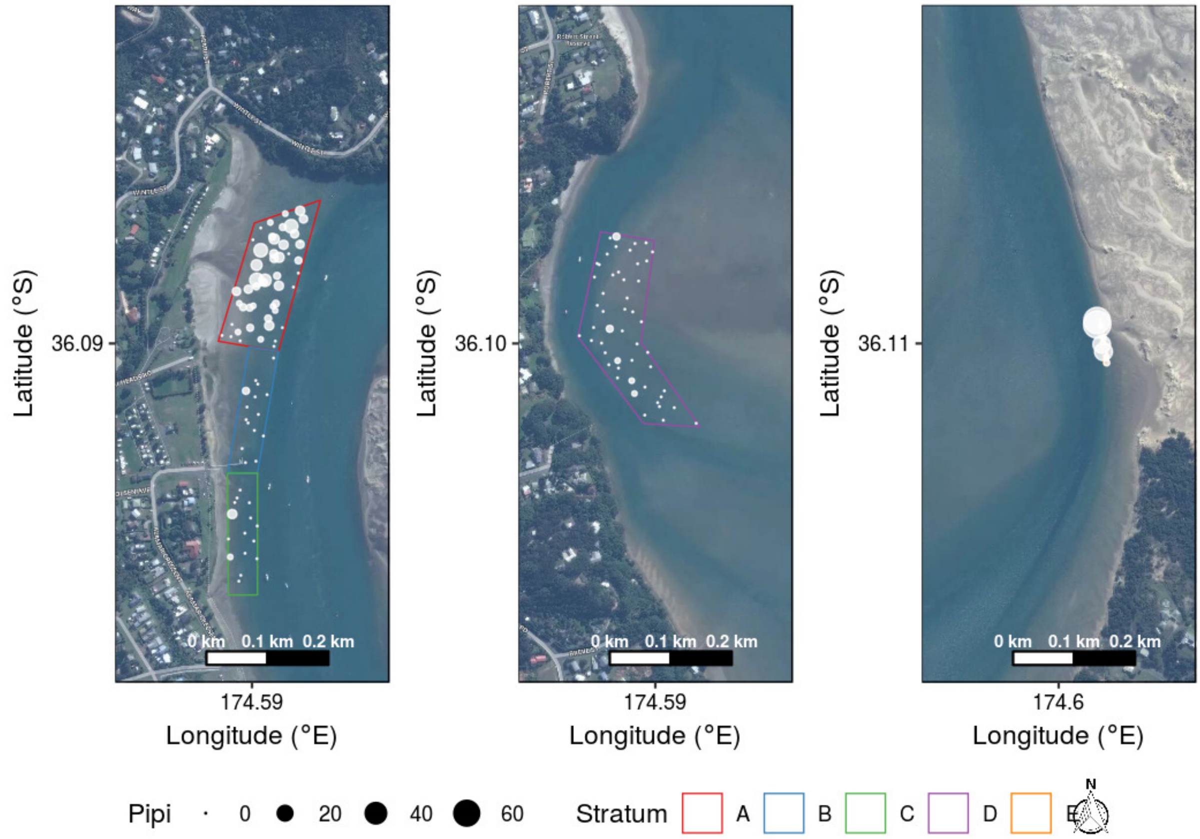


Figure 16: Map of sample strata and individual sample locations for pipi at Mangawhai Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of pipi abundance at Mangawhai Harbour, by stratum, for 2018–19. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	2.2	50	122	1.55	70	15.54
B	1.0	15	2	0.04	4	>100
C	1.0	15	5	0.09	10	81.06
D	3.0	50	7	0.12	4	45.68
E	0.1	20	192	0.16	274	48.28

Table 17: 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	3	15.23
2000–01	8.4	1.96	23	9.81	1.26	4	9.35
2001–02	8.4	0.78	9	9.56	0.51	2	9.55
2002–03	8.4	1.44	17	11.63	0.37	1	9.27
2003–04	8.4	1.18	14	11.00	0.44	2	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
2018–19	7.2	1.97	27	13.89	0.00	<1	>100

Table 18: 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 (%)
2014–15	25.27	11	8–53	37.53	0.47
2016–17	15.61	11	7–54	85.55	0.41
2018–19	16.53	10	5–54	76.58	0.04

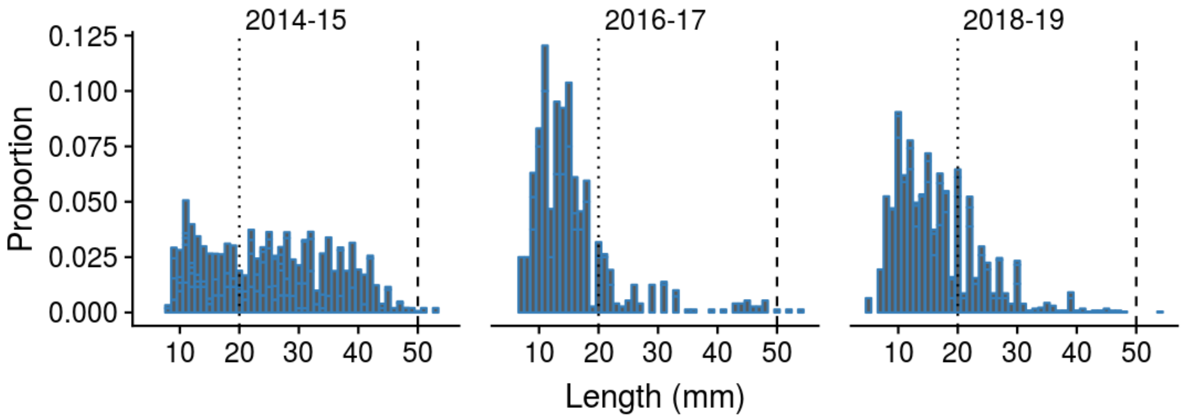


Figure 17: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Mill Bay

Mill Bay is in the northwestern part of Manukau Harbour, in the wider Auckland area. This sheltered intertidal sandflat has been surveyed nine previous times, most recently in 2017–18 (see Appendix A, Tables A-1, A-2). At that time, there were notable numbers of recently-dead and dying cockles, without an obvious cause for this mortality; there were no recent mortalities or moribund individuals during the current field sampling. The current survey focused on the same sampling extent as previous surveys, assessing bivalves across a total of 90 sampling points, split across three strata (Figure 18, Table 19).

Sediment at Mill Bay was low in organic content, with values below 2.6% (Figure 18, and see details in Appendix B, Table B-3). Sediment grain size fractions included up to 14% of fines (grain size $<$63 µm), with relatively similar proportions of fine (grain size $>$125 µm) to coarse (grain size $>$500 µm) sand fractions. All of the samples contained small proportions of gravel (grain size $>$2000 µm), with two samples containing over 10% of sediment in this size fraction.

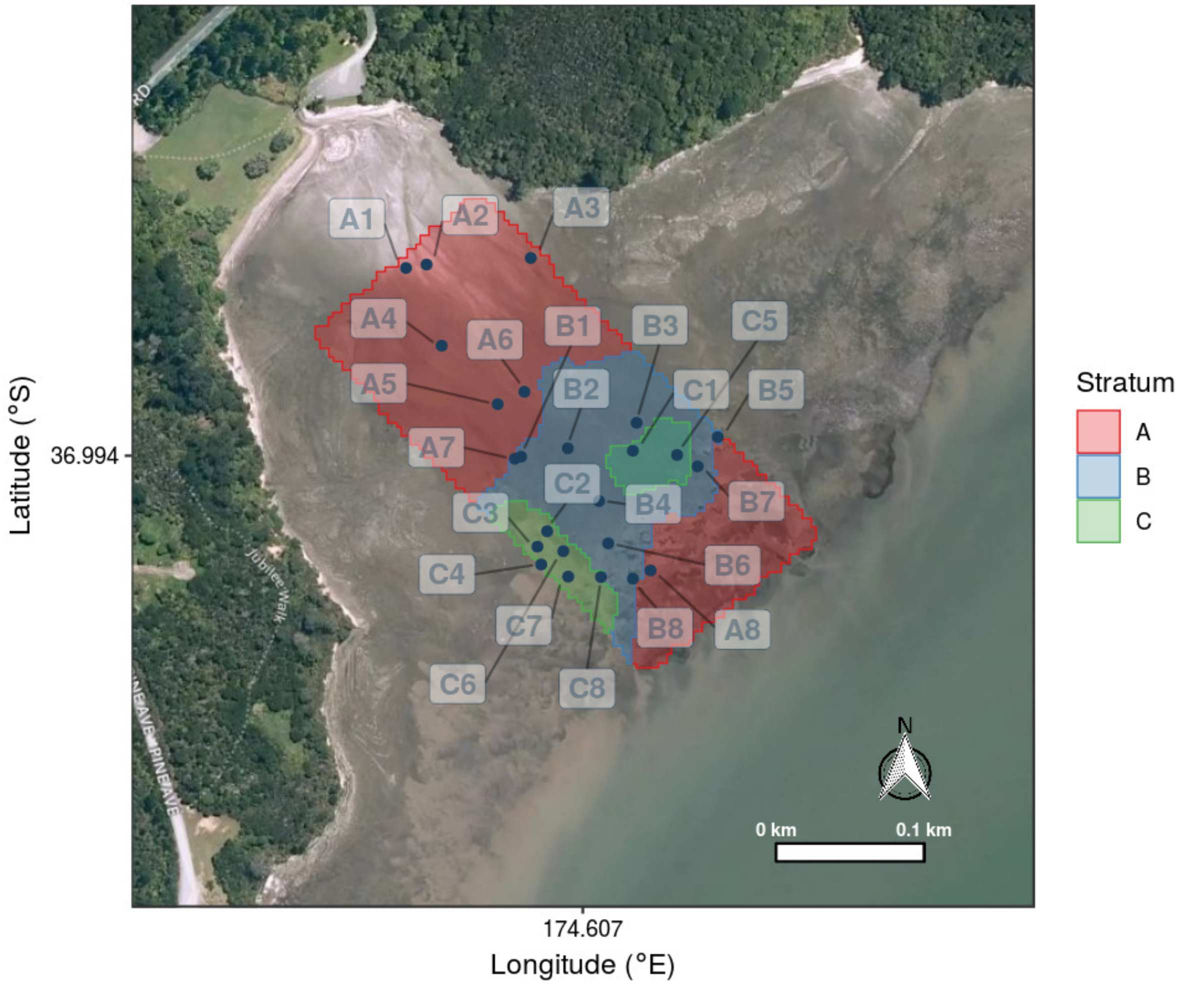
The spatial distribution of the cockle population was focused in the lower intertidal zone, above a seagrass bed, in strata B and C; there were few cockles below this zone or in the upper intertidal area (Figure 19, Table 19). The 2018–19 population estimate of this species was a total of 23.04 million (CV: 14.68%) cockles, and their mean density was estimated at 475 individuals per m^2 (Table 20). These estimates were marked increases from the estimates in the preceding fishing year, when the population had declined to 7.78 million (CV: 25.18%) cockles at a mean density of 160 individuals per m^2.

Similarly, the number of large cockles ($\geq$30 mm shell length) showed an increase in 2018–19, to an estimated 0.67 million (CV: 20.30%) large cockles, occurring at a mean density of five individuals per m^2. This large size class contributed only a small proportion of individuals to the total population (2.90% in 2018–19), consistent with previous assessments (Table 21). At the same time, there was a notable proportion of recruits ($\leq$15 mm shell length) within the cockle population, with an increase to 43.80% of individuals in 2018–19 compared with 31.00% of recruits in 2017–18.

The small and medium sizes of the majority of cockles were reflected in the length-frequency distribution of the population at Mill Bay: the current mean and modal sizes were 17.37 mm and 14 mm shell lengths (Table 21, Figure 20). Growth of some medium-sized cockles toward the large size class resulted in a less uniform unimodal population in 2018–19, indicating a shift towards a bimodal size structure. The findings from the current study suggest that the cockle population at this site has recovered from the mortality event in 2017–18, with continued recruitment of small individuals to the population.

There is no designated pipi bed at Mill Bay, but individuals of this species were distributed from the upper to the mid-intertidal area of the sampling extent (Figure 21, Table 22). The overall sample size of pipi was small (106 individuals), resulting in high uncertainty surrounding the population estimates: the total abundance was 3.35 million (CV: 31.22%) pipi and the corresponding mean density was 69 pipi per m^2 (Table 23). Throughout the sampling series, the pipi population at Mill Bay has been small and characterised by a lack of large pipi ($\geq$50 mm shell length). Although the current estimates reflected an increase from the preceding assessment, large pipi continued to be absent at this site.

The observed increase in the pipi population was caused by a significant recruitment event, with the majority of the current population consisting of recruits—91.35% of all individuals were at sizes $\leq$20 mm shell length (Table 24, Figure 22). In comparison, data from previous surveys documented that this size class only made up about a third of the Mill Bay pipi population in 2014–15 and 2017–18. The current influx of recruits resulted in a marked decrease in modal size, from 25 mm shell length in the previous year to 10 mm in 2018–19. The current population size structure corresponded with a single cohort of recruits around this modal size.



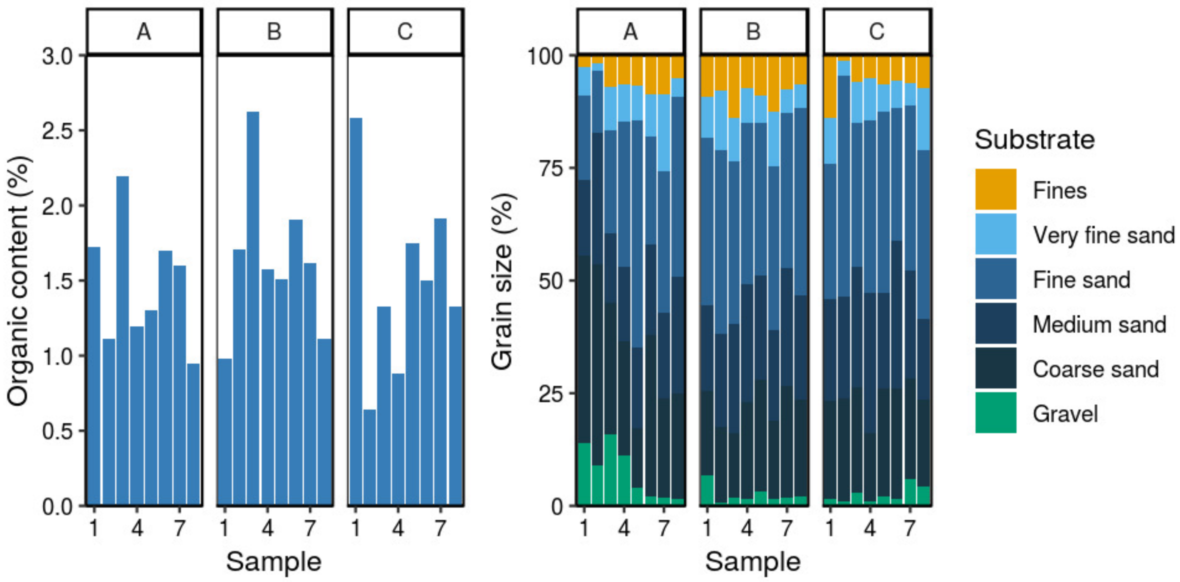


Figure 18: Sediment sample locations and characteristics at Mill Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm;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

3.5.1 Cockles at Mill Bay

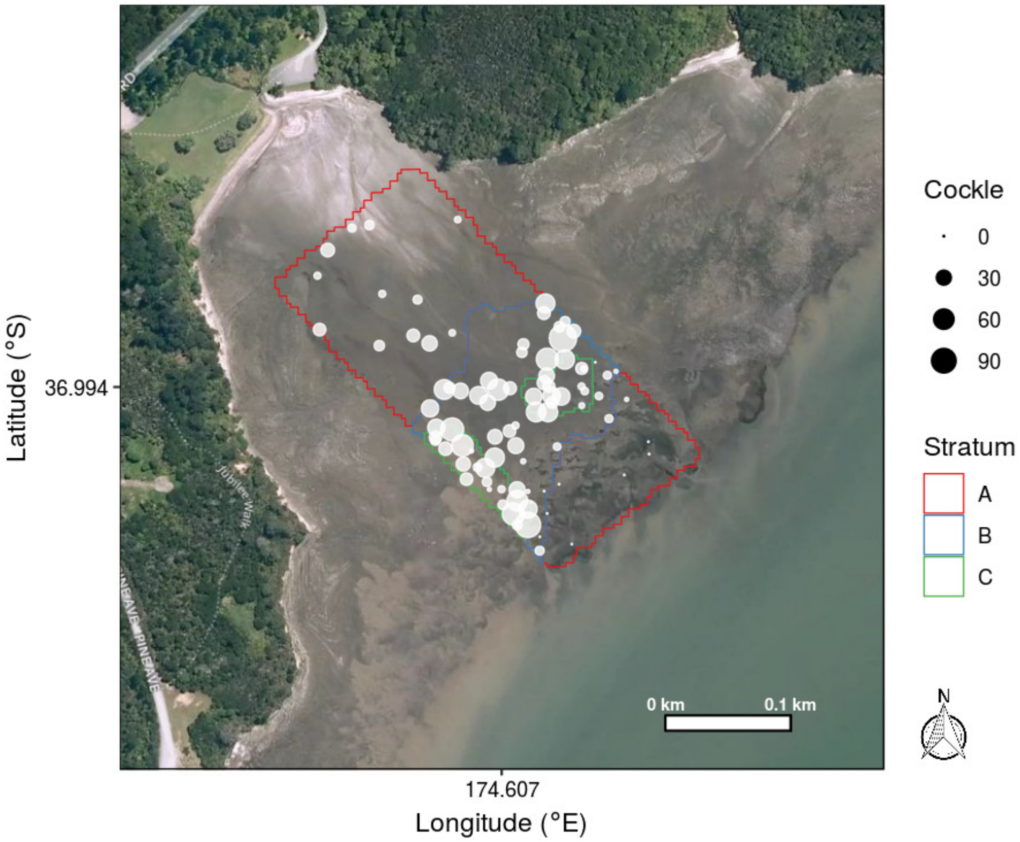


Figure 19: Map of sample strata and individual sample locations for cockles at Mill Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of cockle abundance at Mill Bay, by stratum, for 2018–19. 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	3.1	20	213	9.37	304	30.28
B	1.3	35	913	9.78	745	18.13
C	0.5	35	1 026	3.90	838	13.12

Table 20: Estimates of cockle abundance at Mill Bay for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	4.6	4.91	107	7.87	0.74	5	12.06
2000–01	4.8	10.24	213	6.32	1.23	4	9.50
2001–02	4.5	5.21	116	6.89	0.38	3	13.26
2003–04	4.5	5.33	118	7.69	0.32	2	14.64
2004–05	4.5	4.23	94	7.30	0.30	1	14.45
2005–06	4.5	6.72	149	6.66	0.39	1	11.89
2009–10	5.0	11.31	229	8.92	0.18	4	31.80
2014–15	4.9	16.66	342	9.56	0.07	1	42.43
2017–18	4.9	7.78	160	25.18	0.21	1	41.00
2018–19	4.9	23.04	475	14.68	0.67	5	20.30

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	19.42	22	4–32	24.37	0.43
2017–18	18.02	17	6–33	31.00	2.67
2018–19	17.37	14	5–35	43.80	2.90

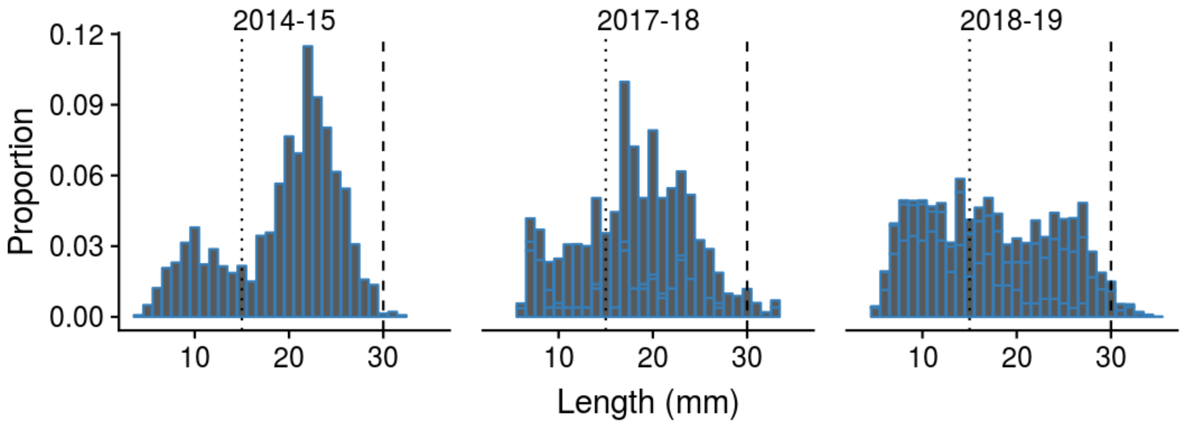


Figure 20: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mill Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5.2 Pipi at Mill Bay

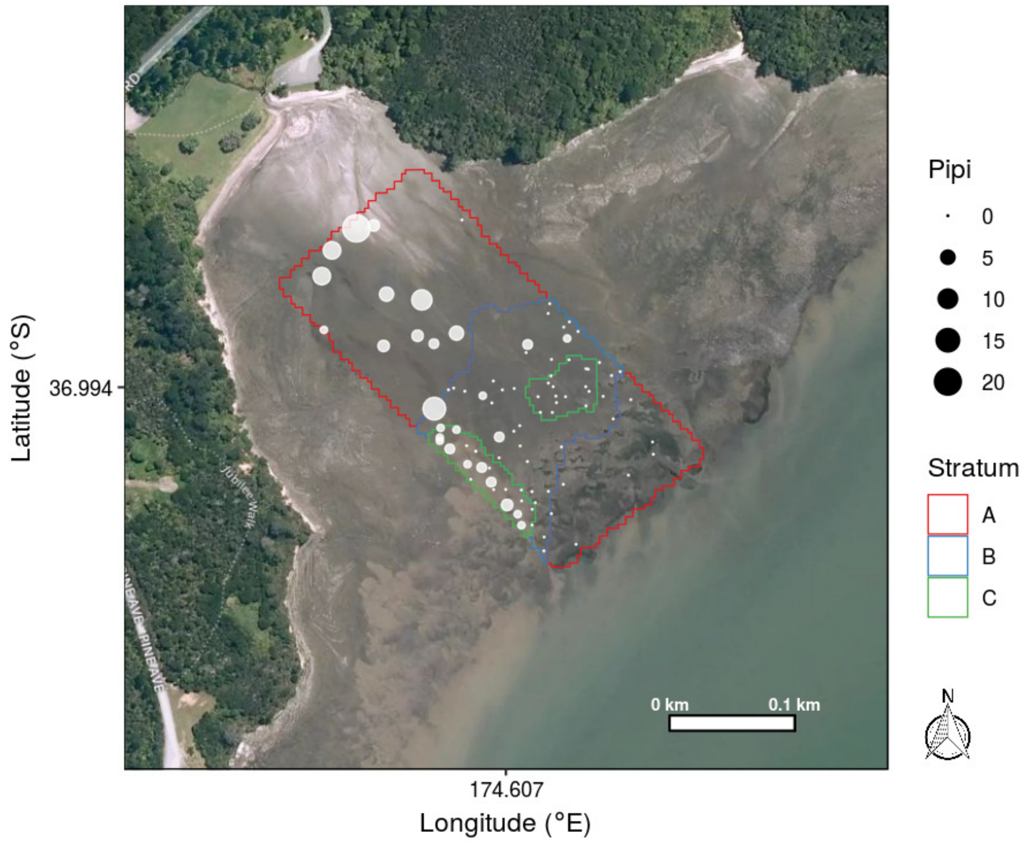


Figure 21: Map of sample strata and individual sample locations for pipi at Mill Bay, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of pipi abundance at Mill Bay, by stratum, for 2018–19. 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	3.1	20	70	3.08	100	33.65
B	1.3	35	20	0.21	16	70.76
C	0.5	35	16	0.06	13	28.84

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	4.6	0.49	11	13.59	0.01	<1	>100
2000–01	4.8	6.37	133	11.26	0.03	<1	37.87
2001–02	4.5	1.76	39	9.63	0.01	<1	91.42
2003–04	4.5	0.49	11	11.50	0.00	0	
2004–05	4.5	1.41	31	12.06	0.00	<1	>100
2005–06	4.5	0.79	18	13.50	0.00	<1	>100
2009–10	5.0	5.65	114	17.37	0.00	0	
2014–15	4.9	4.41	90	14.32	0.00	0	
2017–18	4.9	0.77	16	18.86	0.00	0	
2018–19	4.9	3.35	69	31.22	0.00	0	

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	24.78	29	7–42	32.06	0.00
2017–18	22.58	25	8–38	32.61	0.00
2018–19	14.66	10	7–41	91.35	0.00

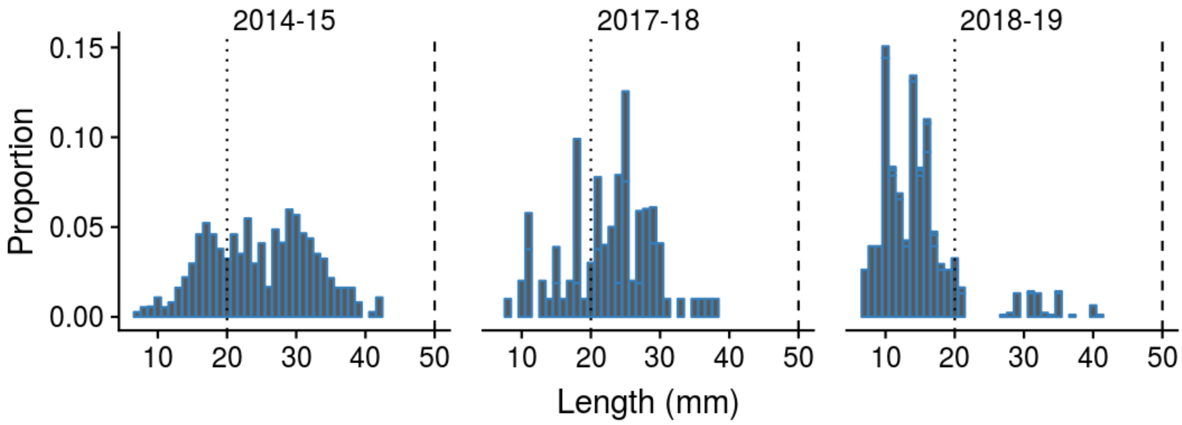


Figure 22: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mill Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Ngunguru Estuary

Ngunguru Estuary is a small Northland estuary, just north of Whangārei. This estuary was closed to the collection of cockles and pipi in January 2016 (Department of Internal Affairs 2015, 135). It was included in the bivalve sampling series on five occasions, with the most recent assessment in 2016–17 immediately preceding the current study (see Appendix A, Tables A-1, A-2). The sampling extent has remained consistent since 2014–15, when an extensive cockle bed in the middle of the estuary was included in the field survey. Some small changes to the sampling extent since then were caused by shifts in the location and size of the pipi bed associated with the estuary channel. In 2018–19, the sampling extent was split into four strata, including one pipi stratum, with bivalves assessed in a total of 120 sampling points (Table 25, Figure 23).

Sediment samples from the cockle strata contained up to 5% organics (Figure 23, and see details in Appendix B, Table B-3). The majority of sediment consisted of fine sand (grain size $>$125 µm), with only small proportions in other grain size fractions. The latter included sediment fines (grain size $<$63 µm) which made up to 5% of the sediment across samples.

The cockle population at Ngunguru Estuary was distributed across all strata, with particularly high numbers and densities in strata A to C (Table 25, Figure 24). This population had an estimated total abundance of 129.23 million (CV: 6.57%) cockles, and an estimated density of 1997 individuals per m^2 (Table 26). Both estimates were the highest values in the survey series and related to the high number of recruits ($\leq$15 mm shell length), with almost half (42.75%) of the total cockle population in this size class (Table 27).

At the same time, there were few large cockles ($\geq$30 mm shell length) present in 2018–19, and this finding was consistent with previous surveys: their current abundance estimate was 0.28 million (CV: 51.20%) individuals and their corresponding density estimate was one large cockle per m^2 (Table 26). Within the total population, only 0.22% of all individuals were in this large size class (Table 27).

The considerable increase in recruits shifted mean and modal shell lengths to smaller sizes; for example, the modal size decreased from 20 mm in 2016–17 to 15 mm in the current study (Table 27). Small-sized cockles strongly influenced the unimodal population size structure, and previous surveys showed similar length-frequency distributions at this site, which generally consisted of a strong cohort of recruits and small-sized individuals (Figure 25).

In contrast to cockles, pipi were more restricted in their distribution, and largely confined to the pipi bed in stratum D, with a few individuals in the lower part of stratum C (Figure 26, Table 28). The current population estimate for Ngunguru Estuary was 42.39 million (CV: 6.03%) pipi, continuing the marked population increase first observed in 2016–17 (Table 29). The 2018–19 density estimate corresponded with this increase, with the current mean density of 655 pipi per m^2. The population included few large pipi ($\geq$50 mm shell length), and their abundance was estimated at 0.40 million (CV: 43.99%) individuals, at a density of two pipi per m^2.

The large size class was a minor part of the population, contributing only 0.94% of individuals (Table 30). In contrast, an influx in recruits ($\leq$20 mm shell length) in 2018–19 resulted in a third (33.19%) of the current population comprising of this size class. These findings indicate that some of the recent population increase can be attributed to this influx of recruits. The majority of pipi were of small and medium sizes, with the increase in recruits leading to notably smaller mean and modal sizes than previous surveys: the two parameters decreased from 38.61 mm and 42 mm in 2016–17 to 26.75 mm and 18 mm shell length in 2018–19, respectively (Table 30, Figure 27). The overall decrease in pipi sizes was evident in the length-frequency distributions over time, as the previously bimodal population changed to a unimodal size structure dominated by small-sized pipi.

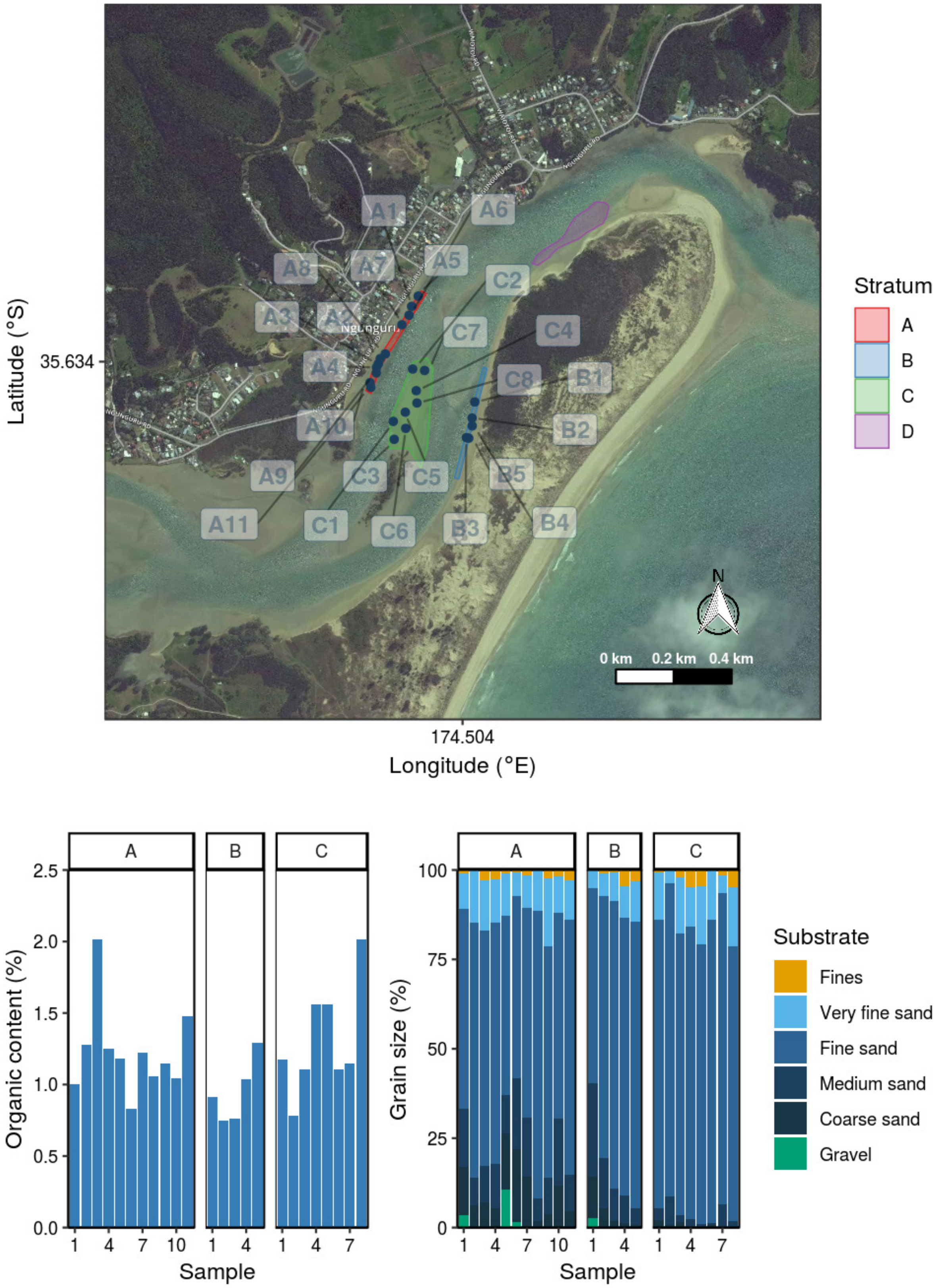


Figure 23: Sediment sample locations and characteristics at Ngunguru Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >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 2018–19. 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	20	867	9.87	1 239	26.44
B	0.6	20	1 236	10.33	1 766	19.24
C	3.6	50	4 718	98.32	2 696	7.50
D	1.4	30	779	10.70	742	24.50

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	13	11.70
2004–05	1.8	9.79	544	7.77	0.34	10	18.85
2010–11	1.8	19.55	1 086	10.72	0.07	2	35.49
2014–15	5.5	92.67	1 696	7.53	0.38	2	32.11
2016–17	6.3	91.81	1 461	7.19	0.22	1	48.15
2018–19	6.5	129.23	1 997	6.57	0.28	1	51.20

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 (%)
2014–15	19.07	20	4–34	18.71	0.41
2016–17	17.88	20	4–34	27.30	0.24
2018–19	16.52	15	4–45	42.75	0.22

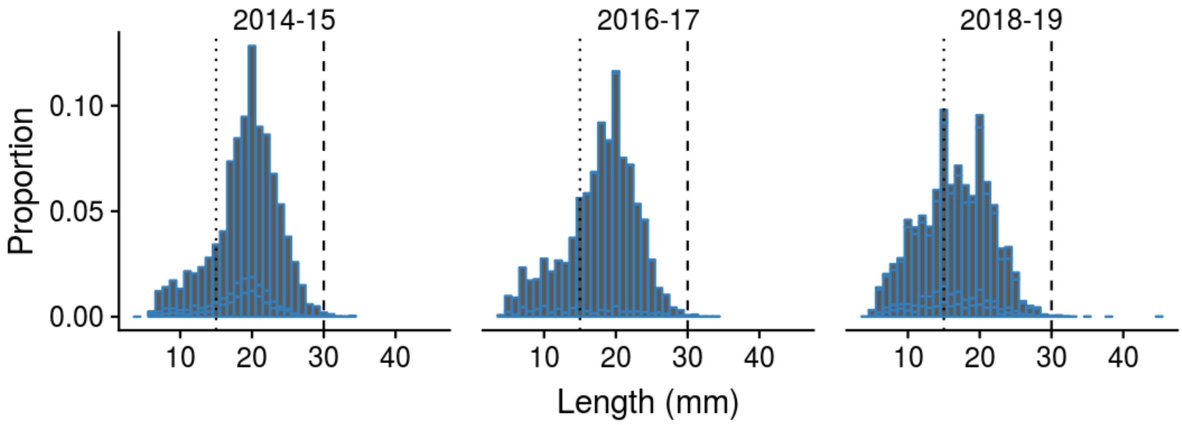


Figure 25: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

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 2018–19. 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	20	0	0.00	0	
B	0.6	20	21	0.18	30	44.50
C	3.6	50	144	3.00	82	52.52
D	1.4	30	2 855	39.21	2 719	12.06

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	17	9.04
2004–05	1.8	2.23	124	5.37	0.95	18	7.83
2010–11	1.8	0.73	40	16.60	0.25	3	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	1	31.61
2018–19	6.5	42.39	655	11.76	0.40	2	43.99

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 (%)
2014–15	34.31	40	8–49	14.84	0.00
2016–17	38.61	42	4–56	7.72	0.79
2018–19	26.75	18	6–53	33.19	0.94

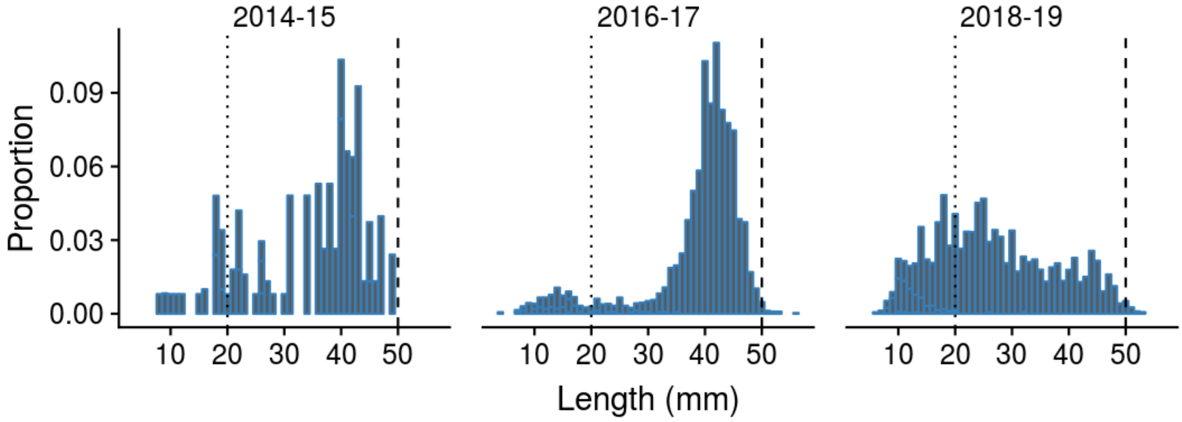


Figure 27: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Ohiwa Harbour

Ohiwa Harbour is one of the Bay of Plenty sites. This large inlet has been assessed in six previous bivalve surveys, and the most recent previous assessment was in 2015–16 (see Appendix A, Tables A-1, A-2). Across surveys, there have been some changes in the sampling extent, mostly owing to changes in the locations and sizes of pipi beds sampled. The current sampling effort focused on a smaller area than previous surveys, with a total of 160 sampling points across four separate strata (Figure 28, Table 31).

Sediment sampling in the cockle strata documented a low organic content (less than 2%) and a varying proportion of sediment fines (grain size <63 µm), ranging from 0 to over 11% (Figure 28, and see details in Appendix B, Table B-3). Most of the sediment consisted of fine sand (grain size >125 µm) with up to 90% of sediment in the former grain size fraction. Coarser size fractions were small, and none of the samples included gravel.

The cockle population at this site was spread across three of the strata, including one of the pipi beds in stratum D (Figure 29, Table 31). The total population estimate for this species was 5.57 million (CV: 13.38%) cockles, and their corresponding density was 219 cockles per m^2 (Table 32). These values indicated a smaller cockle population than in previous assessments, i.e., since 2005–06. Although the current sampling extent was smaller than in 2015–16, it was similar to the area sampled in 2012–13, which supported a considerably larger cockle population. Although large cockles ($\geq$30 mm shell length) only occurred in small numbers in the current population, their estimated abundance confirmed a continuing increase to 0.82 million (CV: 39.04%) individuals in 2018–19. Similarly, their mean density increased from two large cockle per m^2 in 2015–16 to eight large cockles per m^2 in the present assessment.

This increase in the number of large cockles (and the concomitant decrease in the total population size) resulted in a larger proportion of this size class in the current Ohiwa Harbour population (Table 33). In 2018–19, 14.69% of all individuals were large cockles, whereas their proportion in 2015–16 was 1.13%. At the same time, the cockle population was augmented by consistently strong recruitment, with 19.65% of the 2018–19 population comprising of recruits ($\leq$15 mm shell length).

Length-frequency distributions over time documented few changes in the population size structure in recent surveys Figure 30). The unimodal cockle population remained centred on a cohort dominated by medium-sized individuals, with mean and modal shell lengths of 22.47 mm and 24 mm shell length, respectively. The increasing influence of large cockles resulted in a slight shift towards this size class in the present assessment.

Pipi at Ohiwa Harbour occurred in two separate strata, strata C and D (Figure 31, Table 34). The current population estimate at this site was 13.05 million (CV: 13.00%) pipi, which occurred at an estimated mean density of 514 pipi per m^2 (Table 35). The 2018–19 estimates indicated marked reductions in the size and density of the population compared with the two preceding surveys in 2012–13 and 2015–16, paticularly in view of the similar-sized sampling extent in the former preceding survey. Included in the population were an estimated 1.24 million (CV: 19.69%) large pipi ($\geq$50 mm shell length), and their density was 12 large pipi per m^2. Both these estimated indicated a recent reduction in the large pipi population.

The concomitant decrease in the total population size meant that the proportion of large pipi (8.96%) in 2018–19 was similar to that in the previous survey (Table 36). At the same time, recruits ($\leq$20 mm shell length) were considerably less abundant than in previous surveys, when half of the total population consisted of this size class. In 2018–19, the proportion of recruits declined to 11.26%. The smaller influence of recruits resulted in increases in mean and modal shell lengths. For example, the latter increased from 20 mm in 2015–16 to 30 mm in 2018–19. These changes led to a notable difference in the current population size structure: while the two recent population assessments each revealed two separate cohorts of recruits and large pipi each, the current length-frequency distribution highlighted the decrease in recruits and concomitant prevalence of medium-sized pipi (Figure 32). These changes over time indicated that growth within the strong cohort of recruits and small pipi in previous surveys contributed to the medium size class in 2018–19, with pipi at medium and large sizes persisting in the population.

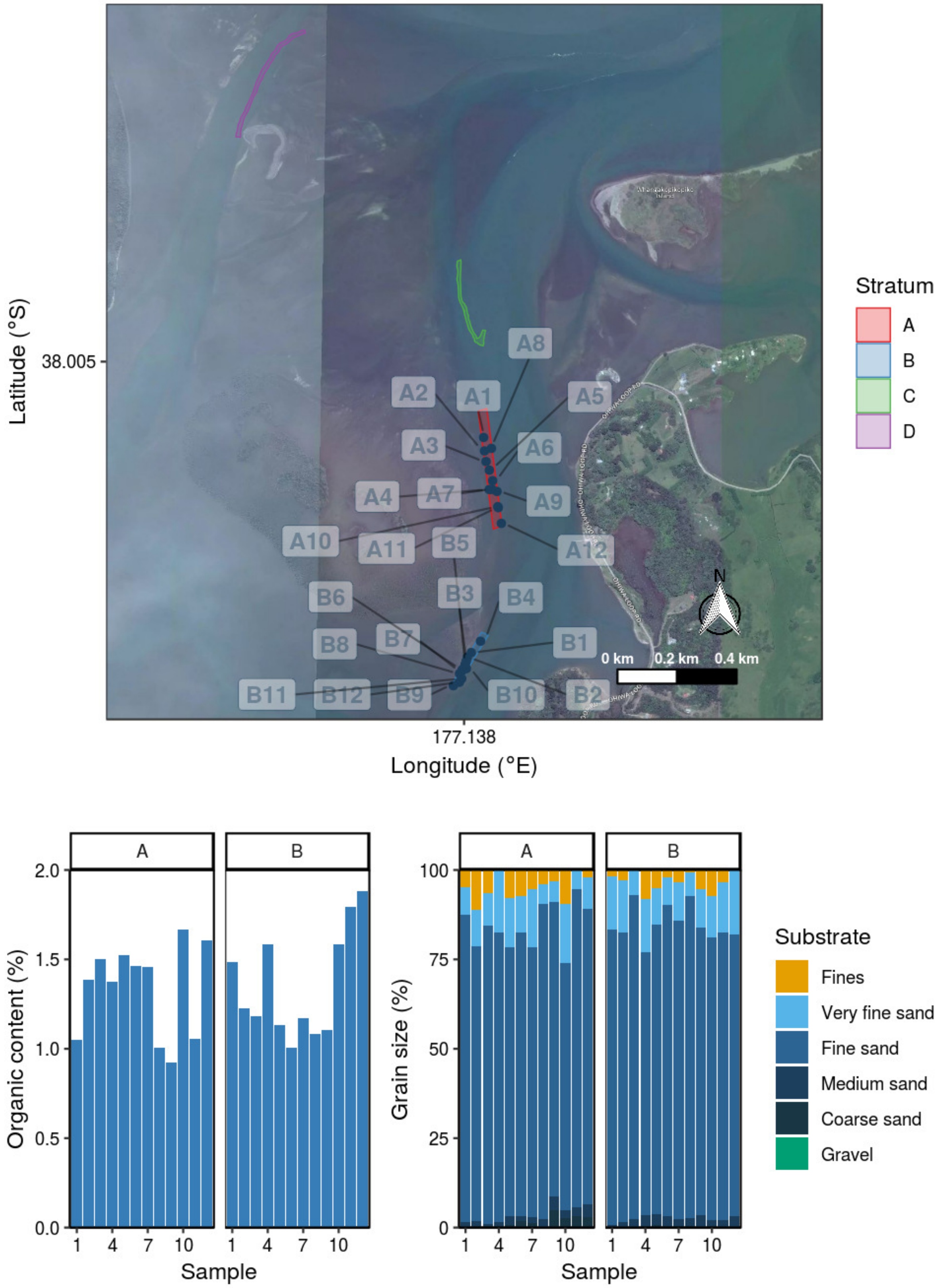


Figure 28: Sediment sample locations and characteristics at Ohiwa Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.7.1 Cockles at Ohiwa Harbour

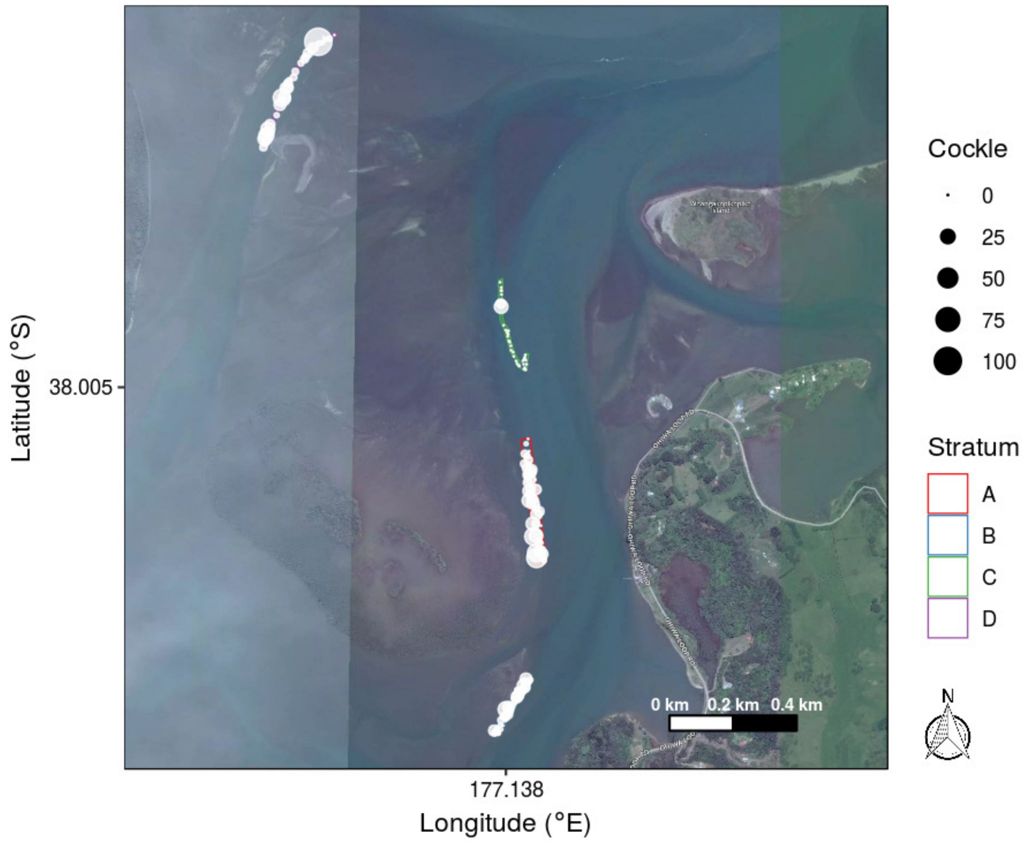


Figure 29: Map of sample strata and individual sample locations for cockles at Ohiwa Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Ohiwa Harbour, by stratum, for 2018–19. 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	45	431	3.31	274	17.65
B	0.5	45	210	0.62	133	19.11
C	0.4	35	31	0.09	25	75.88
D	0.5	35	375	1.56	306	28.49

Table 32: Estimates of cockle abundance at Ohiwa Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	4.53	201	7.82	0.16	2	22.37
2005–06	2.7	3.69	137	7.07	0.17	2	15.69
2006–07	5.7	17.48	307	10.59	1.12	4	14.47
2009–10	2.1	6.47	308	8.79	0.03	<1	51.49
2012–13	2.6	9.05	344	10.49	0.05	<1	36.42
2015–16	3.4	23.01	683	14.33	0.26	2	30.87
2018–19	2.5	5.57	219	13.38	0.82	8	39.04

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	17.41	20	4–31	33.31	0.56
2015–16	19.17	22	5–33	25.08	1.13
2018–19	22.47	24	5–62	19.65	14.69

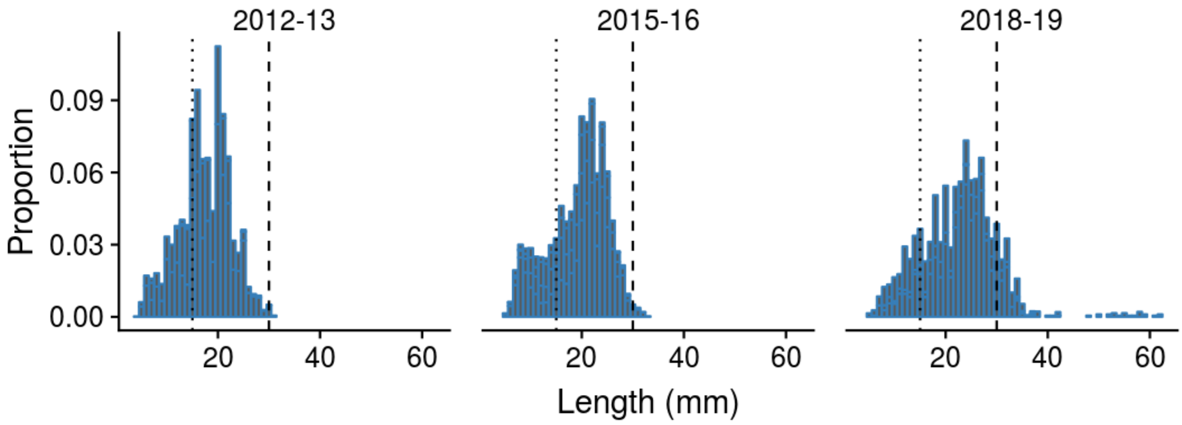


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ohiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7.2 Pipi at Ohiwa Harbour

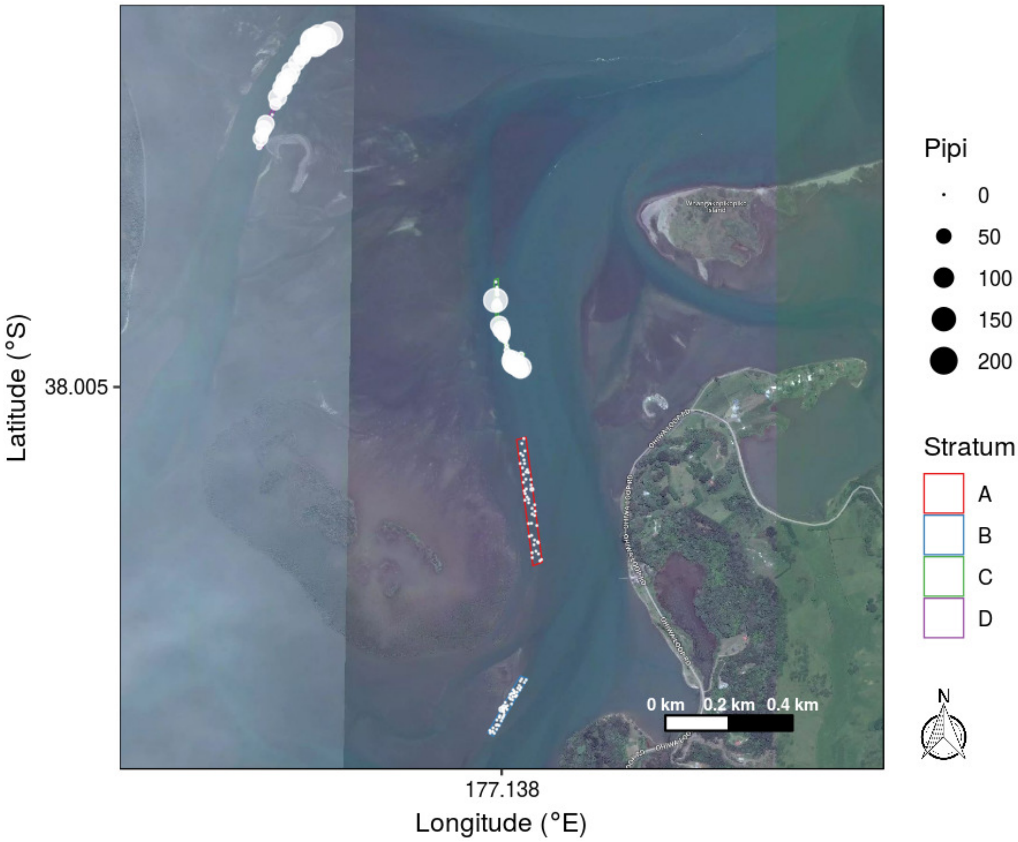


Figure 31: Map of sample strata and individual sample locations for pipi at Ohiwa Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Ohiwa Harbour, by stratum, for 2018–19. 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	45	1	0.01	<1	>100
B	0.5	45	6	0.02	4	73.85
C	0.4	35	1 196	3.50	976	21.94
D	0.5	35	2 295	9.53	1873	15.88

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	5.67	252	6.88	2.14	24	7.46
2005–06	2.7	3.40	126	7.27	2.52	23	6.36
2006–07	5.7	8.27	145	10.52	2.14	9	13.78
2009–10	2.1	15.25	726	14.46	1.63	19	18.77
2012–13	2.6	41.59	1 581	14.39	1.03	7	31.52
2015–16	3.4	41.26	1 225	12.10	3.70	22	18.37
2018–19	2.5	13.05	514	13.00	1.24	12	19.69

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2012–13	26.81	12	3–56	50.22	2.48
2015–16	25.71	20	7–64	53.42	8.96
2018–19	32.67	30	6–64	11.26	9.47

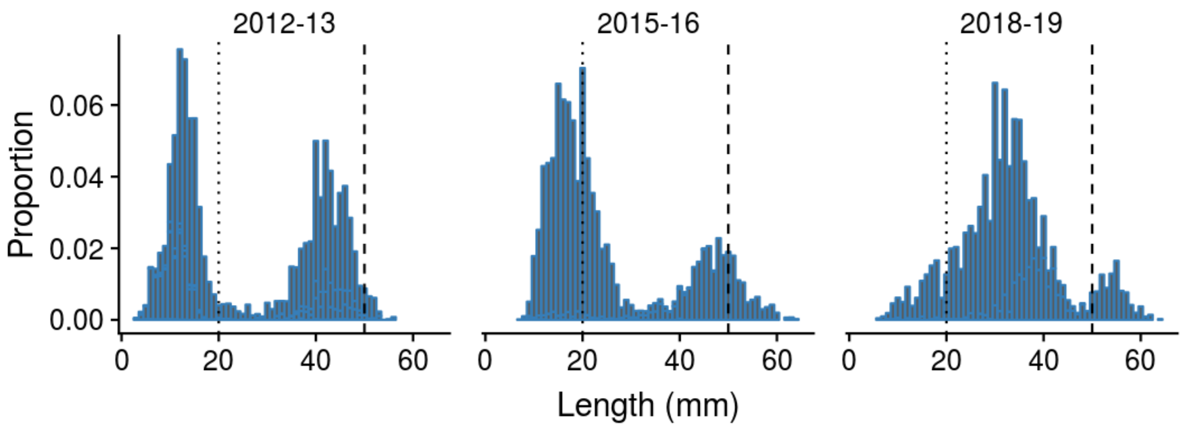


Figure 32: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ohiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Otūmoetai (Tauranga Harbour)

Otūmoetai is in the south-eastern part of Tauranga Harbour, in Bay of Plenty. Bivalves at this site have been monitored in seven previous assessments since 1999–2000, and the most recent preceding survey was in 2016–17 (see Appendix A, Tables A-1, A-2). The sampling extent at this site has been relatively consistent throughout the survey series, encompassing two separate sampling areas for cockles and pipi. The survey in 2018–19 sampled bivalves across a total of 85 sampling points in three strata (Table 37).

The two adjacent cockle strata were characterised by sediment with a low organic content (<1.5%) (Figure 33, and see details in Appendix B, Table B-3). The grain size composition was dominated by fine sand (>125 µm), with over 70% of sediment in this grain size fraction. All other size fractions made up only a small proportion of the sediment at the cockle strata, including the proportion of sediment fines (grain size <63 µm), which made up less than 4% in the samples.

The cockle population was concentrated in stratum A, with some cockles also occurring in the pipi bed in stratum C (Figure 34, Table 37). The total abundance of cockles was estimated at 21.95 million (CV: 10.48%) individuals, and their corresponding density estimate was a mean of 272 cockles per m^2 (Table 38). The current abundance and density estimates were about half of the values of the two preceding surveys, and there was a concomitant decrease in the number and density of large cockles (≥30 mm shell length) in 2018–19. Although the large size class has been consistently scarce at Otūmoetai, the current estimate of 0.01 million (CV: 100%) large individuals was a distinct decrease from the preceding estimate of 0.34 million (CV: >100%) large cockles, although their estimated densities were similar, about one large cockle per m^2 in 2018–19. The low number of large individuals meant that the uncertainty of the estimates was consistently high.

The small population of large individuals was only a minor proportion of the Otūmoetai cockle population, and this finding was consistent across the three most recent surveys. In 2016–17, 0.85% of the population were individuals with shell lengths ≥30 mm, and this proportion declined to 0.04% in 2018–19 (Table 39, Figure 35). The near-absence of large cockles was offset by a significant proportion of recruits (≤15 mm shell length): about half of the population in recent surveys consisted of cockles in this size class. Their prevalence was reflected in small mean and modal sizes, with the latter remaining at 15 mm shell length in 2018–19. This modal length formed a single strong cohort, with a similar unimodal size structure across recent surveys. These findings showed that the cockle population at Otūmoetai was largely determined by regular recruitment events, with few individuals growing to medium or large sizes.

The pipi population at Otūmoetai was associated with one of the main side channels, with some variation in the size and location of this pipi bed across surveys. In 2018–19, pipi were concentrated in this bed, defined as stratum C (Figure 36, Table 40). Based on the field sampling, the current abundance estimate was a total of 58.86 million (CV: 10.94%) pipi, with an estimated mean density of 731 pipi per m^2 (Table 41). These estimates were lower than preceding values and signified a continued decline from previously high estimates in 2014–15. In contrast to the decline in the total pipi population, there was a small increase in the abundance and density of large pipi (≥50 mm shell length), although their population remained small. There were 0.30 million (CV: 40.75%) large pipi in 2018–19, and their density was two large individuals per m^2.

Their contribution to the overall population also remained minor, with only 0.52% of the total population in this size class, compared with 5.66% of recruits (≤20 mm shell length) (Table 42). The latter showed a decrease from their previous proportion of 17.23%. The smaller number of recruits was also evident in the length-frequency data, which illustrated the shift from recruits to small and medium sizes in 2018–19. The population structure changed at the same time to a distinctly unimodal population, with a modal shell length of 30 mm (Figure 37). These data suggest a stable pipi population at Otūmoetai, with regular recruitment over time and a prevalence of medium-sized pipi.

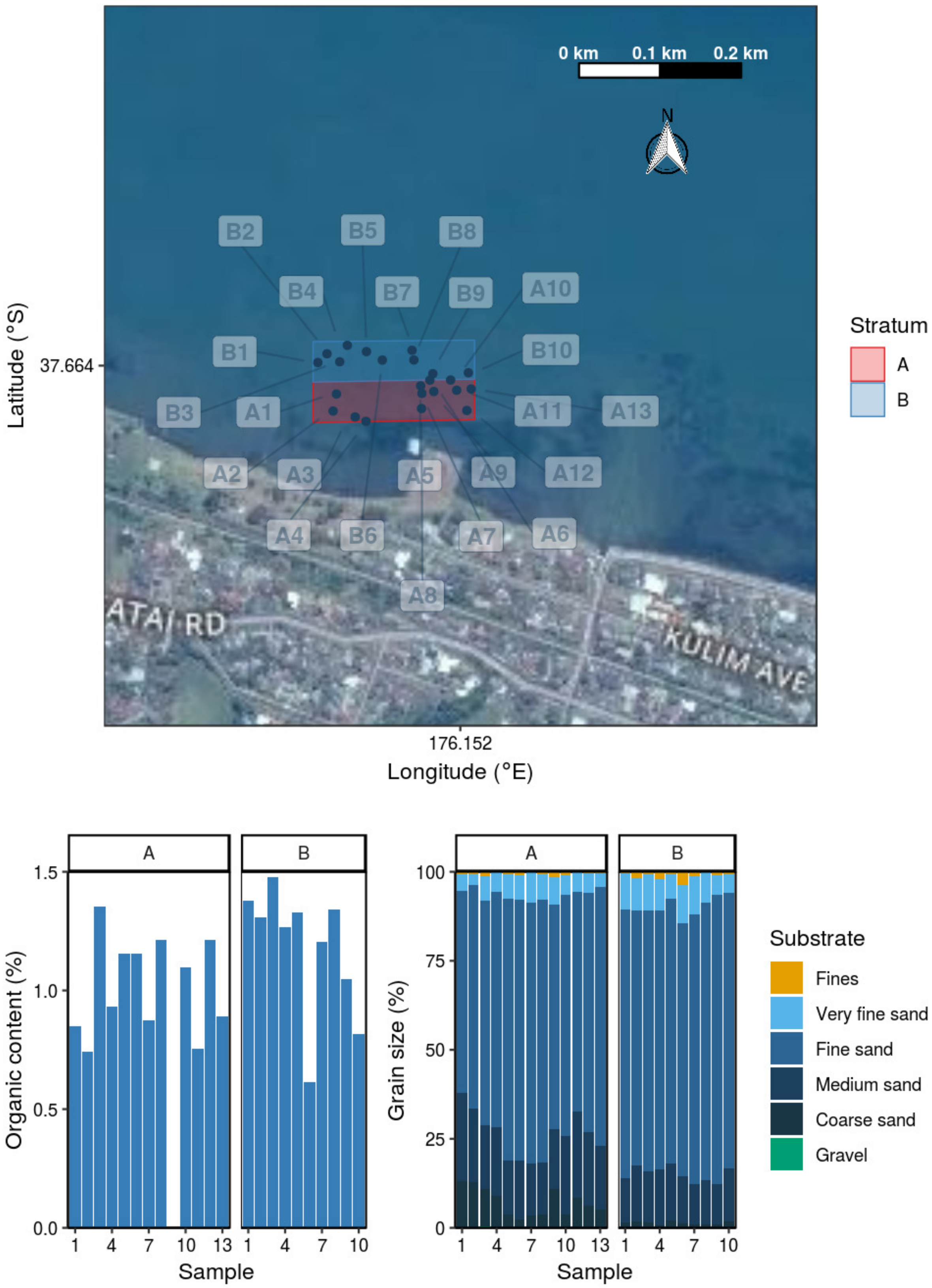


Figure 33: Sediment sample locations and characteristics at Otūmoetai (Tauranga Harbour). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63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

3.8.1 Cockles at Otūmoetai (Tauranga Harbour)

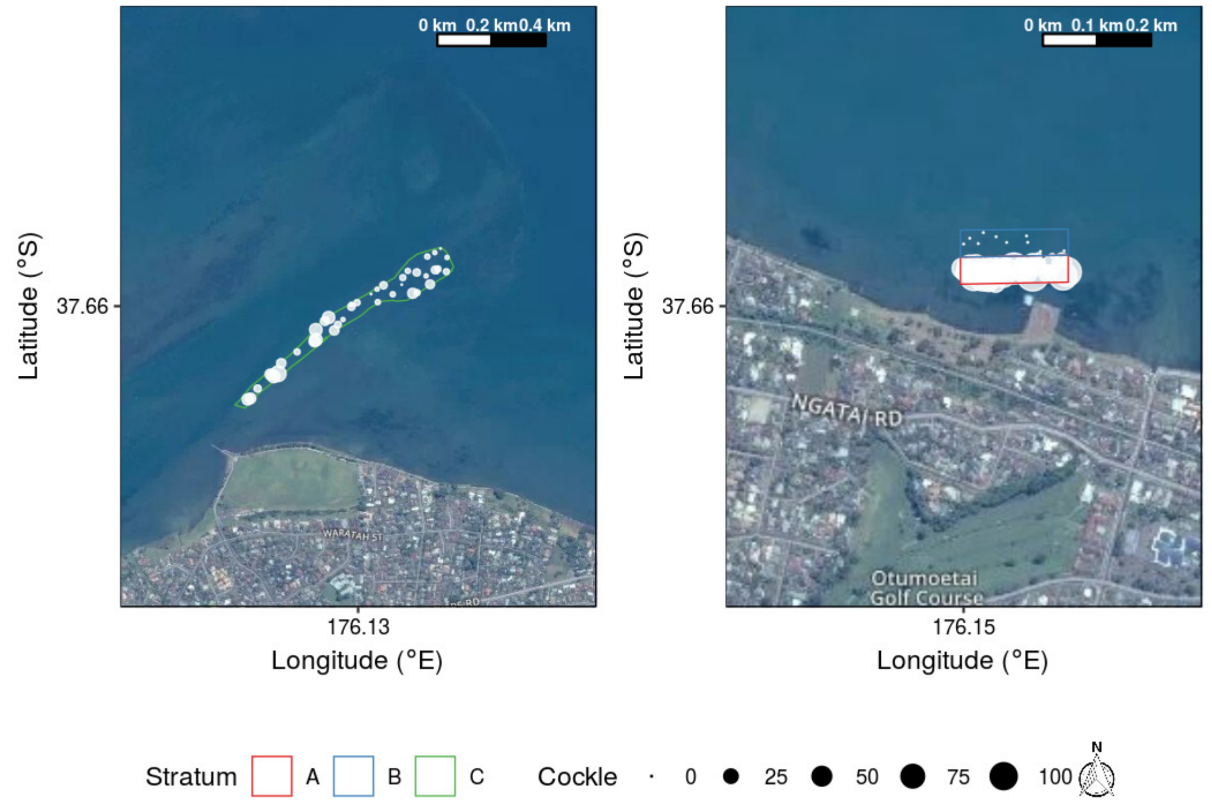


Figure 34: Map of sample strata and individual sample locations for cockles at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of cockle abundance at Otūmoetai, by stratum, for 2018–19. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.0	35	1 301	10.62	1 062	12.61
B	1.0	10	0	0.00	0	
C	6.1	40	261	11.33	186	16.52

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	5.6	5.62	100	9.04	0.54	3	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	<1	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	1	>100
2018–19	8.1	21.95	272	10.48	0.01	<1	100

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	15.73	17	5–32	47.56	0.05
2016–17	15.49	15	5–39	52.88	0.85
2018–19	15.80	15	5–30	48.12	0.04

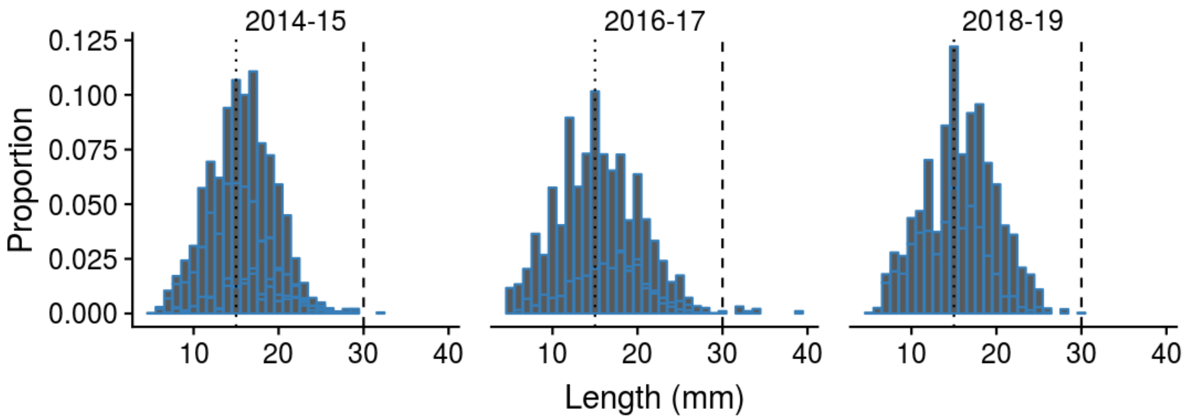


Figure 35: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8.2 Pipi at Otūmoetai (Tauranga Harbour)

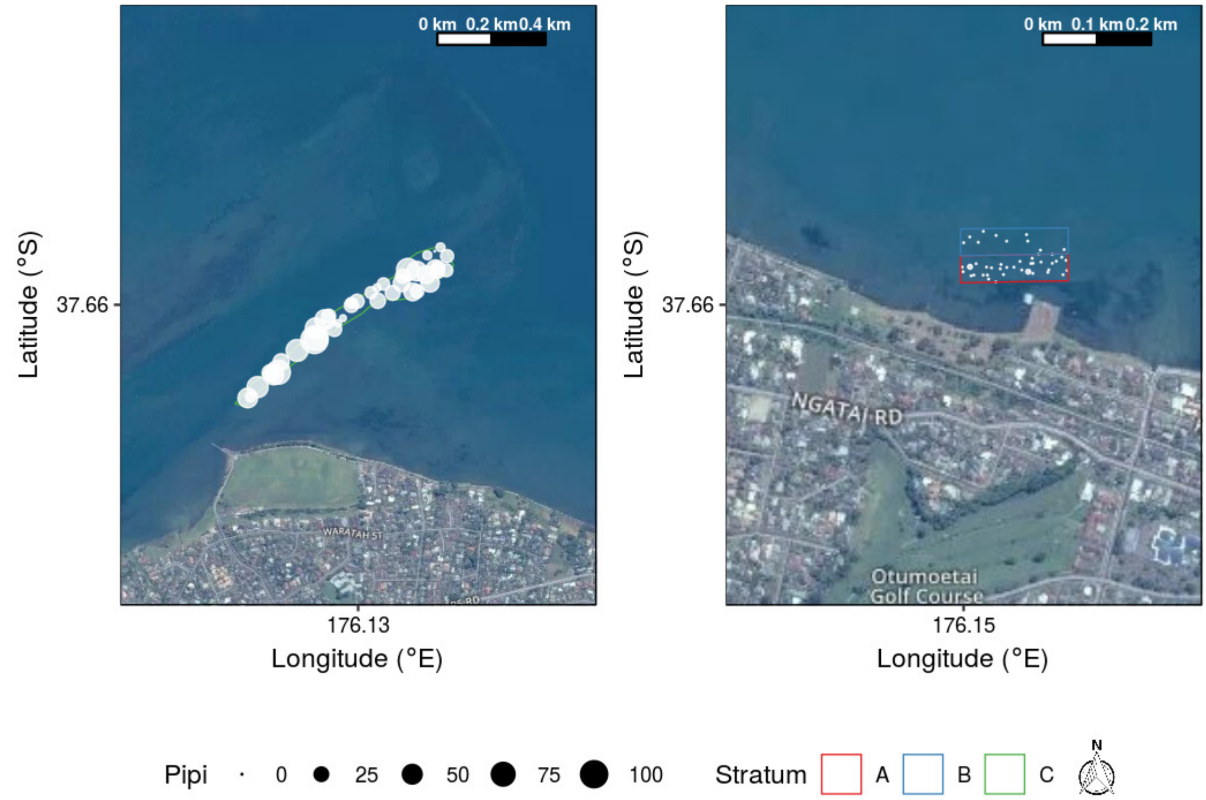


Figure 36: Map of sample strata and individual sample locations for pipi at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of pipi abundance at Otūmoetai, by stratum, for 2018–19. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.0	35	2	0.02	2	69.66
B	1.0	10	0	0.00	0	
C	6.1	40	1 356	58.85	969	10.94

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	5.6	24.76	442	3.30	9.17	82	3.56
2002–03	5.6	20.37	364	3.63	2.06	18	7.56
2005–06	4.6	34.26	745	2.76	1.62	18	7.11
2006–07	4.6	23.63	514	6.61	1.02	11	17.46
2009–10	5.6	17.35	310	7.23	0.63	6	27.44
2014–15	7.7	92.59	1 207	5.59	0.47	2	29.21
2016–17	8.1	71.90	889	11.16	0.13	<1	56.94
2018–19	8.1	58.86	731	10.94	0.30	2	40.75

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	26.62	24	9–55	15.80	0.50
2016–17	29.91	34	3–50	17.23	0.18
2018–19	30.85	30	7–52	5.66	0.52

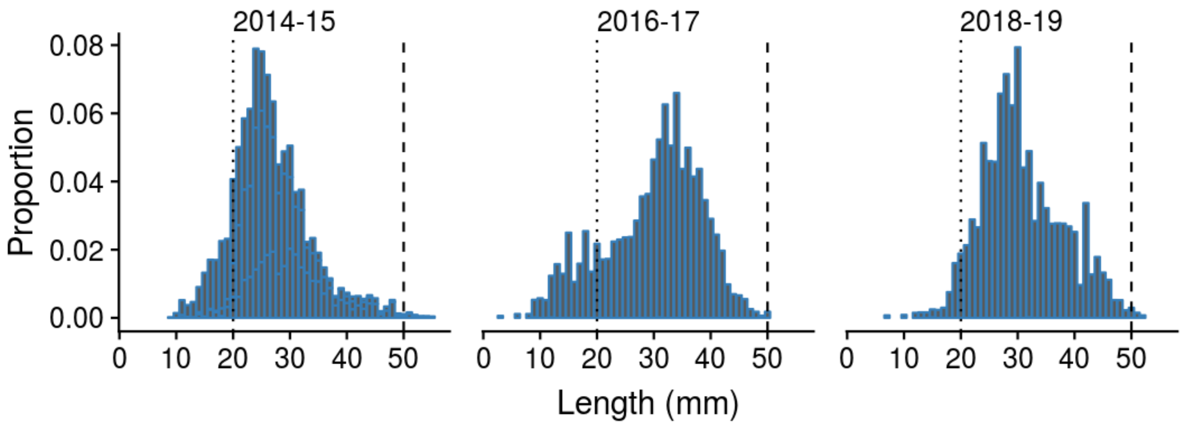


Figure 37: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Ruakaka Estuary

Ruakaka Estuary is a small Northland estuary in Bream Bay, located just south of Whangārei. This site was added to the bivalve monitoring series in 2006–07, with a total of five surveys, including the current study (see Appendix A, Tables A-1, A-2). Sampling at this site has focused on areas associated with the main channel, which has been relatively dynamic throughout the survey series, including substantial changes to its course at the estuary entrance. These changes have led to differences in the sampling extent, with the present study sampling a smaller spatial area than preceding surveys (Figure 38). The 2018–19 field sampling surveyed four strata in 2018–19 and bivalves were assessed at a total of 125 sampling points (Figure 39, Table 43).

The sediment at Ruakaka Estuary was characterised by a low organic content ($<$1.5%) and similar grain size distributions across strata (Figure 38, and see details in Appendix B, Table B-3). Most of the sediment was fine sand (grain size $>$125 µm), with up to 91% in this size fraction, followed by medium sand (grain size $>$250 µm). There was a varying proportion of fines (grain size $<$63 µm), with up to 5.7% of fines in the samples. None of the samples contained gravel (grain size $>$2000 µm).

Cockles at Ruakaka Estuary were concentrated in stratum A, directly adjacent to the main channel, and in separate stratum D, with fewer numbers in stratum B (Figure 39, Table 43). The estimated population size was a total 3.46 million (CV: 12.25%) cockles, occurring at a density of 88 cockles per m^2 (Table 44). The current estimates were markedly lower than values in the two most recent preceding surveys; however the high estimates in the 2014–15 and 2016–17 surveys were partly caused by large influxes of recruits ($\leq$15 mm shell length): this small size class made up over half of the population in the two preceding surveys (Table 45). In contrast, recruitment prior to the 2018–19 assessment was lower, so that recruits only constituted 33.16% of all cockles in this survey year. This variable recruitment across surveys explains some of the observed changes in the population, such as some of the sudden increases and decrease in population size.

In 2018–19, there was a small increase in large cockles ($\geq$30 mm shell length), following the absence of this size class in 2016–17. The abundance and density estimates of large cockles were 0.03 million individuals and <1 large individual per m^2, but the uncertainty of these estimates was high (CV: >100%). The proportion of large cockles within the population was 0.73%, and their scarcity meant that mean and modal sizes were similar to those in the 2016–17 survey (Table 45, Figure 40). The current modal size was 17-mm shell length, and the unimodal population structure showed a shift from a strong influence of recruits in preceding surveys towards medium sizes in the current study.

The pipi population at this site was concentrated in the main channel, in stratum C (Figure 41, Table 46). In contrast to the cockle population, pipi showed a considerable increase in population size and density at Ruakaka Estuary, with an estimated 91.64 million (CV: 17.84%) pipi in 2018–19 (Table 47). Their mean density more than doubled from the 2016–17 estimate of 1008 pipi per m^2 to 2333 pipi per m^2. Nevertheless, the population only included few large pipi ($\geq$50 mm shell length), with recent estimates revealing decreases in their abundance and density. Even though this part of the population has been consistently small, large pipi declined from 1.12 million (CV: 46.67%) large pipi and five large individuals per m^2 in 2016–17 to the current estimates of 0.19 million (CV: 51.87%) large individuals and one large pipi per m^2.

In view of their small population size, large pipi were only a minor proportion of the total population, contributing 0.21% of individuals (Table 48). In comparison, recruits ($\leq$20 mm shell length) represented 51.08% of the 2018–19 pipi population, explaining the marked increase in the total population estimates. The prevalence of recruits and small pipi was also evident in the length-frequency distributions of recent surveys Figure 42. The previously bimodal population, consisting of a cohort each of recruits and medium-sized pipi changed to a unimodal size structure, dominated by a strong cohort of recruits and small pipi, and fewer medium-sized individuals. The modal size of the current population was 15-mm shell length, reflecting the dominance of recruits.

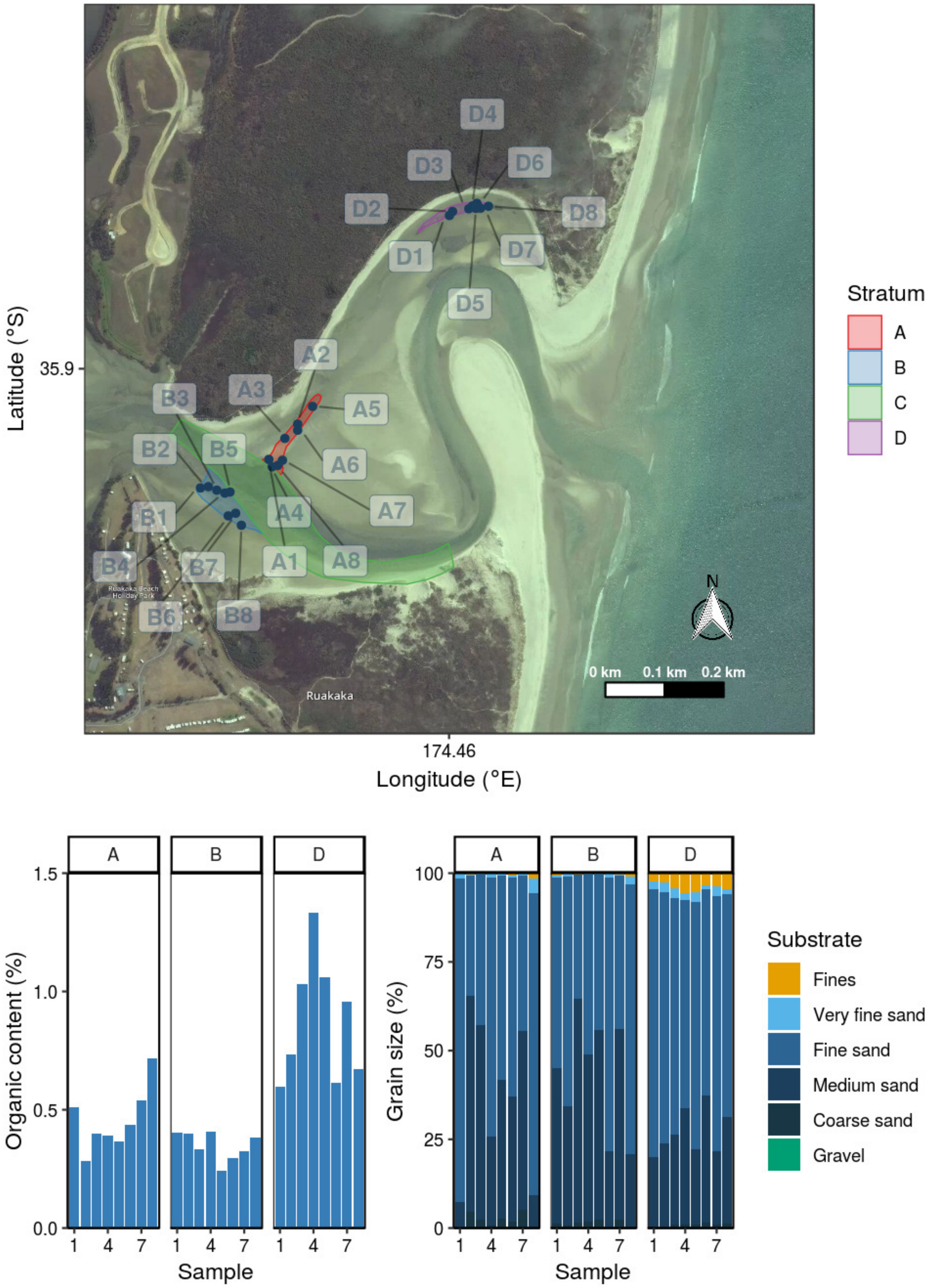


Figure 38: Sediment sample locations and characteristics at Ruakaka Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.9.1 Cockles at Ruakaka Estuary

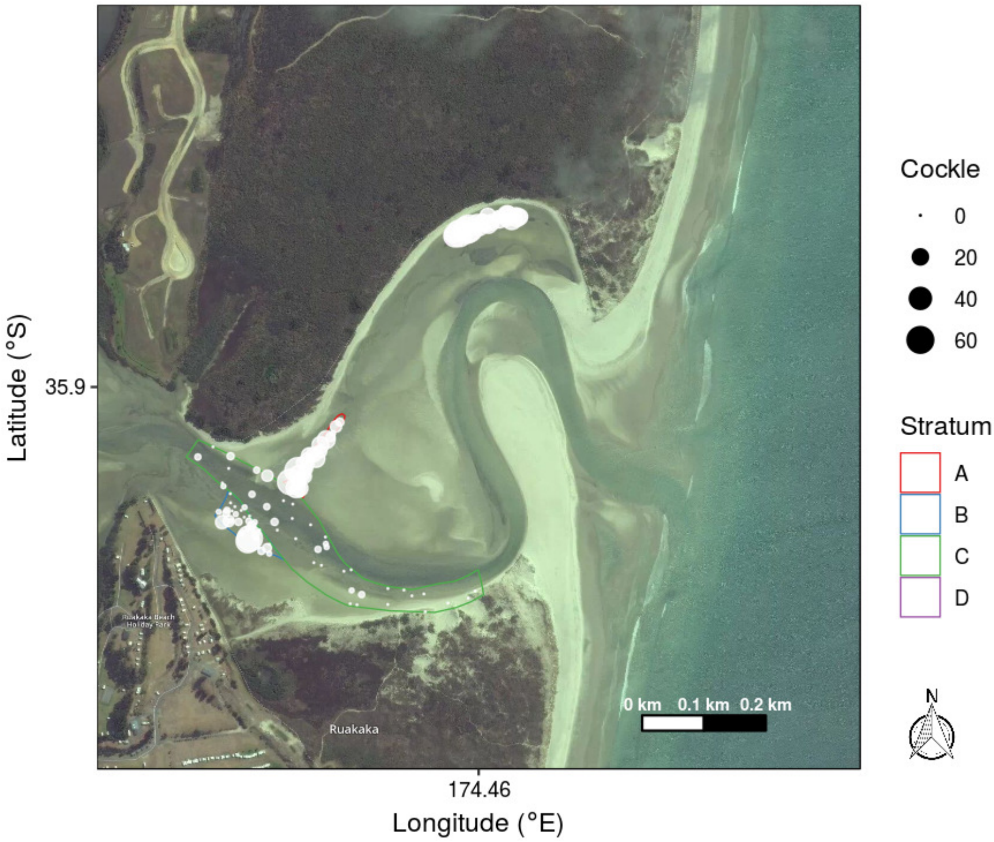


Figure 39: Map of sample strata and individual sample locations for cockles at Ruakaka Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of cockle abundance at Ruakaka Estuary, by stratum, for 2018–19. 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	0.2	25	413	1.16	472	17.65
B	0.4	30	156	0.60	149	44.57
C	3.1	40	33	0.74	24	30.96
D	0.1	30	685	0.96	652	12.31

Table 44: 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	<1	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	<1	35.4
2016–17	5.6	13.08	233	18.38	0.00	0	
2018–19	3.9	3.46	88	12.25	0.03	<1	>100

Table 45: 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 (%)
2014–15	15.87	14	5–40	53.82	0.35
2016–17	15.34	20	4–29	52.17	0.00
2018–19	17.22	17	6–32	33.16	0.73

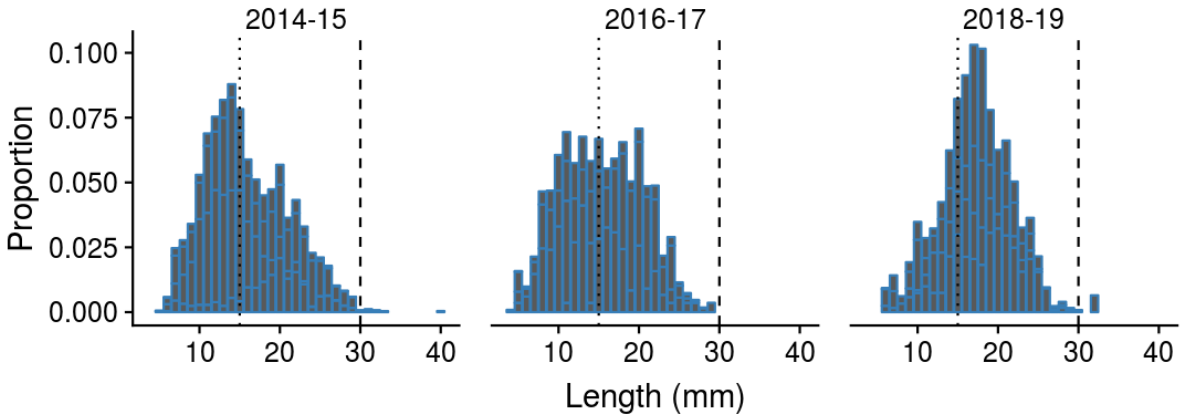


Figure 40: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ruakaka Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9.2 Pipi at Ruakaka Estuary

Figure 41: 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 46: Estimates of pipi abundance at Ruakaka Estuary, by stratum, for 2018–19. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.2	25	59	0.17	67	23.19
B	0.4	30	63	0.24	60	32.56
C	3.1	40	4 074	91.17	2 910	17.93
D	0.1	30	45	0.06	43	20.15

Table 47: 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	4	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	5	46.67
2018–19	3.9	91.64	2 333	17.84	0.19	1	51.87

Table 48: 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 (%)
2014–15	26.52	25	8–51	24.91	0.09
2016–17	27.29	13	5–55	37.25	1.97
2018–19	21.07	15	7–128	51.08	0.21

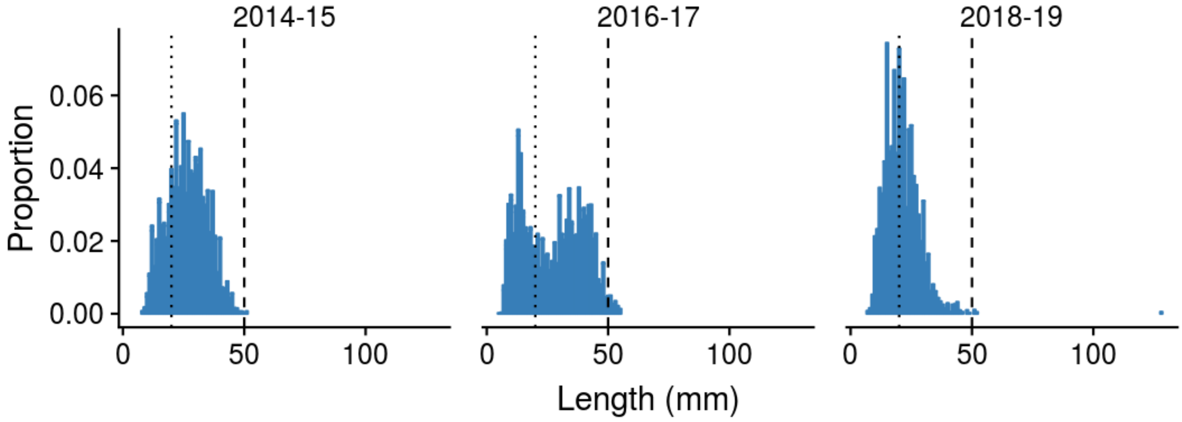


Figure 42: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ruakaka Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Te Haumi

Te Haumi is situated on the east coast of Northland. Bivalves at this site have been assessed in 11 monitoring surveys since 1999–2000, including the current study (see Appendix A, Tables A-1, A-2). The sampling extent has been consistently split across two areas on either side of State Highway 11, with changes to the pipi beds causing changes to the size of the sampling area. In 2018–19, the sampling extent was slightly smaller than in previous recent surveys (i.e., between 2009–10 and 2016–17), and was split into six strata (Figure 43). The sampling effort consisted of a total of 128 sampling points across these strata, including 28 points in phase-2 sampling (Table 49).

The sediment sampling at Te Haumi revealed a low organic content (maximum 3% across all samples) and variable sediment grain size distributions (Figure 43, and see details in Appendix B, Table B-3). The latter showed distinct differences, particular between stratum A and the remaining strata, with stratum A containing comparatively high proportions of coarse sand and gravel (grain sizes >500 µm and >2000 µm), with values exceeding 39 and 27%, respectively. The bulk of the sediment was fine sand (up to 86%; grain size >125 µm) followed by very fine sand (grain size >63 µm), with a variable proportion of fines ranging between <0.5% to 8% (grain size <63 µm).

Cockles were present in all strata, but only occurred at relatively high densities in stratum A and B (Figure 44, Table 49). The total abundance of cockles at Te Haumi was estimated at 79.69 million (CV: 11.69%) individuals, an increase from the preceding survey in 2016–17, particularly in view of the smaller sampling extent (Table 50). The corresponding population density increased to 669 cockles per m^2, compared with 548 individuals per m^2 in 2016–17. Throughout the survey series, the cockle population showed some fluctuation over time, but an overall population growth, with the highest estimates in the current study.

There was also an increase in large cockles (≥30 mm shell length), with an estimated 3.71 million (CV: 19.30%) large individuals, occurring at a density of five large cockles per m^2 in 2018–19. Nevertheless, large cockles continued to be only a small part of the total population, contributing 4.65% of all individuals (Table 51, Figure 45). Most of the population consisted of small and medium-sized individuals, which dominated the population size structure in recent surveys. There has been a varying proportion of recruits (≤15 mm shell length), decreasing to 17.72% in 2018–19, after constituting half of the population in 2016–17. The reduction in recruits resulted in an increase in mean and modal shell lengths, e.g., the modal size increased from 10 mm in 2016–17 to 20 mm in the present study. Length-frequency distributions revealed a shift in the bimodal population towards a smaller cohort of recruits and a second stronger cohort of medium-sized cockles. These findings indicate a stable population at Te Haumi, with regular recruitment events and the persistence of medium- and large-sized cockles.

Pipi at Te Haumi were distributed throughout stratum E, with a localised high-density spot in the north-eastern area of the cockle strata; there were few pipi in stratum F (Figure 46, Table 52). The current population estimates documented a considerable decrease in the pipi population, with total abundance and density estimates of 48.57 million (CV: 20.19%) pipi and 795 pipi per m^2 (Table 53). These estimates signified a 50% decrease compared with the population size in 2016–17, but the high estimates in the preceding survey were largely determined by a strong recruitment event, and the current estimates were consistent with earlier survey findings.

The population of large pipi (≥50 mm shell length) continued to be small, with similar abundance and density estimates as recent surveys, at 0.45 million (CV: 24.34%) pipi and <1 large individuals per m^2. This size class made up a minor proportion (0.92%) of the total population, which mostly consisted of medium-sized pipi and a notable proportion (26.62%) of recruits (≤20 mm shell length) (Table 54, Figure 47). As numbers of recruits in 2016–17 grew towards small and medium sizes in 20128–19, the bimodal population structure became more even and both cohorts were similar. The growth of recruits was also documented in the larger modal size of 42 mm shell length, compared with 18 mm shell length in 2016–17. Based on these data, the pipi population appears to be stable with consistent recruitment and growth of individuals between surveys.

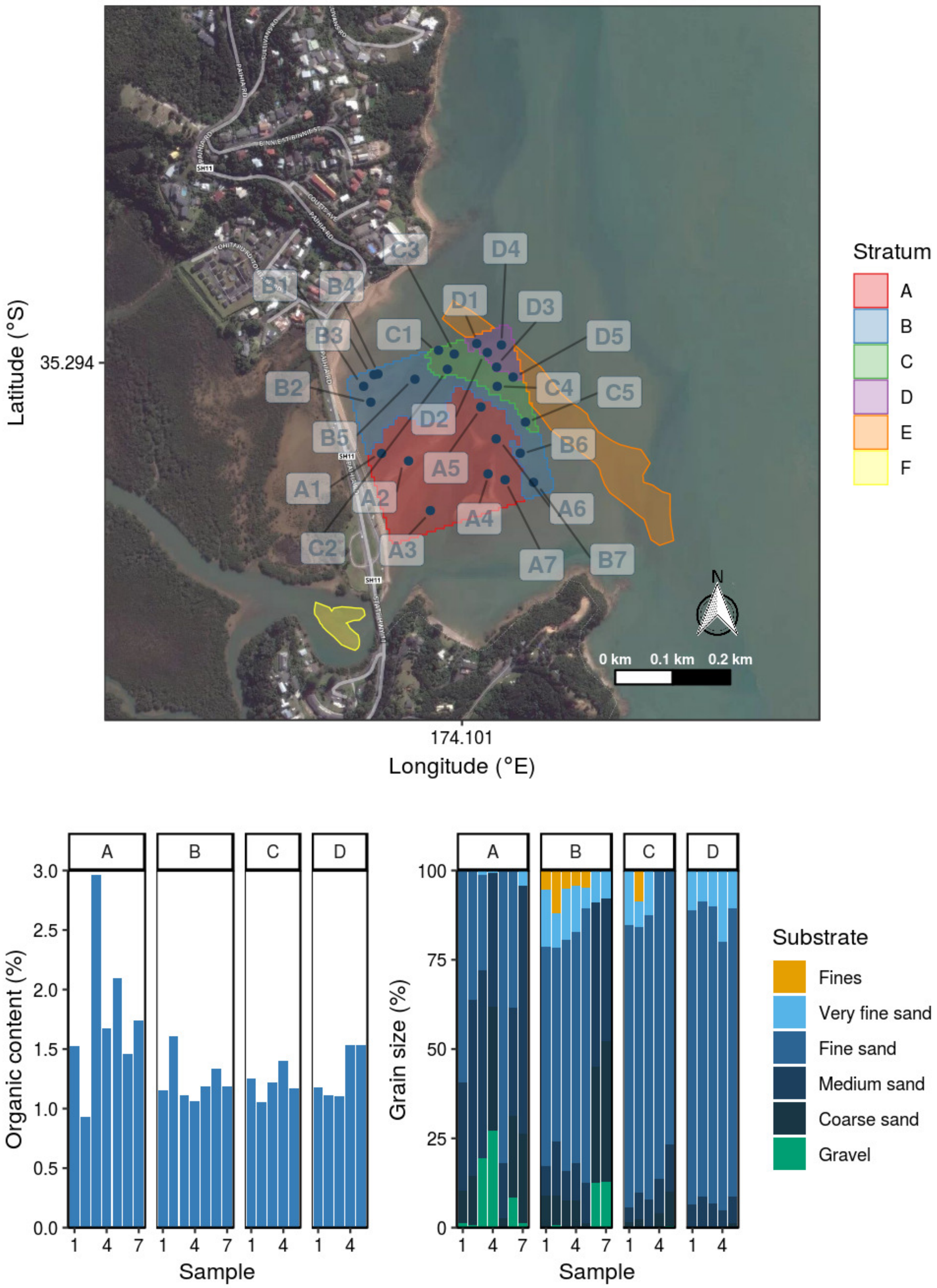


Figure 43: Sediment sample locations and characteristics at Te Haumi. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm;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

3.10.1 Cockles at Te Haumi

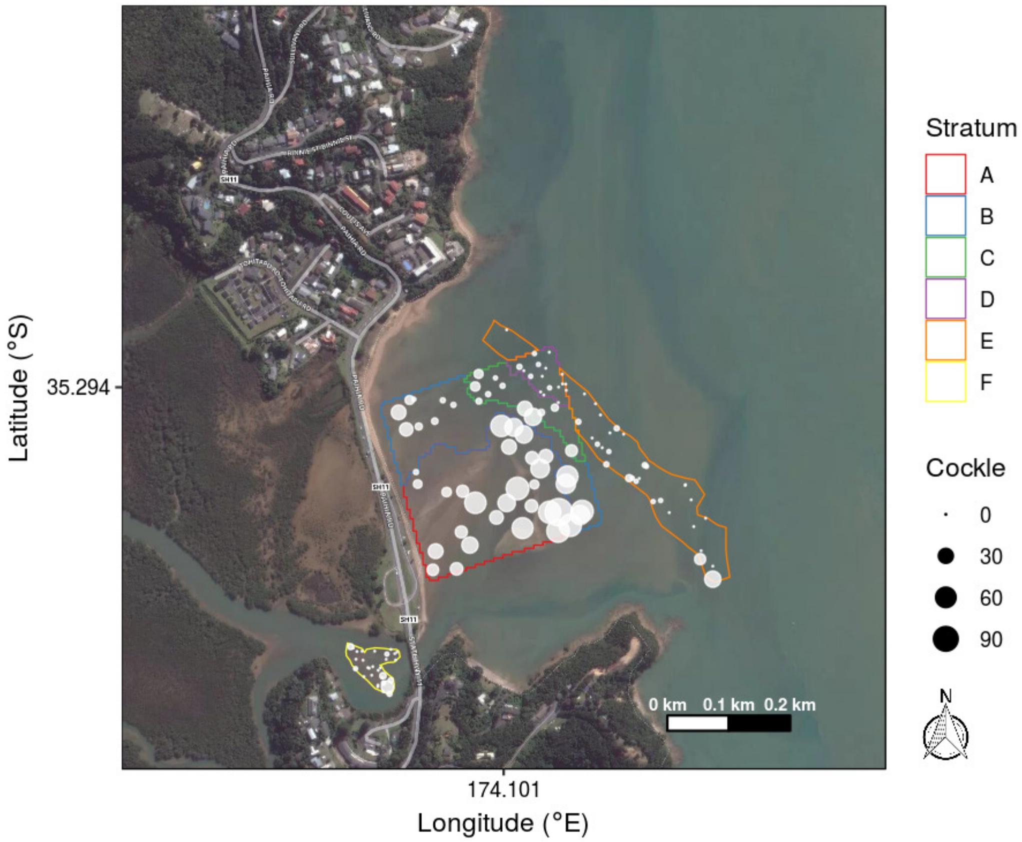


Figure 44: Map of sample strata and individual sample locations for cockles at Te Haumi, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of cockle abundance at Te Haumi, by stratum, for 2018–19. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.8	25	989	54.66	1 130	13.43
B	2.7	15	394	19.90	750	27.86
C	1.0	10	120	3.40	343	35.16
D	0.5	15	6	0.06	11	40.82
E	2.5	33	71	1.55	61	53.83
F	0.4	30	33	0.12	31	58.54

Table 50: Estimates of cockle abundance at Te Haumi 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	28	8.86
2000–01	9.9	17.06	172	11.00	4.11	14	10.27
2001–02	9.9	24.67	249	9.92	1.75	6	11.52
2002–03	9.9	41.77	422	7.97	2.16	11	13.99
2006–07	9.8	15.73	160	12.87	1.98	7	14.53
2009–10	12.1	34.99	290	9.66	2.13	4	26.58
2012–13	12.1	44.67	370	12.28	3.27	7	40.71
2014–15	12.8	35.36	277	11.35	3.42	7	19.75
2016–17	12.8	69.91	548	12.39	2.96	6	24.82
2018–19	11.9	79.69	669	11.69	3.71	5	19.30

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	20.45	18	6–38	21.40	9.67
2016–17	17.01	10	5–39	49.33	4.24
2018–19	20.71	20	5–39	17.72	4.65

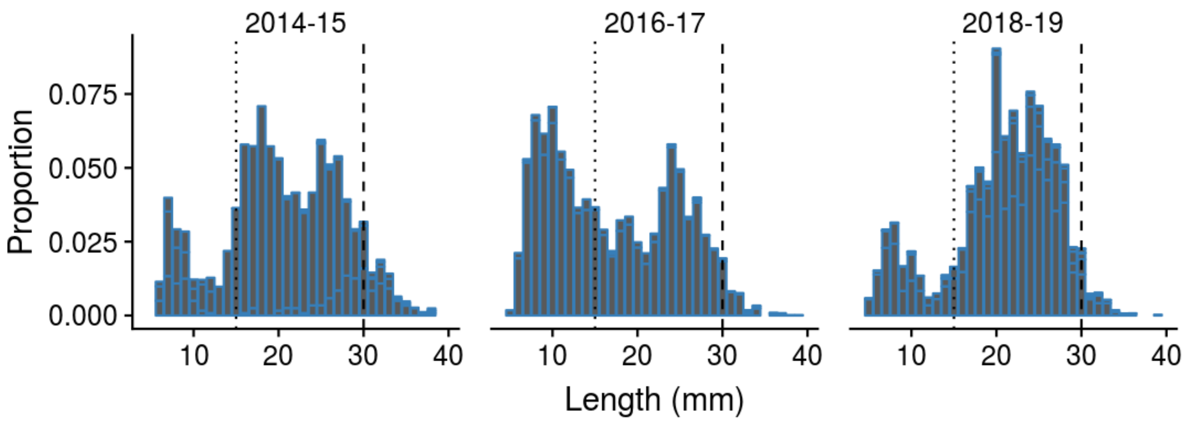


Figure 45: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Te Haumi. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10.2 Pipi at Te Haumi

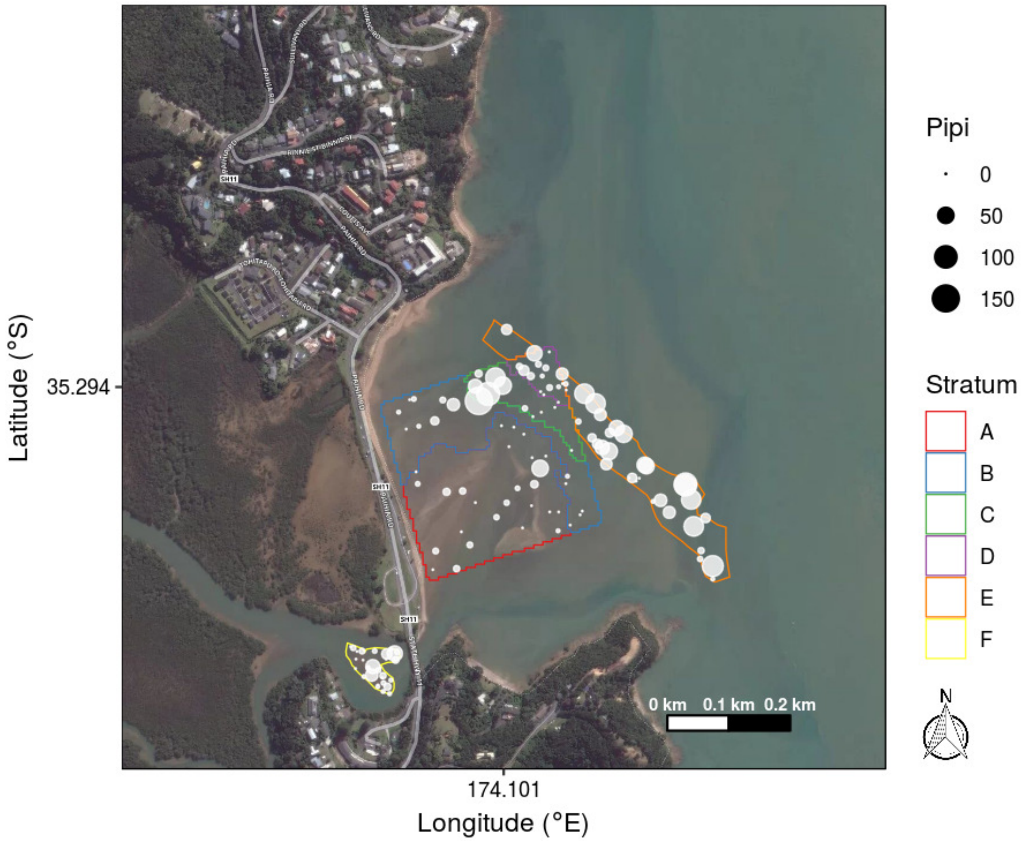


Figure 46: Map of sample strata and individual sample locations for pipi at Te Haumi, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of pipi abundance at Te Haumi, by stratum, for 2018–19. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.8	25	95	5.25	109	53.31
B	2.7	15	200	10.10	381	77.04
C	1.0	10	286	8.09	817	43.07
D	0.5	15	89	0.86	170	49.68
E	2.5	33	1 081	23.64	936	16.58
F	0.4	30	166	0.63	158	36.15

Table 53: Estimates of pipi abundance at Te Haumi 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	24	17.30
2000–01	9.9	62.33	630	9.35	12.17	41	11.94
2001–02	9.9	16.73	169	13.44	1.85	6	16.64
2002–03	9.9	34.04	344	11.17	2.39	8	24.56
2006–07	9.8	31.84	325	13.07	1.14	4	18.85
2009–10	12.1	43.93	364	12.64	0.20	<1	33.60
2012–13	12.1	76.45	634	20.73	0.71	1	74.98
2014–15	12.8	55.91	438	18.38	1.16	2	47.92
2016–17	12.8	101.49	795	24.80	0.55	1	37.83
2018–19	11.9	48.57	408	20.19	0.45	<1	24.34

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	28.22	19	8–58	36.92	2.07
2016–17	23.03	18	3–58	52.71	0.54
2018–19	30.42	42	6–58	26.62	0.92

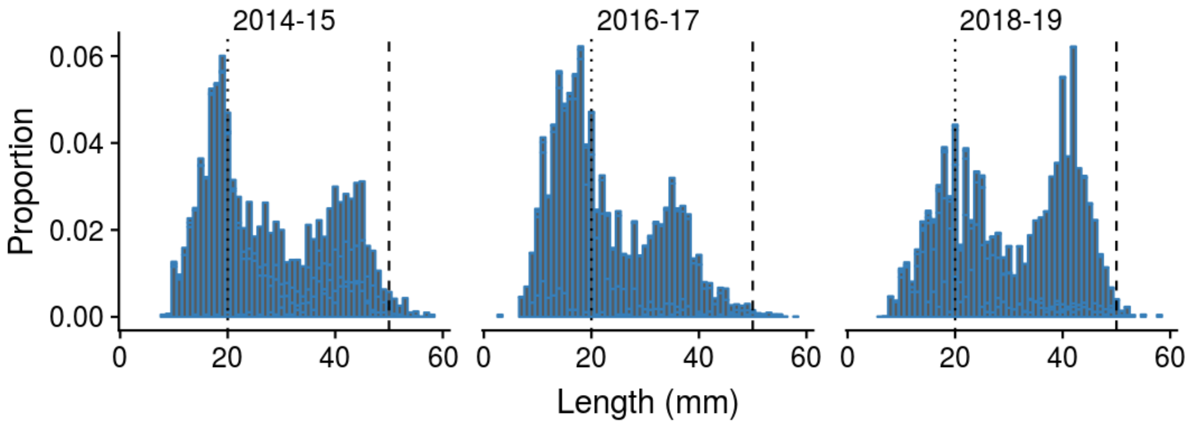


Figure 47: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Haumi. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Whangamatā Harbour

Whangamatā Harbour is on the eastern side of Coromandel Peninsula, in the Waikato region. Bivalve populations in this estuary have been monitored in ten previous surveys, most recently in 2016–17 (see Appendix A, Tables A-1, A-2). Across the survey series, the sampling extent has included areas on either side of the tidal channel of Moanaanuanu Estuary, sampling bivalves on the intertidal mudflat and adjacent to the main harbour channel, close to the entrance (Figure 48). Changes to the sampling extent between surveys were primarily due to the location and spatial extent of pipi beds in the harbour. Across the current sampling extent, there were four strata and a total of 90 sampling points (Figure 48, Table 55).

The sediment organic content in the cockle strata at Whangamatā Harbour was low at less than 3.3% (Figure 48, and see details in Appendix B, Table B-3). The prevalent sediment grain size was fine sand (grain size $>$125 µm), followed by medium sand (grain size $>$250 µm). Sediment fines ($<$63 µm grain size) made up a small fraction of the sediment grain size, although three samples contained over 10% of sediment fines.

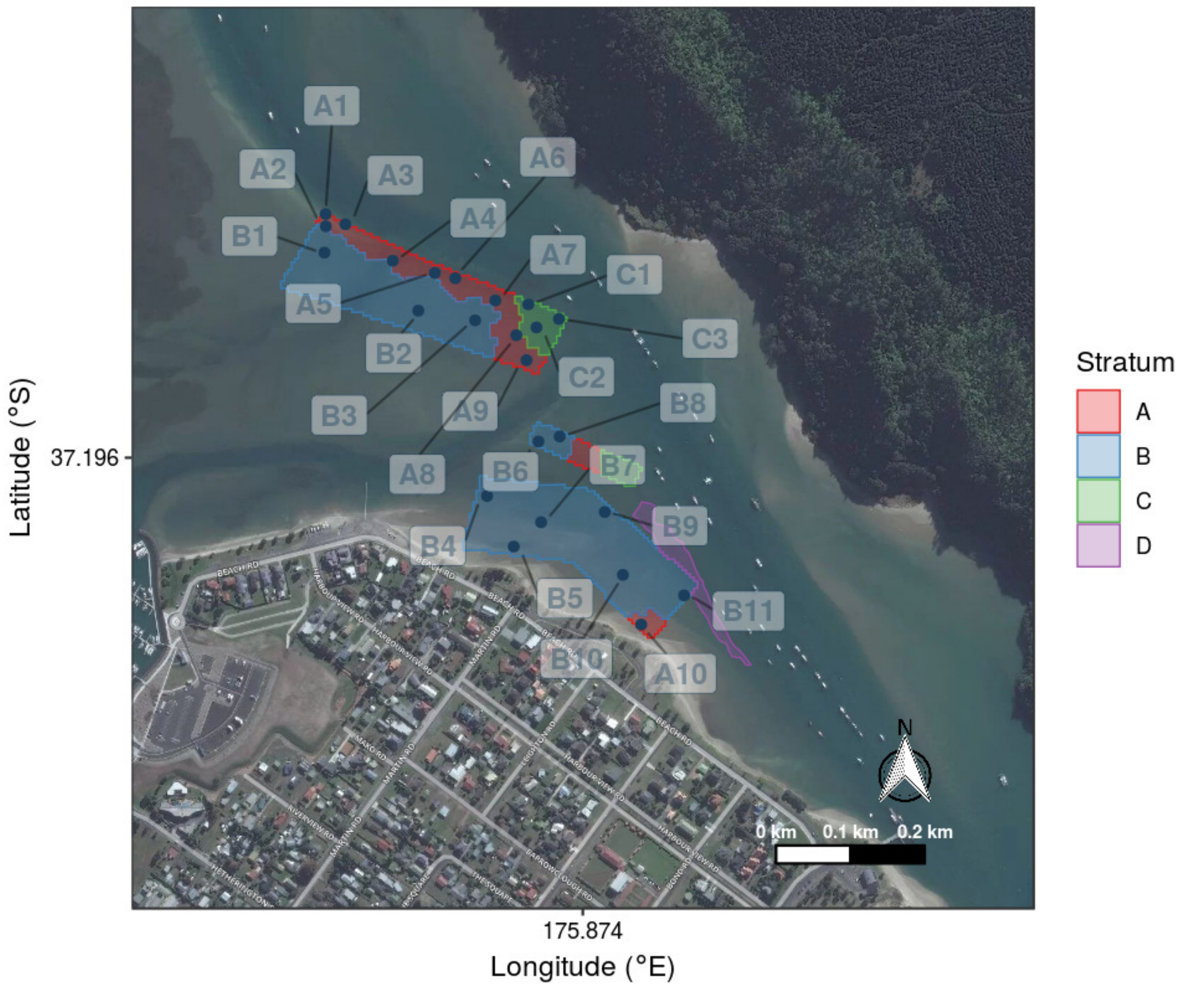
Cockles were present in three of the strata at this site, but were most abundant in stratum B, which encompassed the intertidal mudflat areas on either side of the side channel (Figure 49, Table 55). The population estimate for this species was a total of 78.98 million (CV: 11.38%) cockles in 2018–19, and their corresponding density was 1047 cockles per m^2 (Table 56). Although the present estimates signified a continuing population decrease from the two preceding surveys, the density estimate remained high at $>$1000 individuals per m^2.

A recent decrease was evident in the population estimates of large cockles ($\geq$30 mm shell length). There were comparatively few cockles in this size class, with current abundance and density estimates of 2.41 million (CV: 36.69%) large individuals and eight cockles per m^2, respectively. Large cockles have been relatively scarce at Whangamatā Harbour since 2006–07, indicating an overall decline of individuals in this size class.

The low number of large cockles was reflected in the length-frequency distribution of the population at this site (Table 57, Figure 50). Large individuals made up 3.05% of the current population, whereas recruits ($\leq$15 mm shell length), constituted 31.45%, following a strong recruitment event in 2018–19. Overall, the population continued to be dominated by small and medium-sized individuals, as documented in the mean and modal shell lengths of 18.74 mm and 20 mm. The strong cohort of small and medium-sized cockles persisted throughout recent surveys, with few individuals growing to larger sizes over time.

The pipi bed at Whangamatā Harbour was in a relatively shallow, high-flow area, directly adjacent to the main channel, in stratum D; pipi were also present at low numbers in other strata (Figure 51, Table 58). This species had an estimated abundance of 10.01 million (CV: 27.66%) pipi and mean density of 133 individuals per m^2 (Table 59). The current estimates documented an on-going increase in the pipi population in the three most recent surveys (i.e., since 2014–15), and were the highest estimates since 2001–02 (with few changes in the sampling extent over this period). Included in the 2018–19 population were an estimated 2.79 million (CV: 43.95%) individuals in the large size class ($\geq$50 mm shell length). Large pipi occurred at an estimated density of nine pipi per m^2.

Although the large size class contributed over a quarter (27.90%) of individuals to the current population, this contribution was only about half of their previous proportion (50.90% in 2016–17) (Table 60). At the same time, recruitment remained low, with 8.94% of recruits ($\leq$20 mm shell length) in 2018–19 and 6.30% of recruits in 2016–17. The population size structure in the three recent surveys shifted from a bimodal population determined by small pipi and large individuals to a unimodal population of primarily medium-sized and large pipi (Figure 52). Mean and modal sizes of 40.82 mm and 34 mm shell length confirmed the influence of medium-sized individuals and the relative decrease in large pipi. Based on these survey results, the pipi population at Whangamatā Harbour appeared to be stable, with regular (albeit small) recruitment events and the persistence of large individuals.



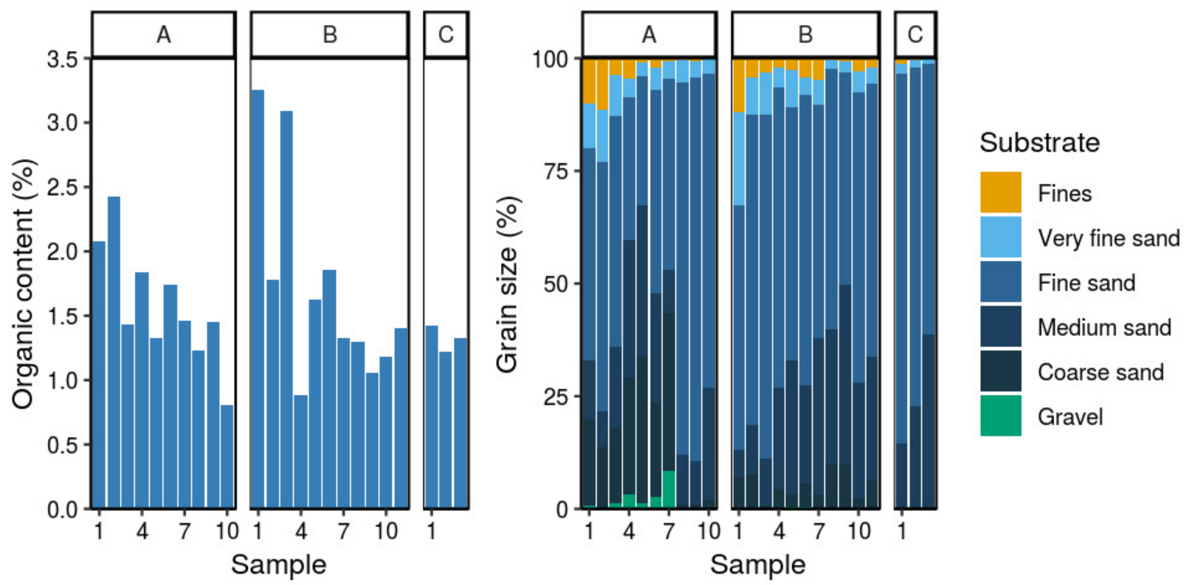


Figure 48: Sediment sample locations and characteristics at Whangamatā Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.11.1 Cockles at Whangamatā Harbour

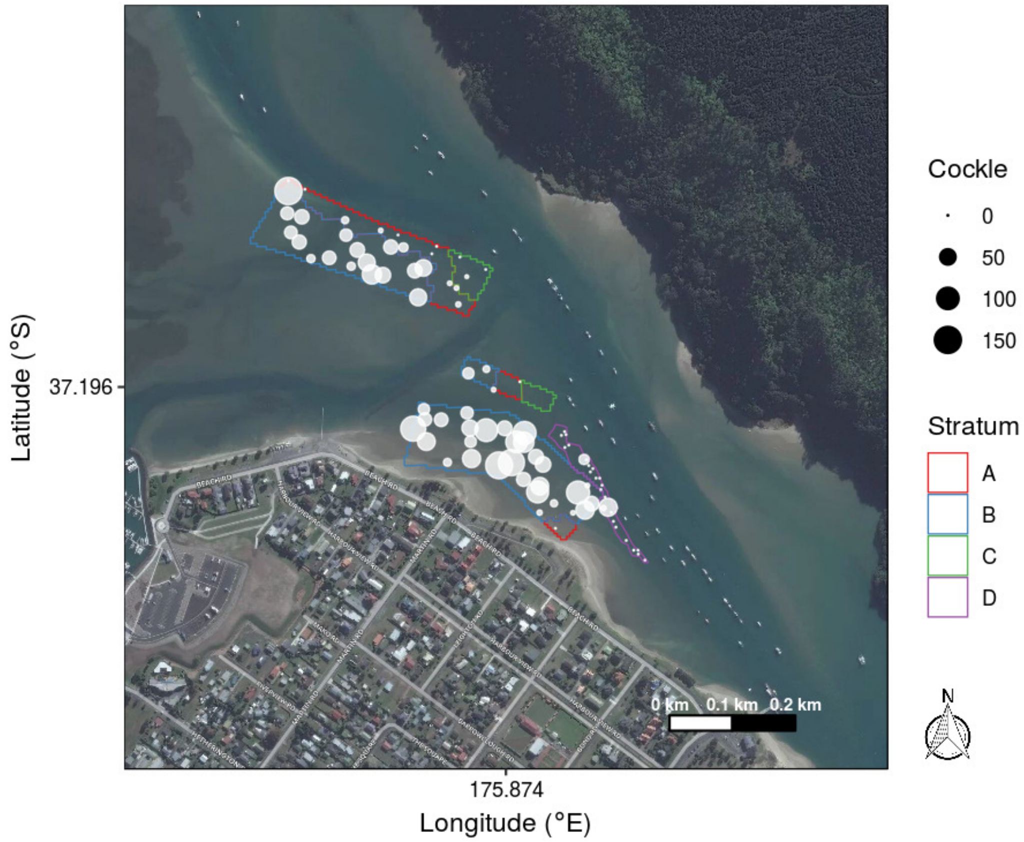


Figure 49: Map of sample strata and individual sample locations for cockles at Whangamatā Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of cockle abundance at Whangamatā Harbour, by stratum, for 2018–19. 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	15	185	4.73	352	82.38
B	5.3	47	2 294	73.80	1 395	10.96
C	0.5	3	1	0.05	10	>100
D	0.4	25	82	0.40	94	77.46

Table 56: Estimates of cockle abundance at Whangamatā Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	70.55	1 287	4.31	17.14	104	6.65
2000–01	5.5	60.33	1 101	4.29	13.95	64	7.60
2001–02	5.5	38.80	708	4.08	6.87	31	7.24
2002–03	5.5	29.78	543	6.61	8.03	37	9.27
2003–04	5.5	43.47	793	4.18	13.10	60	5.18
2004–05	5.5	38.85	709	4.64	9.94	45	4.62
2006–07	24.6	348.01	1 414	0.71	2.86	2	12.99
2010–11	5.9	84.83	1 441	7.06	1.38	6	18.66
2014–15	7.6	104.53	1 372	6.59	2.73	9	19.83
2016–17	7.7	86.78	1 125	7.86	4.00	10	24.60
2018–19	7.5	78.98	1 047	11.38	2.41	8	36.69

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	19.92	20	5–35	21.27	2.61
2016–17	21.21	24	5–58	15.55	4.61
2018–19	18.74	20	4–58	31.45	3.05

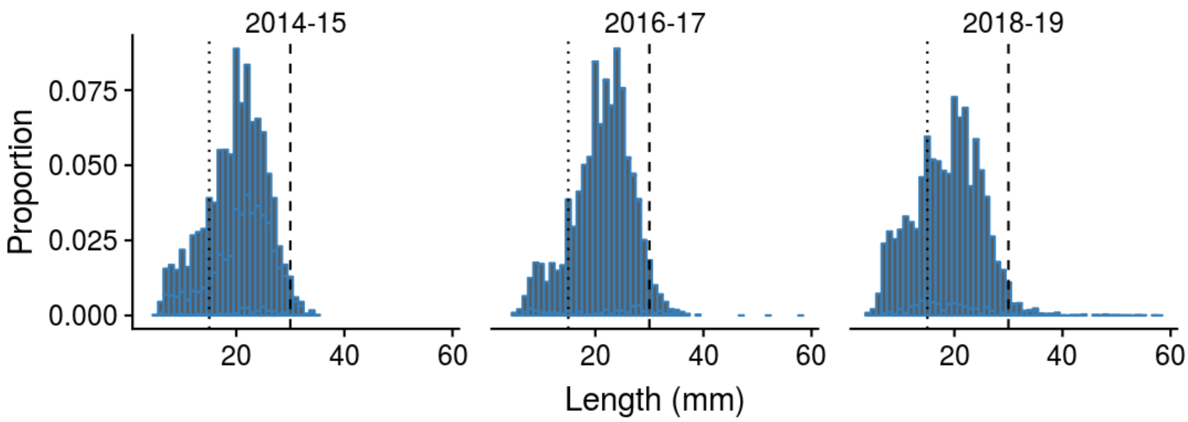


Figure 50: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11.2 Pipi at Whangamatā Harbour

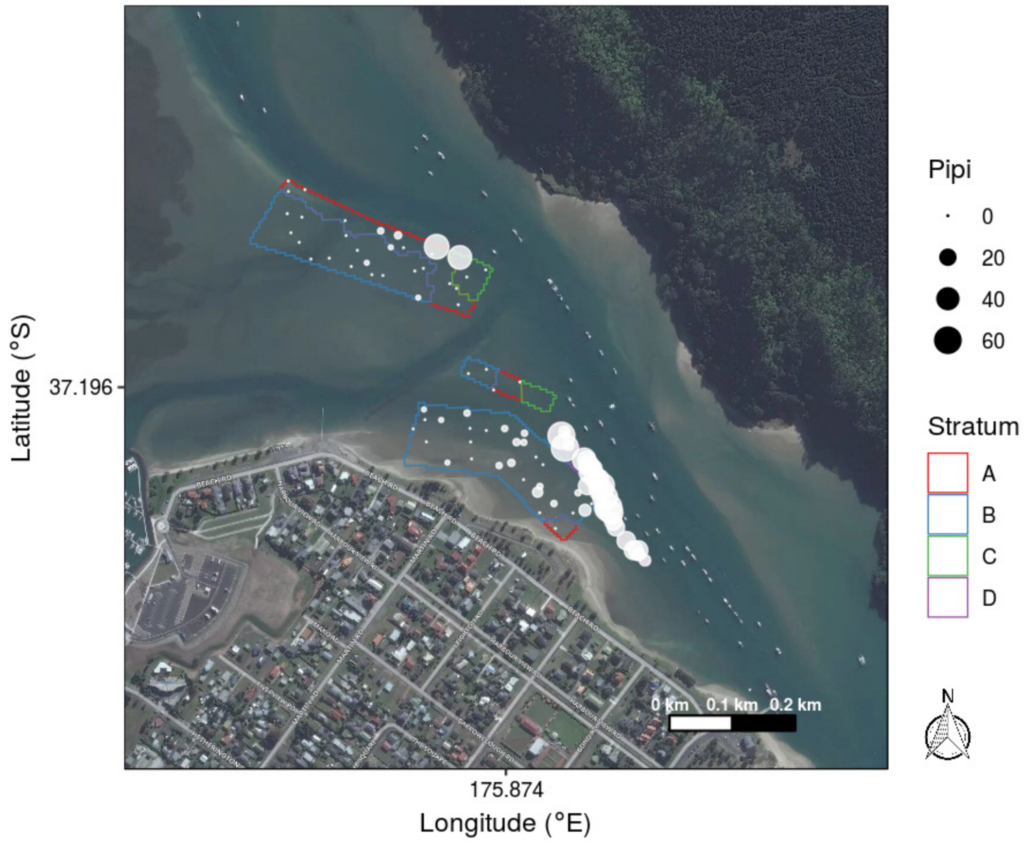


Figure 51: Map of sample strata and individual sample locations for pipi at Whangamatā Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 58: Estimates of pipi abundance at Whangamatā Harbour, by stratum, for 2018–19. 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	15	57	1.46	109	90.81
B	5.3	47	71	2.28	43	39.6
C	0.5	3	48	2.21	457	>100
D	0.4	25	832	4.06	951	11.07

Table 59: Estimates of pipi abundance at Whangamatā Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	15.07	275	9.25	7.25	44	10.78
2000–01	5.5	11.86	216	11.17	5.05	23	21.86
2001–02	5.5	6.38	116	10.45	2.71	12	19.77
2002–03	5.5	5.95	109	10.95	1.60	7	10.55
2003–04	5.5	4.84	88	7.82	2.03	9	9.50
2004–05	5.5	2.30	42	11.13	1.26	6	12.05
2006–07	24.6	3.26	13	7.50	1.49	1	15.43
2010–11	5.9	5.56	94	15.02	1.62	7	39.20
2014–15	7.6	3.79	50	19.69	1.53	5	75.18
2016–17	7.7	7.65	99	24.21	3.87	10	20.49
2018–19	7.5	10.01	133	27.66	2.79	9	43.95

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2014–15	41.81	51	9–62	10.71	40.59
2016–17	46.71	60	7–70	6.30	50.90
2018–19	40.82	34	6–66	8.94	27.90

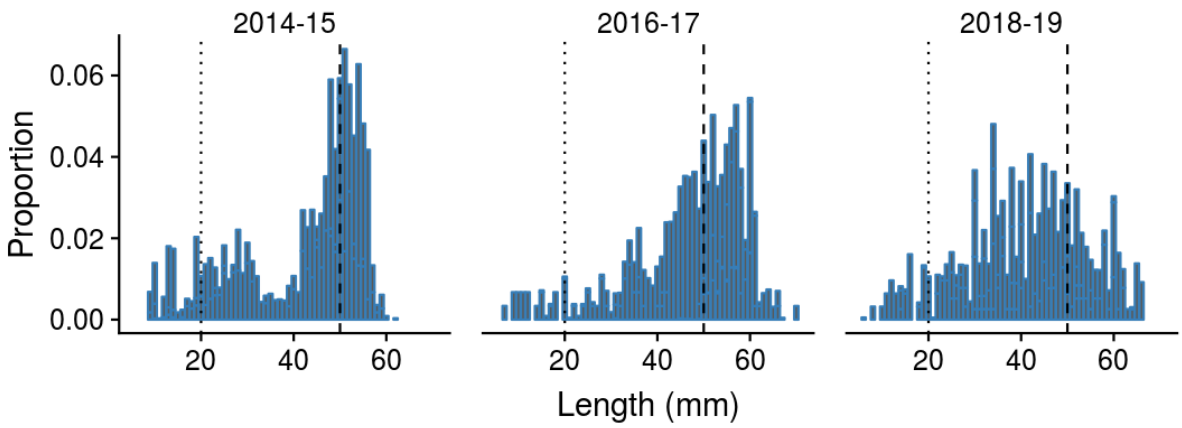


Figure 52: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Whangapoua Harbour

Whangapoua Harbour is a Waikato site, situated on the eastern side of Coromandel Peninsula. There have been seven previous bivalve surveys at this tidal inlet, including the immediately preceding assessment in 2016–17 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent at this site has remained similar, except for some variation in the location and size of the pipi bed. Sampling of the latter has been focused on the pipi population at the harbour entrance, with some changes to its spatial extent and accessibility over time. Consistent with previous surveys, the sampling extent in 2018–19 was split across four disjunct strata, with three cockle and one pipi strata (D); two of the cockle strata were at Matarangi. Across all strata, bivalves were assessed in a total of 160 points (Table 61).

Sediment samples from the cockle strata in Whangapoua Harbour were characterised by a low organic content, with values below 2.5% (Figure 53, and see details in Appendix B, Table B-3). The sediment grain size was predominantly fine sand (grain size >125 μm), with up to 90% of sediment in this size fraction, and a smaller proportion of medium sand (grain size >250 μm). Other grain size fractions were minor, including sediment fines (grain size <63 μm), with less than 3% of sediment in this grain size across all samples.

Cockles at this site were almost exclusively in strata A to C, with their highest abundance in stratum B (Figure 54, Table 61). Their population abundance was estimated at a total of 64.97 million (CV: 10.62%) cockles, with a corresponding density of 1229 cockles per m^2 (Table 62). Both estimates reflected notable increases in the cockle population overall, continuing the upward population trend. Nevertheless, there were few large cockles (≥30 mm shell length) in the 2018–19 population, with an abundance estimate of 0.52 million (CV: 27.22%) large cockles, occurring at a density of two individuals per m^2. These estimates reflected a 50% decrease in estimates of the large size class since the preceding survey in 2016–17.

In contrast to the small contribution (0.80%) of large individuals to the total cockle population, almost a third (28.93%) of all cockles at Whangapoua Harbour were recruits (≤15 mm shell length) (Table 63, Figure 55). This size class was similarly strong in the previous survey (i.e., in 2016–17), indicating substantial recruitment prior to the recent field surveys. The population size structure was dominated by small and medium-sized cockles and the prevalence of the latter size group was evident in current mean and modal sizes of 18.25 mm and 21 mm shell lengths, respectively. The growth of recruits and small individuals to medium sizes since the previous survey resulted in a change from a bimodal population in 2016–17 to the current unimodal population size structure. In summary, the cockle population at Whangapoua Harbour continued to show a population increase in the current survey and consistent recruitment, but large cockles remained scarce.

The pipi population at Whangapoua Harbour was restricted to stratum D, close to the harbour entrance (Figure 56, Table 64). Throughout the survey series, the pipi bed has been consistently surveyed in this general area, although there has been some movement and changes across surveys. In 2018–19, population estimates for this pipi bed were a total of 4.17 million (CV: 14.71%) pipi at a density of 79 individuals per m^2 (Table 65). The population included a considerable number of large pipi (≥50 mm shell length), with an estimated 1.44 million (CV: 13.32%) individuals in this size class; their corresponding density was also high with 27 large pipi per m^2.

Considering the contribution of different size classes to the pipi population overall, large pipi signified 34.64% of the total population compared with 23.59% of recruits (≤20 mm shell length) (Table 66, Figure 57). The mean and modal sizes in the three most recent surveys were similar, with current sizes at 36.49 mm and 52 mm shell length. These sizes confirmed the influence of large-sized individuals on the population, with a cohort of large individuals and a second cohort of recruits and small-sized pipi constituting the bimodal population size structure. With the persistence of large pipi at this site, Whangapoua Harbour remains one of few northern survey sites with a discernible proportion of this large size class.

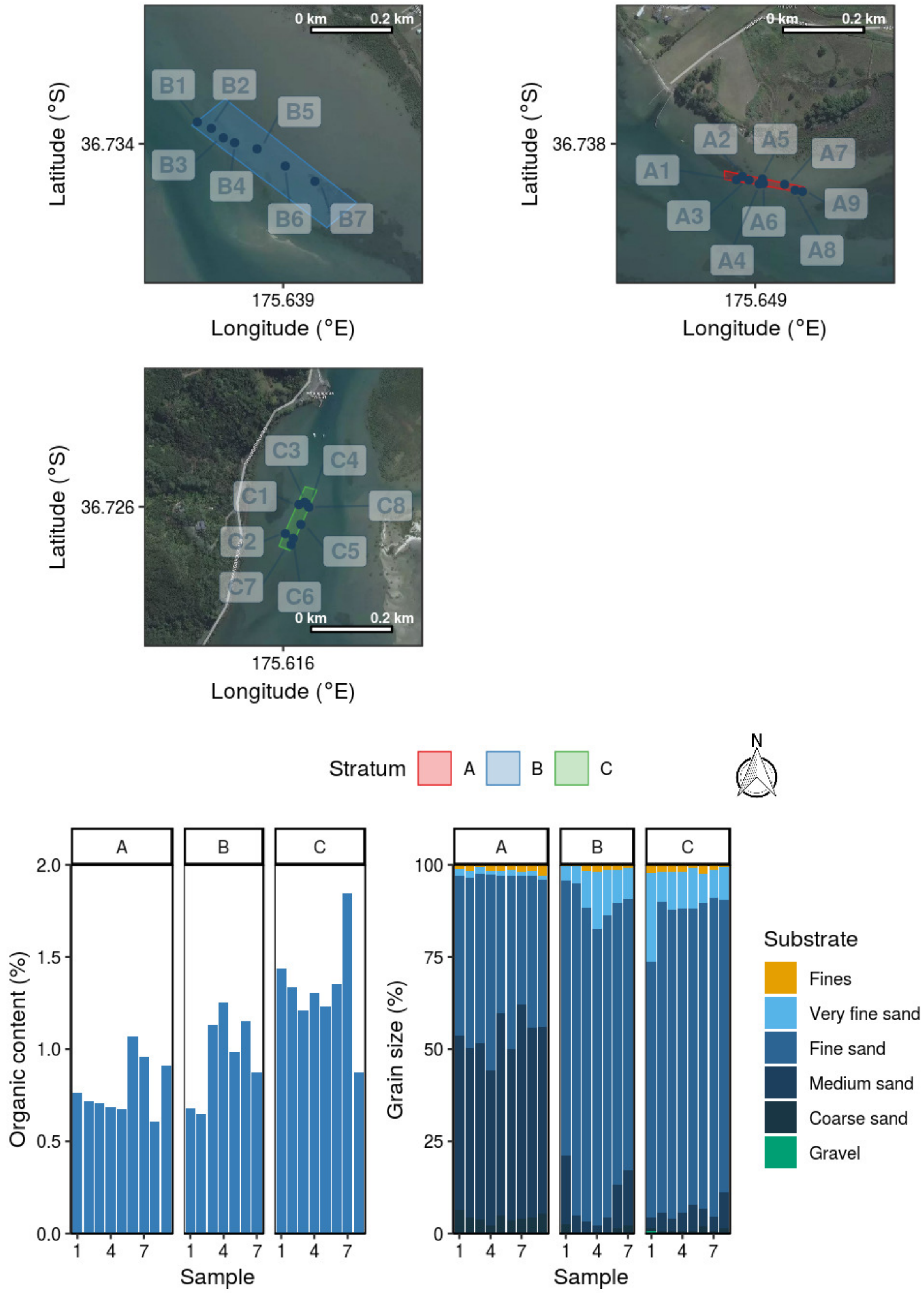


Figure 53: Sediment sample locations and characteristics at Whangapoua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >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

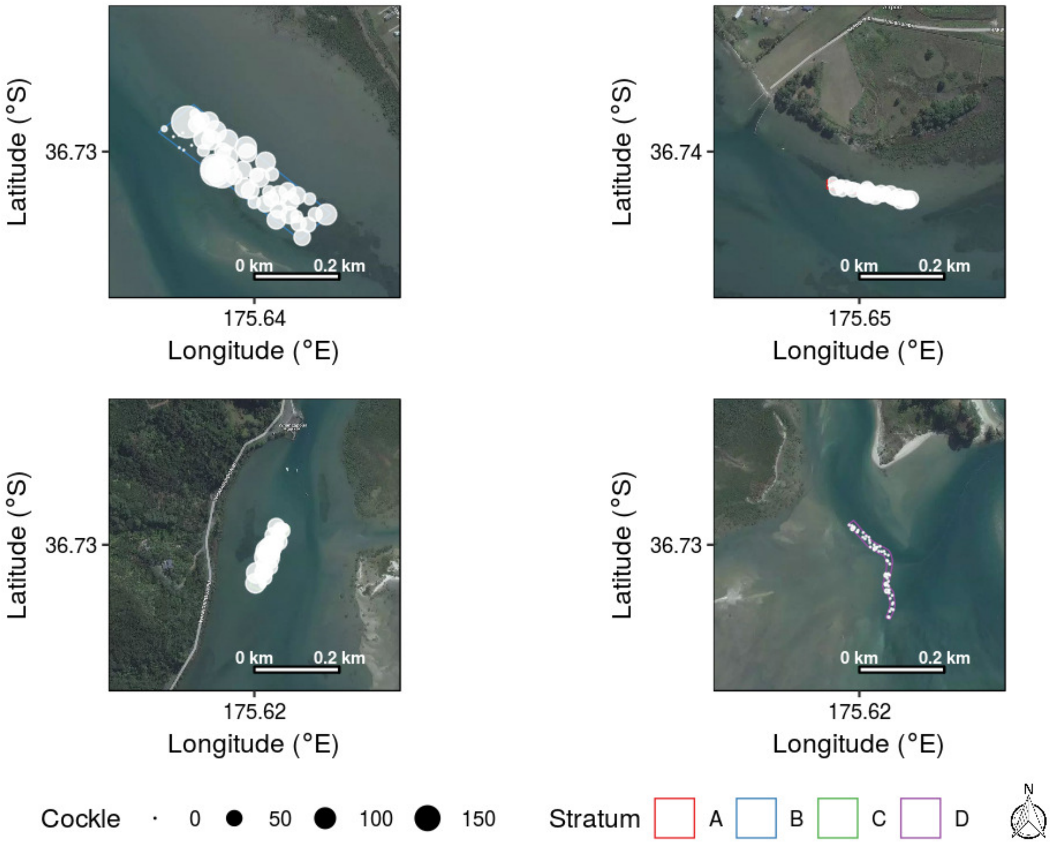


Figure 54: Map of sample strata and individual sample locations for cockles at Whangapoua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 61: Estimates of cockle abundance at Whangapoua Harbour, by stratum, for 2018–19. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	30	746	2.41	710	11.45
B	4.1	50	2 495	58.20	1 426	11.79
C	0.5	30	952	4.34	907	15.60
D	0.4	50	6	0.01	3	45.43

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	1.7	11.30	680	4.87	2.71	41	7.69
2003–04	5.2	19.19	369	4.23	6.37	41	8.45
2004–05	5.2	33.19	638	4.07	5.18	25	9.22
2010–11	5.2	32.06	617	9.71	2.83	14	18.88
2014–15	6.3	33.67	533	9.54	1.43	5	15.18
2016–17	5.3	43.80	827	16.02	1.08	4	16.30
2018–19	5.3	64.97	1 229	10.62	0.52	2	27.22

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 (%)
2014–15	21.83	25	6–40	10.55	4.25
2016–17	17.92	20	5–58	32.84	2.47
2018–19	18.25	21	5–38	28.93	0.80

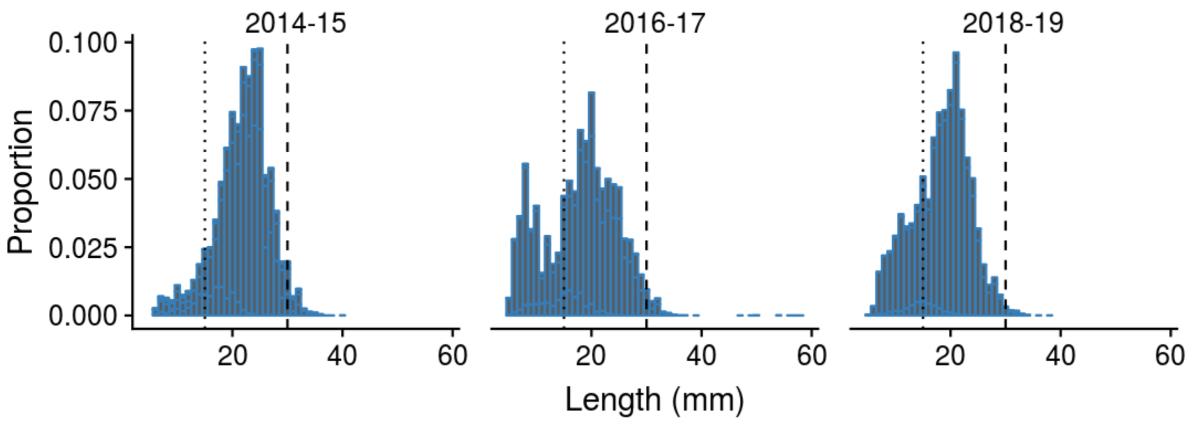


Figure 55: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12.2 Pipi at Whangapoua Harbour

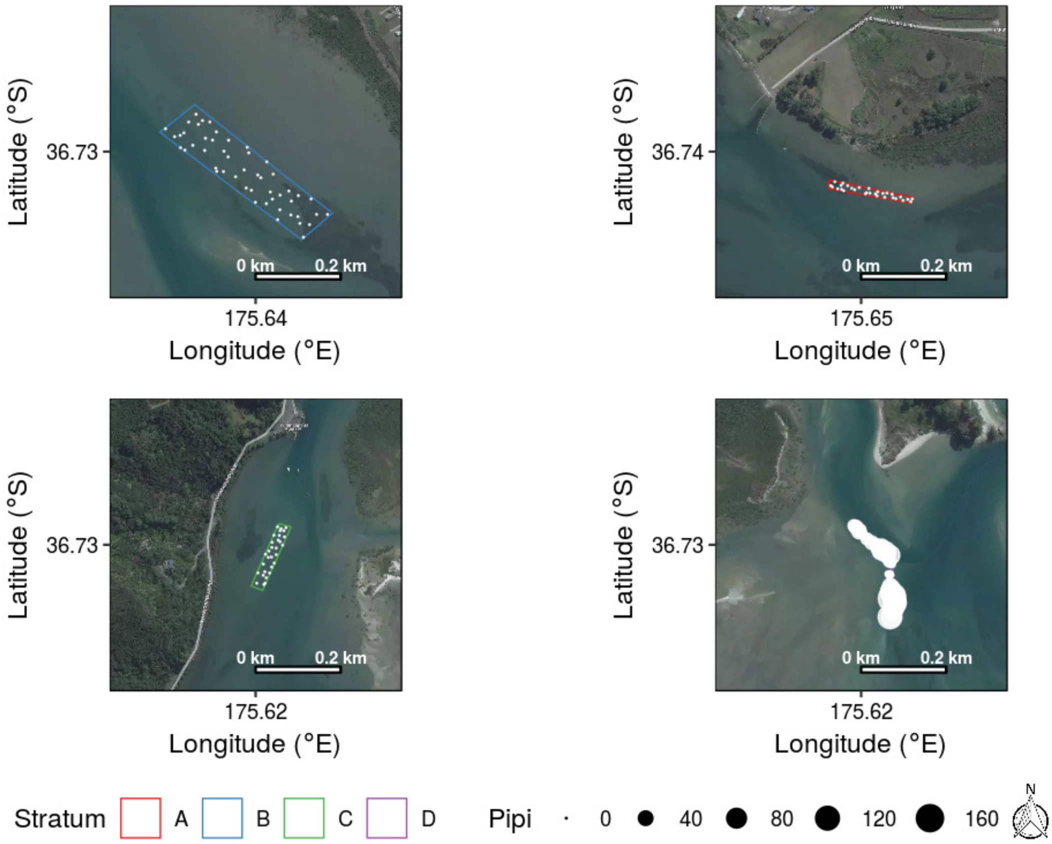


Figure 56: Map of sample strata and individual sample locations for pipi at Whangapoua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 64: Estimates of pipi abundance at Whangapoua Harbour, by stratum, for 2018–19. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	30	0	0.00	0	
B	4.1	50	0	0.00	0	
C	0.5	30	0	0.00	0	
D	0.4	50	1 899	4.17	1 085	14.71

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	104	8.28
2003–04	5.2	5.05	97	9.98	1.75	17	7.90
2004–05	5.2	7.47	144	5.25	3.75	36	5.08
2010–11	5.2	2.74	53	18.82	1.18	8	22.54
2014–15	6.3	2.27	36	20.24	0.34	2	22.32
2016–17	5.3	2.01	38	21.05	0.66	5	29.84
2018–19	5.3	4.17	79	14.71	1.44	27	13.32

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 (%)
2014–15	38.42	47	9–60	10.78	14.90
2016–17	34.19	55	5–65	34.36	33.19
2018–19	36.49	52	8–66	23.59	34.64

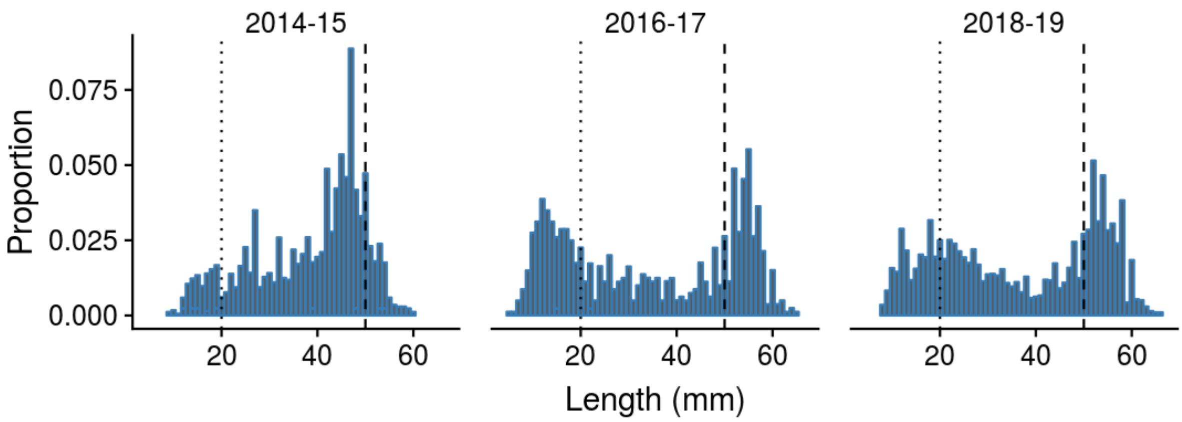


Figure 57: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

The 12 northern North Island sites included in the 2018–19 survey covered a diverse range of intertidal habitats, from extensive sandflats (e.g., Kawakawa Bay (West)) to relatively small mudflats adjacent to mangroves (e.g., Ngunguru Estuary). All of the sites supported cockle populations, and the survey effort was sufficient to provide population estimates with a CV below the 20% target for each site (Table 67). Nevertheless, two sites, Kawakawa Bay (West) and Te Haumi, required phase-2 sampling to meet the target CV.

Cockle abundance and density estimates were high (i.e., more than 100 million individuals) at two sites, Kawakawa Bay (West) and Ngunguru Estuary, where total cockle abundance was 222.41 million (CV: 17.52%) and 129.23 million (CV: 6.57%) cockles, respectively. In contrast, both Ohiwa Harbour and Ruakaka Estuary only supported small cockle populations, with estimated total population sizes of 5.57 million (CV: 13.38%) and 3.46 million (CV: 12.25%) cockles in 2018–19.

Comparison of the density estimates showed that most of the 2018–19 sites supported population densities of several hundred individuals per m^2. In addition, four of the sites supported high cockle densities (i.e., more than 1000 cockles per m^2): these sites were Ngunguru Estuary and Whangapoua, Mangawhai and Whangamatā harbours. The highest density estimate of 1997 cockles per m^2 was at Ngunguru Estuary. In contrast, the only site with a comparatively low cockle density was Ruakaka Estuary, where the estimate was 88 cockles per m^2. At all other sites, density estimates ranged from 219 cockles per m^2 (Ohiwa Harbour) to 669 cockles per m^2 (Te Haumi) in 2018–19.

Although the total population estimates were generally high, none of the 2018–19 populations included a notable number of large cockles ($\geq$30 mm shell length). Individuals in this size class were near-absent at Otūmoetai (Tauranga Harbour) and Ruakaka Estuary, and the remaining sites had low abundance and density estimates (frequently with high uncertainty) for this size class. The highest estimates were at Mangawhai, Ohiwa and Whangamatā harbours, where densities of large cockles were seven to eight individuals per m^2. The small population sizes meant that large cockles were only a minor part of the total population at each site.

Throughout the monitoring series, there was some fluctuation in cockle densities at all sites with time-series data, with a number of populations exhibiting an overall increase in density compared with the initial surveys (Figure 58). This trend was evident across different regions, with Kawakawa Bay (West) and Mill Bay in the wider Auckland region, Ngunguru Estuary and Te Haumi in Northland, and Whangapoua Harbour in Waikato. At Mill Bay and Ngunguru Estuary, the overall increase was augmented by a marked increase in cockle density in 2018–19. At Mill Bay, this increase followed a significant decline in cockle density in 2017–18, which had coincided with a mass mortality event observed during the previous field survey.

At two sites, Ohiwa Harbour and Ruakaka Estuary, there were substantial decreases in cockle densities in 2018–19. At Ruakaka Estuary, the current decrease continued the marked decline in cockle density noted in the preceding survey, following a high estimate in 2014–15 (>600 individuals per m^2). Nevertheless, this estuary was characterised by low cockle densities in earlier assessments. Similarly, the 2018–19 density estimate at Ohiwa Harbour was comparable to estimates at the start of the survey series at this site.

The fluctuations in total cockle densities were partly determined by recruitment events, with large influxes of small-sized recruits leading to substantial population increases in some survey years. The growing influence of recruits and small-sized individuals throughout the survey series was evident in the length-frequency distributions, which highlighted a shift towards smaller cockle sizes over time, starting in 2005–06 (Figure 59). This shift was uniform across the current sites and corresponded with a general decrease in large-sized individuals. The resulting population size structures were determined by a cohort consisting of recruits and small and medium-sized individuals.

Time-series data highlighted the scarcity of large cockles (≥30 mm shell length) at the current survey sites (Figure 60). In addition to low estimates in 2018–19, this size class occurred at only low densities throughout the assessment period; at the majority of sites, the density estimates were less than 15 large cockles per m^2. At Mangawhai and Whangamatā harbours, density estimates were about 100 large individuals per m^2 at the start of the survey series, but declined since then with no subsequent increases in large cockles.

Table 67: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2018–19 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	82.34	423	11.06	0.96	2	32.86
Hokianga Harbour	25.54	254	11.88	0.32	1	49.47
Kawakawa Bay	222.41	365	17.52	9.34	5	28.81
Mangawhai Harbour	78.89	1 091	8.56	2.48	7	17.36
Mill Bay	23.04	475	14.68	0.67	5	20.3
Ngunguru Estuary	129.23	1 997	6.57	0.28	1	51.2
Ohiwa Harbour	5.57	219	13.38	0.82	8	39.04
Otūmoetai	21.95	272	10.48	0.01	<1	>100
Ruakaka Estuary	3.46	88	12.25	0.03	<1	>100
Te Haumi	79.69	669	11.69	3.71	5	19.3
Whangamatā Harbour	78.98	1 047	11.38	2.41	8	36.69
Whangapoua Harbour	64.97	1 229	10.62	0.52	2	27.22

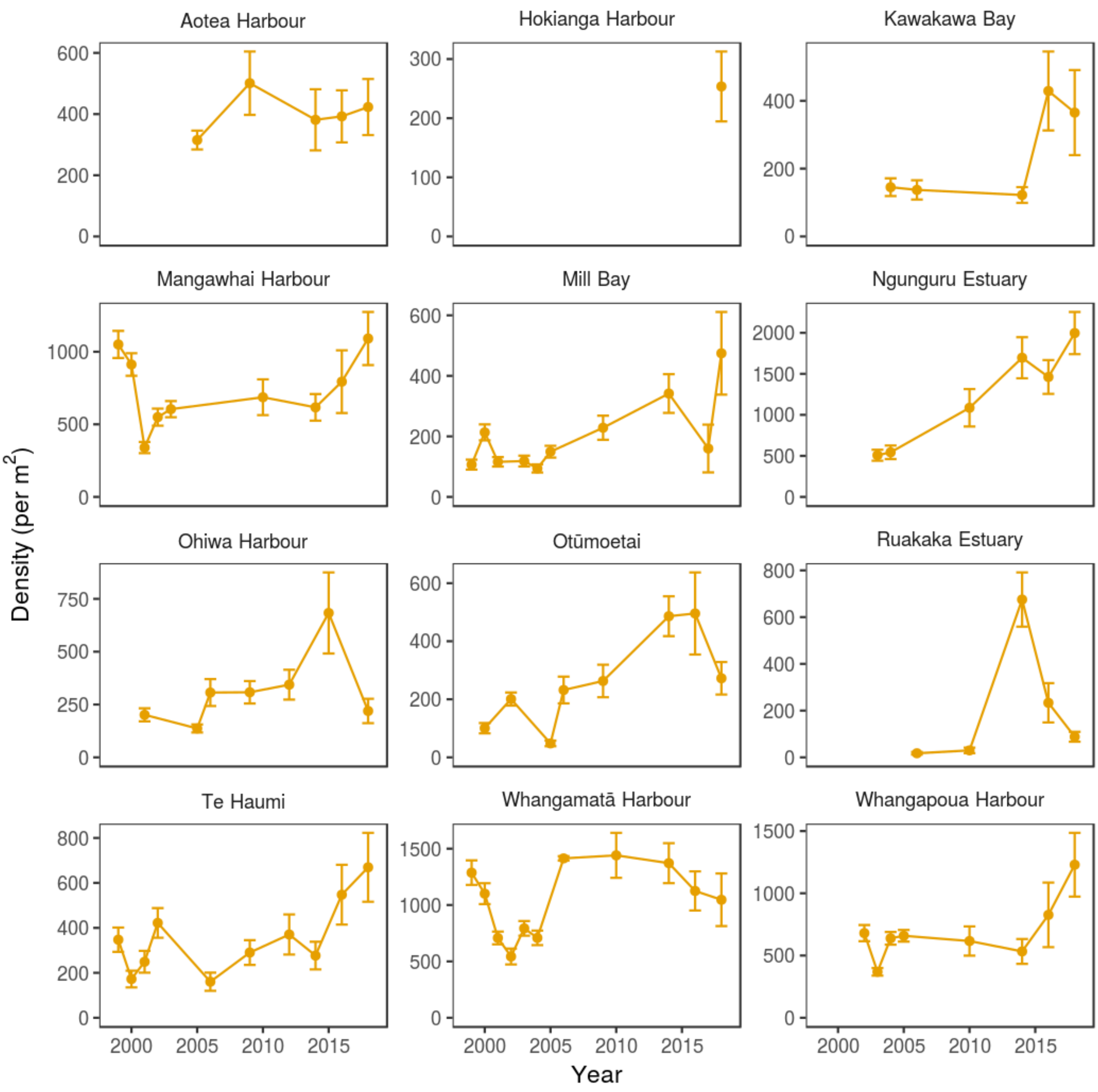


Figure 58: Estimated density of cockles for all sites included in the 2018–19 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

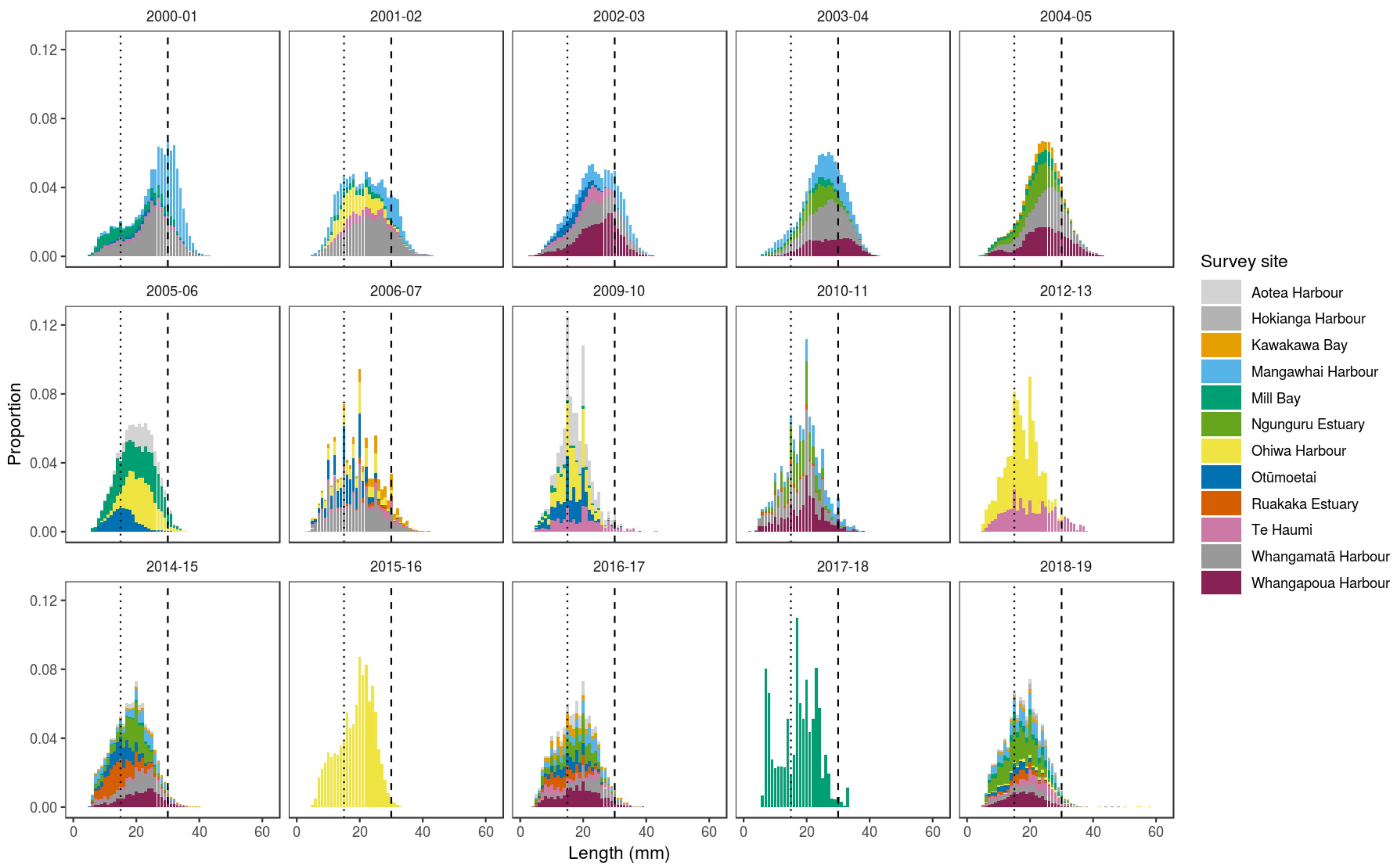


Figure 59: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2018–19 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note not all sites were surveyed each year, and the sampling extent may vary across years.)

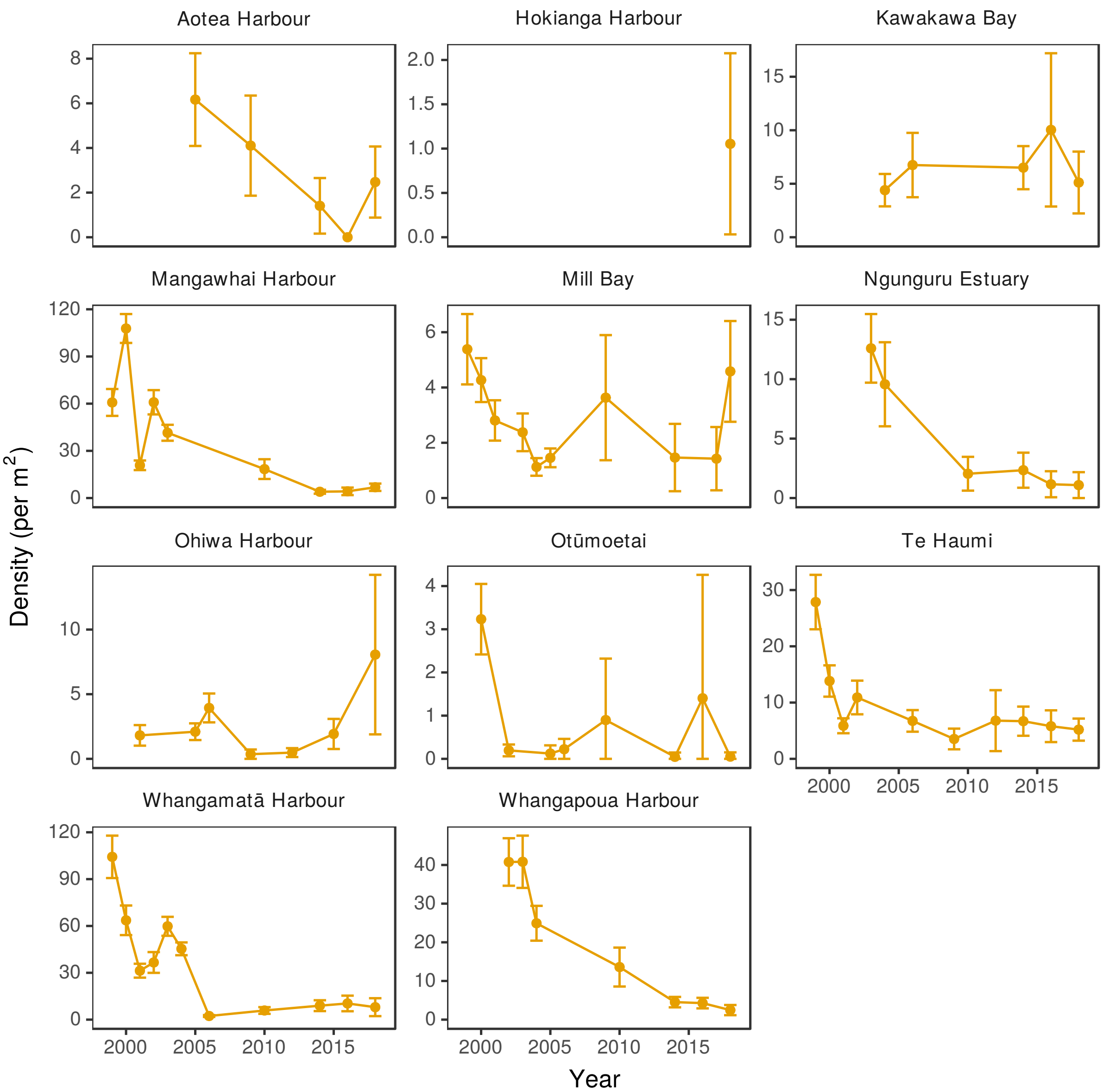


Figure 60: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

Pipi were present at eleven of the 2018–19 survey sites, but sample sizes were small at Kawakawa Bay (West) and Mill Bay: only 14 and 106 pipi were sampled, respectively, and over 80% of the samples were recruits. At the remaining nine sites, total pipi population sizes varied from a low abundance of 1.97 million (CV: 13.89%) pipi at Mangawhai Harbour to 91.64 million (CV: 17.84%) pipi at Ruakaka Estuary (Table 68). Most of the sites contained designated pipi beds, but at Kawakawa Bay (West) and Mill Bay, small numbers of pipi were present in localised high-density spots; at Whangamatā Harbour, pipi occurred outside the pipi stratum in a high-density spot in the low intertidal part of a cockle stratum. At these sites, total pipi population estimates had high uncertainty (i.e., >20%). At Te Haumi, the CV remained above 20% (at 20.19%), despite additional phase-2 sampling.

Across all sites, Ruakaka Estuary supported the largest pipi population and the highest estimated pipi density, with 2333 pipi per m^2. The next highest estimate was at Hokianga Harbour, with 868 individuals per m^2. Density estimates ranged between 408 and character(0) individuals per m^2 at Te Haumi, Ohiwa Harbour, Ngunguru Estuary and Otūmoetai (Tauranga Harbour); densities were notably lower at the remaining sites, with the lowest density estimate of 27 individuals per m^2 (Mangawhai Harbour; excepting Kawakawa Bay (West), where only 14 individuals were sampled).

Similar to the cockle populations at the current sites, few of the surveyed pipi populations included large-sized individuals ($\geq$50 mm shell length). The highest density estimate of this size class was 27 million (CV: 13.32%) large pipi per m^2 at Whangapoua Harbour, whereas most of the populations contained no large pipi or only one individual per m^2. The latter sites included Ruakaka Estuary, which supported the largest total pipi population and highest pipi density in 2018–19 but contained few large individuals.

Survey data across the entire study period (i.e., from 1999–2000 onwards) showed that most pipi population densities fluctuated over time (Figure 61). These fluctuations included an overall decrease in pipi density over the survey period (Whangamatā and Whangapoua harbours), and also significant declines in recent surveys (Mangawhai and Ohiwa harbours). At two sites, pipi showed substantial increases in density in recent surveys, including Ngunguru and Ruakaka estuaries, although this increase was significant only at the former site.

The combined length-frequency data for the current survey sites illustrated a change in size structure from large pipi ($\geq$50 mm shell length) in early survey years to smaller size classes in subsequent assessments, especially since 2014–15 (Figure 62). In these recent surveys, pipi populations were greatly influenced by recruits, which determined the single cohort in unimodal frequency distributions or one of two cohorts in bimodal population size structures. In the latter, small and medium-sized pipi made up the second cohort, whereas large pipi played only a small role in determining the population size structure.

Overall, densities of large pipi varied across sites that contained this large size class, but all of the estimates showed a decline at some time during the survey period (Figure 63). Once estimates were low, pipi densities showed little sign of returning to previously high values at the start of the monitoring series, regardless of initial densities. Excepting Whangapoua Harbour, densities of large pipi were low at all sites, ranging from several individuals to fewer than one individual per m^2.

Table 68: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2018–19 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 (%)
Hokianga Harbour	87.39	868	10.87	0.00	<1	>100
Mangawhai Harbour	1.97	27	13.89	0.00	<1	>100
Mill Bay	3.35	69	31.22	0.00	0	
Ngunguru Estuary	42.39	655	11.76	0.40	2	43.99
Ohiwa Harbour	13.05	514	13.00	1.24	12	19.69
Otūmoetai	58.86	731	10.94	0.30	2	40.75
Ruakaka Estuary	91.64	2 333	17.84	0.19	1	51.87
Te Haumi	48.57	408	20.19	0.45	<1	24.34
Whangamatā Harbour	10.01	133	27.66	2.79	9	43.95
Whangapoua Harbour	4.17	79	14.71	1.44	27	13.32

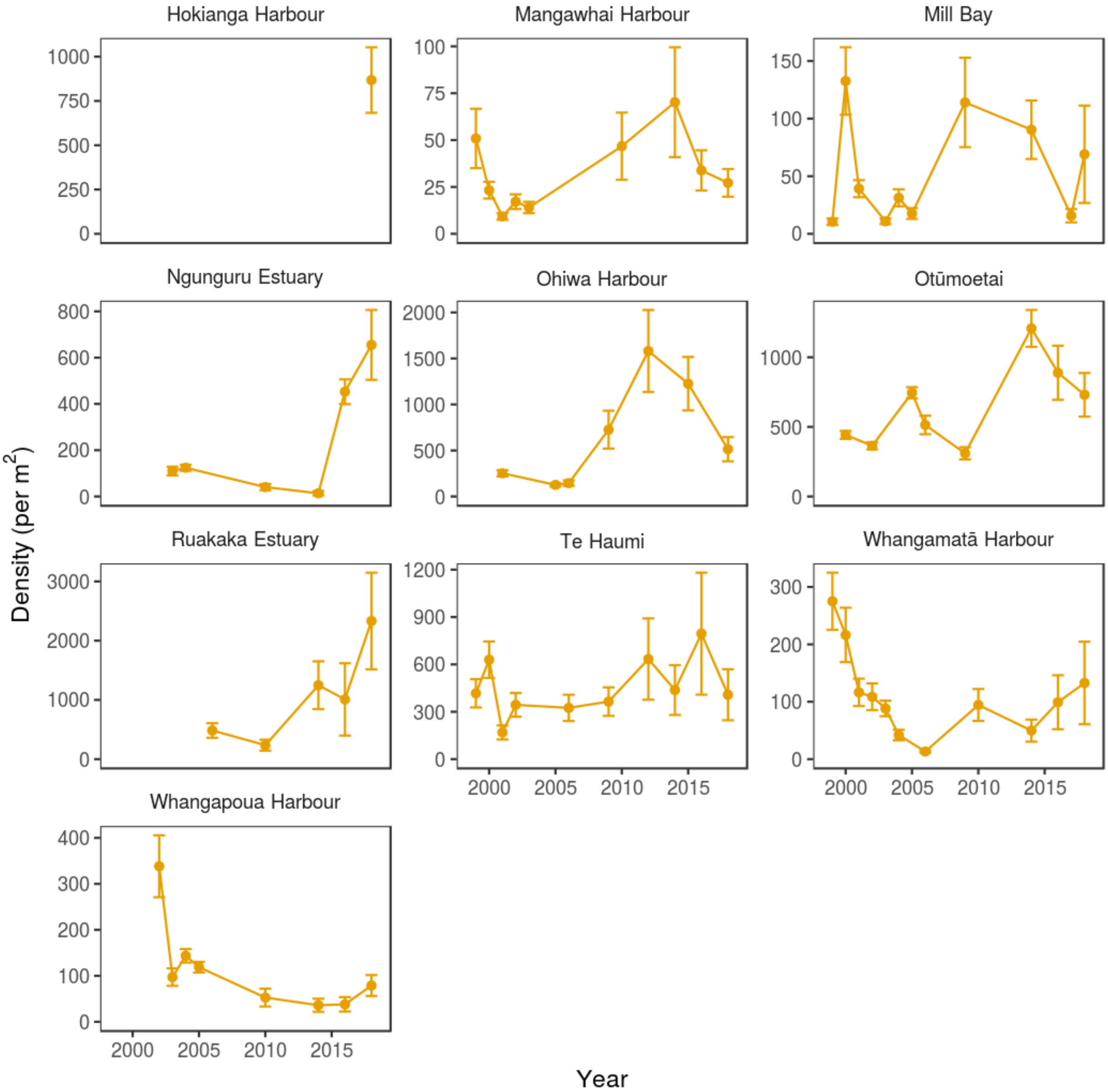


Figure 61: Estimated density of pipi for all sites included in the 2018–19 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

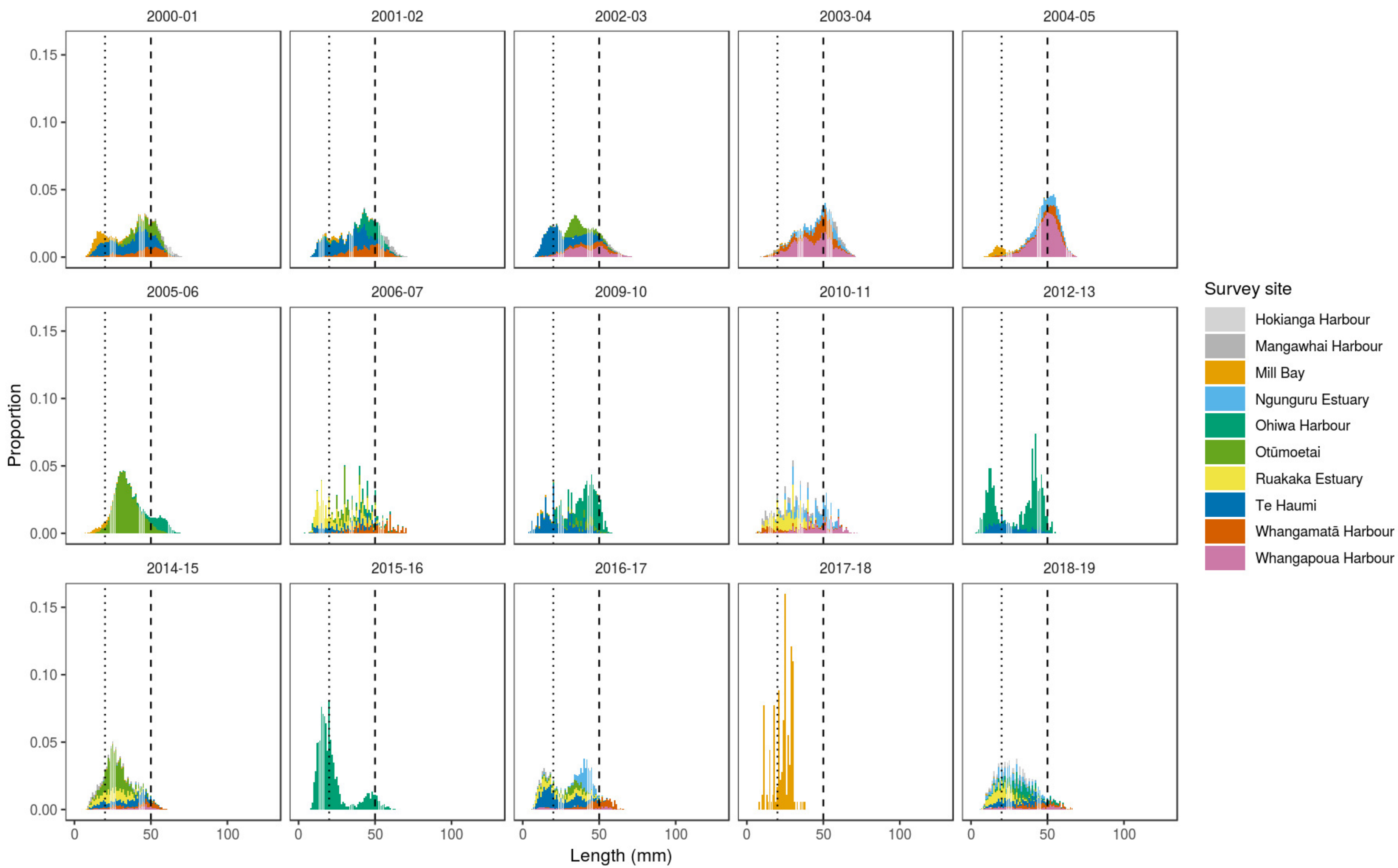


Figure 62: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2018–19 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

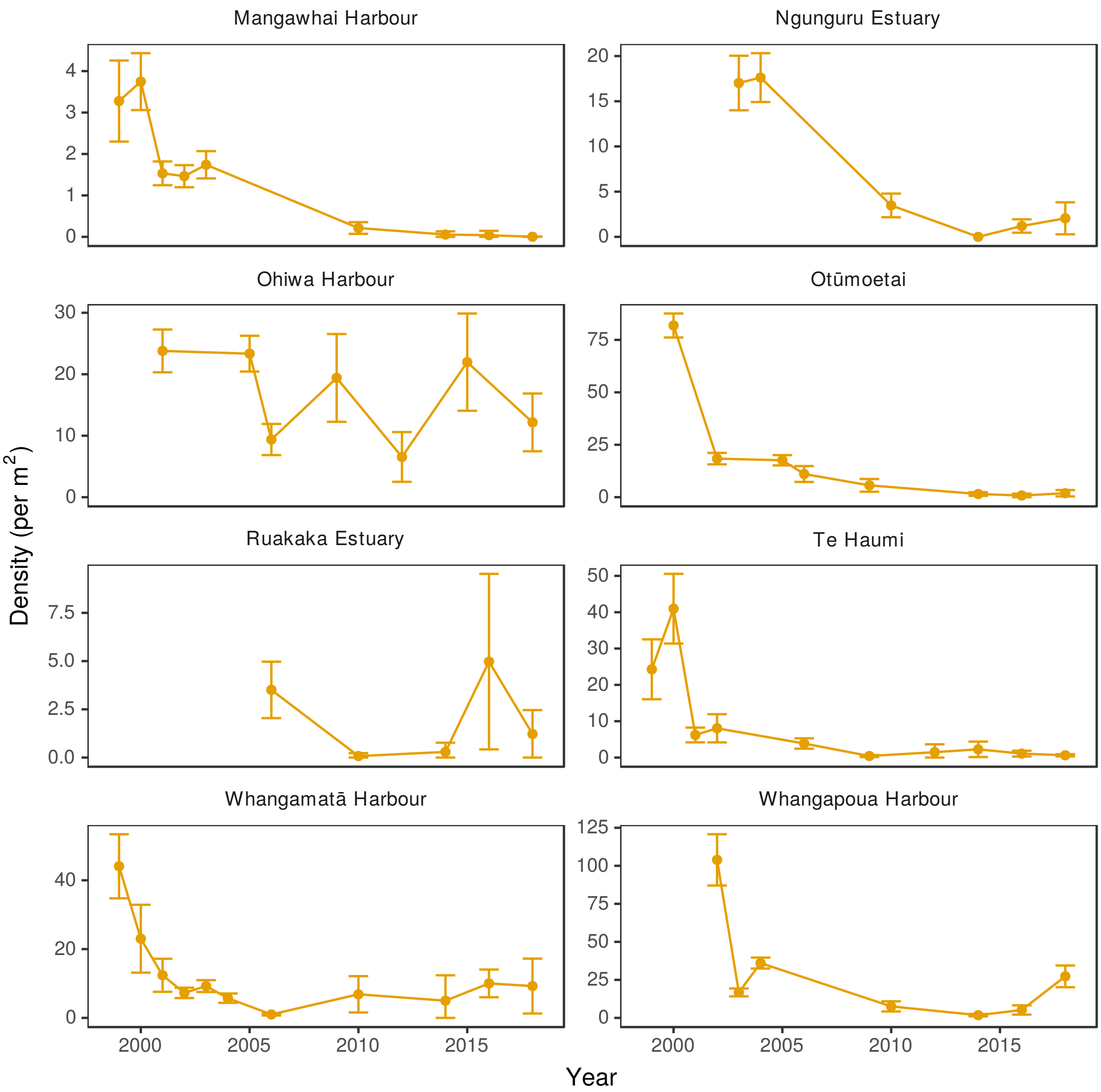


Figure 63: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

5. DISCUSSION

The most recent assessment in the bivalve monitoring series included 12 northern North Island sites in Northland, Waikato, Bay of Plenty and the wider Auckland region. The survey sites represented a wide range of intertidal sedimentary habitats, from sheltered bays and large inlets to sand and mudflats and small estuaries. All of the sites have been regularly part of the monitoring series, except for Hokianga Harbour, which was added for the first time in the present assessment.

At Hokianga Harbour, cockles and pipi were assessed across two areas close to the harbour entrance. One of these areas was unusual in supporting populations of both species in sediments that were uncharacteristically coarse for bivalve habitat (Appendix C, Figure C-2). Furthermore, this site appeared to be different to other northern sites in that the extensive pipi bed in the second sampling area was spread across the tidal extent of the sandflat, including the upper intertidal zone (Figure C-3), instead of exhibiting a more restricted distribution close to high-flow areas such as tidal channels.

Cockle populations were present at all of the 2018–19 survey sites, and their population densities were generally high, exceeding 200 individuals per m^2 (excepting Ruakaka Estuary). The maximum density of cockles was at Ngunguru Estuary in Northland, with an estimated 1997 cockles per m^2. Density estimates were similarly high at Mangawhai Harbour in Northland, and at Whangapoua and Whangamatā harbours in Waikato (Coromandel Peninsula).

At most sites, the current estimates indicated stable cockle populations or increases in population density, but there were also notable, recent declines at three sites: at Ohiwa Harbour and Otūmoetai (Tauranga Harbour) in Bay of Plenty, and at Ruakaka Estuary in Northland. The reasons for these declines are unknown. Some of the population fluctuations can be attributed to variation in the strength of recruitment events, with large influxes of recruits linked to substantial population increases. At a number of sites (e.g., Kawakawa Bay (West), Mangawhai Harbour), 30 to 50% of the current population consisted of recruits, indicating the significance of recruitments events on overall population parameters.

At the same time, there was a general scarcity or absence of large individuals across the 2018–19 survey sites. For some populations, time-series data highlighted a consistent lack of this size class throughout the survey series (e.g., Ohiwa Harbour); at other sites, the large size class underwent a significant decline without subsequent recovery (e.g., Mangawhai and Whangamatā harbours).

At one of the sites, Mill Bay, significant increases in 2018–19 indicated recent recovery of the cockle population following a mortality event. This site was last surveyed in 2017–18, when large numbers of recently-dead and moribund cockles were detected during the field sampling (Berkenbusch & Neubauer 2018). A year on from this mortality event, the cockle population increased with current estimates exceeding all preceding values since the start of the survey series at this site. Although potential causes for the mortality event are unknown, the observed recovery of the Mill Bay cockle population suggests that habitat at this site has remained suitable for this species, with only short-term adverse impacts from these unknown causes.

There were sizeable pipi populations at nine of the 2018–19 sites, where density estimates varied between 27 pipi and 2333 pipi per m^2 (Mangawhai Harbour and Ruakaka Estuary, respectively). Some of the population estimates had high uncertainty (CV: $>$20%) as total estimates reflected the entire sampling extent, and were not restricted to particular pipi beds. For example, at Whangamatā Harbour, localised high-density patches of pipi were also present in cockle strata, and their patchy distribution resulted in a high CV (27.66%) for the overall population estimate. When considering the population in the pipi stratum only, density estimates increased to 951 pipi per m^2 (cf. 133 per m^2 for the entire sampling extent), with a corresponding CV of 11.07%. This example illustrates that individual pipi (usually recruits) may occur in less suitable habitats such as in the high intertidal area, but these small numbers rarely persist across surveys in these areas outside the high-density pipi beds. At Te Haumi, the increased sampling effort with phase-2 sampling did not succeed in lowering the CV below 20%. At this site, one of the pipi beds had experienced significant decreases since the preceding survey.

For pipi, patterns in population abundance and size structure were similar to those of cockles, including the general lack of large individuals and the strong influence of recruitment events on population dynamics and size structure. Recruits dominated populations at the majority of sites, such as Mangawhai Harbour (76% recruits) and Ruakaka Estuary (50% recruits). Temporal fluctuations in the pipi populations were often due to differences in recruitment over time, such as at Ohiwa Harbour, where the proportion of recruits decreased from 50% previously to only 11% in the current study, corresponding with the observed decrease in total population estimates. Although existing populations rely on regular recruitment, the disproportional influx of recruits in relation to low numbers in the larger size classes means that population estimates are frequently determined by recruitment events. Only some of the sites documented growth to small and medium-size classes over time, highlighting the ephemeral nature of recently-settled recruits.

Considering the present survey findings in the context of the monitoring series, the general outcome of the 2018–19 survey is similar to previous assessments that included different northern sites (e.g., Berkenbusch & Neubauer 2018). In general, few northern cockle or pipi populations contain high numbers of large individuals, and recruits and small-sized bivalves are often the dominant size classes. While large individuals may be preferentially targeted by recreational and customary fishing (e.g., see Hartill et al. 2005), the lack of non-commerical fisheries data prevents elucidation of the potential link between bivalve populations and exploitation pressure. Data are also limited to assess potential limitations to bivalve growth, such as the availability of food, that may prevent small-sized individuals from maturing and contributing to the adult population.

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

Table A-1: Sampling years (coloured blue) for sites included in the northern North Island bivalve surveys since 1999–2000.

Survey site	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2009–10	2010–11	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
Aotea Harbour							■		■				■		■		■
Bowentown Beach			■							■	■			■		■	
Cheltenham Beach														■			
Clarks Beach						■											
Cockle Bay									■	■	■	■		■		■	
Cornwallis Wharf			■														
Eastern Beach	■		■										■		■		
Grahams Beach								■		■	■	■			■		
Hokianga Harbour																	■
Howick Harbour							■										
Kawakawa Bay (West)						■		■					■		■		■
Little Waihi Estuary		■		■	■	■		■	■		■	■		■		■	
Mangawhai Harbour	■	■	■	■	■					■			■		■		■
Marokopa Estuary							■			■				■			
Marsden Bank									■		■	■				■	
Mill Bay	■	■	■		■	■	■		■				■			■	■
Ngunguru Estuary					■	■				■			■		■		■
Ohiwa Harbour			■				■	■	■		■			■			■
Okoromai Bay	■		■	■	■	■		■	■		■	■		■		■	
Otūmoetai		■		■			■	■	■				■		■		■
Papamoa Beach	■																
Pataua Estuary				■	■		■					■		■		■	
Raglan Estuary	■	■		■	■				■		■		■			■	
Ruakaka Estuary								■		■			■		■		■
Tairua Harbour	■	■	■	■			■	■		■		■		■		■	
Te Haumi Bay	■	■	■	■				■	■		■		■		■		■
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■		■	
Waikawau Beach	■	■				■	■					■					
Waiotahe Estuary				■	■	■	■		■			■			■		
Whangamatā Harbour	■	■	■	■	■	■		■		■			■		■		■
Whangapoua Harbour				■	■	■	■			■			■		■		■
Whangateau Harbour			■		■	■		■	■	■	■	■		■		■	
Whitianga Harbour											■			■		■	

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–00, including the present survey in 2018–19. Surveys are ordered by site and year.

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
Aotea Harbour	2005–06	17 Jan–18 Jan	9.60	AKI2005-01
	2009–10	26 Mar–13 Jul	28.10	AKI2009-01
	2014–15	19 Feb	19.46	AKI2014-01
	2016–17	9 Feb	19.46	AKI2016-01
	2018–19	3 Feb	19.46	AKI2018-01
Bowentown Beach	2001–02	26 Apr–25 May	1.58	AKI2001-01
	2010–11	18 Mar	1.58	AKI2010-01
	2012–13	8 Feb	1.58	AKI2012-01
	2015–16	20 Jan	1.50	AKI2015-01
	2017–18	22 Feb	1.50	AKI2017-01
Cheltenham Beach	2015–16	14 Jan	31.92	AKI2015-01
Clarks Beach	2004–05	3 Feb–24 Feb	144.71	AKI2004-01
Cockle Bay	2009–10	16 Feb	16.00	AKI2009-01
	2010–11	5 May	16.00	AKI2010-01
	2012–13	31 Jan	16.00	AKI2012-01
	2013–14	29 Mar	15.77	AKI2013-01
	2015–16	18 Jan	15.77	AKI2015-01
	2017–18	27 Jan–28 Jan	15.77	AKI2017-01
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
Hokianga Harbour	2018–19	20 Feb	10.07	AKI2018-01
Howick Harbour	2005–06	23 Dec–24 Jan	6.90	AKI2005-01
Kawakawa Bay (West)	2004–05	5 Feb–8 Apr	60.37	AKI2004-01
	2006–07	19 Apr	62.94	AKI2006-01
	2014–15	17 Feb–25 Feb	60.90	AKI2014-01
	2016–17	27 Feb	60.89	AKI2016-01
	2018–19	4 Feb–25 Feb	60.89	AKI2018-01
Little Waihi Estuary	2000–01	21 Mar–31 Mar	3.00	AKI2000-01
	2002–03	30 Jan–1 Feb	3.00	AKI2002-01
	2003–04	7 Jan–19 Jan	3.12	AKI2003-01
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01
	2006–07	15 Jun–28 Jun	3.16	AKI2006-01
	2009–10	2 Mar	13.92	AKI2009-01
	2012–13	10 Feb	15.42	AKI2012-01
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
	2015–16	8 Feb–11 Feb	18.38	AKI2015-01
	2017–18	23 Feb–24 Feb	18.38	AKI2017-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
Mangawhai Harbour	1999–00	23 Mar–30 Jun	9.40	AKI1999-01
	2000–01	29 Jan–31 Jan	8.40	AKI2000-01
	2001–02	15 Mar–14 Apr	8.40	AKI2001-01
	2002–03	1 Jan–31 Jan	8.40	AKI2002-01
	2003–04	1 Jan–31 Jan	8.40	AKI2003-01
	2010–11	24 Mar–15 Apr	9.00	AKI2010-01
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
	2018–19	18 Jan–19 Jan	7.23	AKI2018-01
Marokopa Estuary	2005–06	18 Feb–20 Feb	2.35	AKI2005-01
	2010–11	16 May	2.35	AKI2010-01
	2015–16	12 Feb–13 Feb	2.58	AKI2015-01
Marsden Bank	2009–10	13 Nov	11.51	IPA2009-12
	2012–13	12 Dec	6.31	AKI2012-01
	2013–14	2 Feb	15.43	AKI2013-01
	2017–18	4 Feb–5 Feb	0.85	AKI2017-01
Mill Bay	1999–00	4 May–30 Jun	4.60	AKI1999-01
	2000–01	20 Feb–23 Feb	4.80	AKI2000-01
	2001–02	20 Mar–22 Apr	4.50	AKI2001-01
	2003–04	26 Jan–28 Jan	4.50	AKI2003-01
	2004–05	24 Dec–24 Jan	4.50	AKI2004-01
	2005–06	20 Dec–24 Dec	4.50	AKI2005-01
	2009–10	13 May	4.95	AKI2009-01
	2014–15	26 Feb	4.88	AKI2014-01
	2017–18	30 Jan–31 Jan	4.86	AKI2017-01
	2018–19	26 Jan	4.86	AKI2018-01
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
	2014–15	23 Jan–24 Jan	5.46	AKI2014-01
	2016–17	13 Feb–15 Feb	6.28	AKI2016-01
	2018–19	22 Feb	6.47	AKI2018-01
Ohiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
	2015–16	9 Feb–10 Feb	3.37	AKI2015-01
	2018–19	1 Feb–2 Feb	2.54	AKI2018-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
	2017–18	6 Feb	19.83	AKI2017-01
Otūmoetai	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
	2016–17	20 Feb–21 Feb	8.09	AKI2016-01
	2018–19	30 Jan–31 Jan	8.06	AKI2018-01
Papamoa Beach	1999–00	1 May–3 May	2.00	AKI1999-01
Pataua Estuary	2002–03	4 Mar–28 Mar	10.65	AKI2002-01
	2003–04	14 Feb–16 Feb	10.45	AKI2003-01
	2005–06	14 Feb–16 Feb	10.45	AKI2005-01
	2013–14	3 Feb–6 Feb	26.30	AKI2013-01
	2015–16	12 Jan–13 Jan	27.89	AKI2015-01
	2017–18	3 Feb–4 Feb	27.71	AKI2017-01
Raglan Estuary	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
	2017–18	29 Jan	7.24	AKI2017-01
Ruakaka Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
	2014–15	25 Jan–26 Jan	6.51	AKI2014-01
	2016–17	14 Feb	5.61	AKI2016-01
	2018–19	23 Feb	3.93	AKI2018-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
	2015–16	6 Feb–7 Feb	8.17	AKI2015-01
	2017–18	20 Feb–22 Feb	6.48	AKI2017-01
Te Haumi Bay	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
	2016–17	12 Feb	12.77	AKI2016-01
	2018–19	21 Feb–24 Feb	11.91	AKI2018-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
	2017–18	28 Jan	33.43	AKI2017-01
Waikawau Beach	1999–00	20 May–30 Jun	2.90	AKI1999-01
	2000–01	24 Feb–15 May	2.70	AKI2000-01
	2004–05	18 Jan–10 Mar	3.10	AKI2004-01
	2005–06	15 Feb–27 Feb	3.10	AKI2005-01
	2013–14	21 Mar		AKI2013-01
Waiotahe Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
Whangamatā Harbour	1999–00	20 May–29 May	5.48	AKI1999-01
	2000–01	15 Feb–16 Feb	5.48	AKI2000-01
	2001–02	9 May–26 May	5.48	AKI2001-01
	2002–03	9 Mar–28 Mar	5.48	AKI2002-01
	2003–04	1 Jan–31 Jan	5.48	AKI2003-01
	2004–05	6 Feb–8 Feb	5.48	AKI2004-01
	2006–07	2 May–2 Aug	24.61	AKI2006-01
	2010–11	19 Apr	5.89	AKI2010-01
	2014–15	28 Jan–30 Jan	7.62	AKI2014-01
	2016–17	24 Feb–26 Feb	7.71	AKI2016-01
	2018–19	29 Jan–30 Jan	7.55	AKI2018-01
Whangapoua 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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2014–15	24 Feb–25 Feb	6.32	AKI2014-01
	2016–17	25 Feb–26 Feb	6.32	AKI2016-01
	2018–19	27 Jan–28 Jan	5.28	AKI2018-01
Whangateau Harbour	2001–02	7 Apr–22 May	64.19	AKI2001-01
	2003–04	17 Dec–2 Mar	64.15	AKI2003-01
	2004–05	2 Feb–26 Mar	64.15	AKI2004-01
	2006–07	19 Mar–2 May	64.15	AKI2006-01
	2009–10	18 Mar–14 Jul	64.51	AKI2009-01
	2010–11	19 May–20 May	64.15	AKI2010-01
	2012–13	14 Dec–17 Dec	64.20	AKI2012-01
	2013–14	29 Jan–6 Feb	110.91	AKI2013-01
	2015–16	15 Jan–17 Jan	110.71	AKI2015-01
	2017–18	1 Feb–2 Feb	110.91	AKI2017-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01
	2017–18	19 Feb–21 Feb	5.81	AKI2017-01

APPENDIX B: Sediment properties

Table B-3: Sediment organic content and sediment grain size distributions at sites surveyed in 2018–19 as part of the northern North Island bivalve surveys. Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm. 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	2	-38.01729	174.82527	1.4	19.9	18.9	49.0	9.0	2.2	1.1
	A	7	-38.01683	174.82652	2.5	17.5	12.9	50.3	16.1	2.8	0.3
	A	8	-38.01625	174.82674	0.8	6.5	16.5	67.0	9.1	1.0	0.0
	A	10	-38.01287	174.83125	1.2	11.5	21.6	61.9	4.6	0.4	0.0
	A	6	-38.01679	174.82569	1.3	17.5	15.4	52.0	12.9	1.9	0.4
	A	4	-38.01762	174.82635	1.5	14.4	24.0	47.8	11.0	2.5	0.3
	A	3	-38.01788	174.82555	1.3	21.1	14.9	46.4	14.6	2.8	0.2
	A	1	-38.01686	174.82454	1.7	24.0	15.8	39.9	9.2	5.2	5.9
	A	5	-38.01594	174.82513	1.2	17.1	12.0	51.1	17.3	2.4	0.1
	A	11	-38.01249	174.83105	0.9	6.9	27.3	61.7	3.6	0.5	0.0
	A	9	-38.01292	174.83045		10.4	19.8	66.1	3.3	0.4	0.0
	B	4	-38.01561	174.82799	1.8	12.7	16.6	58.1	11.0	1.6	0.0
	B	12	-38.01370	174.83085	1.1	8.7	10.8	75.3	4.7	0.5	0.0
	B	7	-38.01403	174.82986	1.2	0.0	29.3	66.5	3.7	0.5	0.0
	B	8	-38.01472	174.83040	1.9	10.9	46.3	42.1	0.6	0.2	0.0
	B	10	-38.01458	174.83085	2.2	17.4	43.8	38.0	0.6	0.2	0.0
	B	13	-38.01361	174.83204	1.1	8.8	14.5	71.6	4.8	0.3	0.0
	B	1	-38.01613	174.82583	1.1	11.2	25.7	52.1	9.8	1.1	0.0
	B	3	-38.01565	174.82682	0.7	4.9	11.3	71.7	11.4	0.7	0.0
	B	2	-38.01510	174.82642	1.0	10.0	18.8	56.3	14.1	0.9	0.0
	B	11	-38.01343	174.83014	1.3	12.1	22.6	61.0	3.7	0.5	0.0
	B	9	-38.01298	174.82946	1.3	15.2	25.3	57.4	1.9	0.3	0.0
	B	6	-38.01385	174.82847	1.9	10.1	31.3	57.3	1.1	0.2	0.0
	B	5	-38.01431	174.82819	0.9	6.3	13.8	67.3	11.0	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
Hokianga Harbour	B	18	-35.49562	173.40285	1.1	1.6	1.6	14.9	36.4	10.0	35.6
	B	17	-35.49552	173.40277	2.1	6.8	3.1	19.0	27.9	6.0	37.3
	B	19	-35.49565	173.40274	1.3	5.7	4.3	18.7	31.0	9.6	30.7
	B	20	-35.49575	173.40277	1.6	2.0	2.8	19.8	31.3	12.0	32.1
	B	16	-35.49580	173.40270	1.4	1.2	2.1	14.9	13.3	4.2	64.4
	B	15	-35.49573	173.40271	1.5	2.4	3.5	22.3	31.9	9.8	30.1
	B	14	-35.49568	173.40272	1.5	0.5	0.6	9.8	29.0	8.8	51.2
	B	13	-35.49557	173.40268	1.4	2.6	3.8	35.4	38.1	13.8	6.3
	B	12	-35.49551	173.40267	1.3	18.2	6.5	33.8	32.6	4.8	4.1
	B	11	-35.49542	173.40270	1.4	10.8	4.9	20.6	14.8	2.9	46.1
	B	6	-35.49540	173.40264	1.0	6.6	3.3	23.6	37.9	5.6	22.9
	B	1	-35.49548	173.40239	1.4	2.9	4.9	31.4	35.4	11.2	14.2
	B	2	-35.49568	173.40236	1.5	2.6	4.6	39.3	27.2	12.4	14.0
	B	10	-35.49572	173.40255	1.1	1.2	1.8	22.9	30.0	24.5	19.6
	B	5	-35.49569	173.40249	2.6	1.2	2.2	27.2	23.2	10.8	35.4
	B	4	-35.49551	173.40253	1.0	6.2	4.2	28.7	44.2	10.8	5.9
	B	3	-35.49540	173.40250	1.1	2.4	3.1	33.0	44.1	12.8	4.6
	B	8	-35.49552	173.40259	0.8	2.8	4.3	35.1	41.1	10.1	6.6
	B	7	-35.49544	173.40256	1.1	6.6	3.4	26.2	25.7	6.5	31.6
	B	9	-35.49560	173.40254	0.9	0.9	2.9	24.7	23.5	6.9	41.1
Kawakawa Bay	A	8	-36.94932	175.15515	1.2	8.5	61.2	25.5	2.9	1.7	0.1
	A	7	-36.94922	175.15599	0.9	3.5	45.2	45.2	4.2	1.9	0.0
	A	5	-36.94800	175.15529	0.9	3.4	38.1	56.8	1.2	0.5	0.0
	A	6	-36.94852	175.15660	0.8	2.9	41.7	52.2	2.5	0.7	0.0
	A	4	-36.94704	175.15699	0.8	3.1	27.6	68.4	0.7	0.2	0.0
	A	3	-36.94396	175.15404	0.8	2.2	38.4	59.2	0.2	0.1	0.0
	A	1	-36.94388	175.15358	1.0	2.6	30.7	66.4	0.2	0.1	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
	A	2	-36.94588	175.15155	1.2	8.5	74.8	14.9	1.1	0.5	0.2
	B	3	-36.94758	175.15243	1.8	20.0	72.6	5.4	1.2	0.7	0.0
	B	4	-36.94736	175.15269	1.5	8.7	64.3	25.4	1.1	0.7	0.0
	B	5	-36.94801	175.15804	1.4	1.8	25.2	61.3	10.3	1.3	0.0
	B	2	-36.94561	175.15375	0.8	3.9	31.7	63.9	0.3	0.2	0.0
	B	1	-36.94490	175.15283	1.1	4.2	50.4	44.4	0.7	0.3	0.0
	B	11	-36.95055	175.15927	0.9	0.7	0.6	34.3	24.4	21.1	18.9
	B	8	-36.94962	175.15787	1.6	42.6	27.4	15.1	8.5	4.8	1.6
	B	7	-36.94960	175.15858	1.5	11.9	13.0	34.6	19.1	17.4	4.0
	B	9	-36.94892	175.16032	1.6	6.5	25.2	50.8	11.7	4.8	1.1
	B	12	-36.94897	175.16341	2.1	6.1	18.7	34.4	10.1	15.0	15.6
	B	10	-36.94719	175.16211	1.8	15.6	29.1	44.6	5.0	4.4	1.3
	B	6	-36.94776	175.15984	1.6	5.4	26.4	48.3	18.7	1.1	0.0
	C	2	-36.94116	175.15219	1.9	12.7	23.5	52.2	6.0	5.6	0.0
	C	3	-36.94158	175.15229	1.6	3.9	55.5	39.1	1.3	0.2	0.0
	C	4	-36.94275	175.15215	1.0	3.6	46.2	49.0	1.0	0.2	0.0
	C	1	-36.94217	175.15053	1.9	19.3	67.4	8.8	1.9	2.6	0.0
Mangawhai Harbour	A	5	-36.08457	174.59074	0.5	1.1	1.1	43.7	49.8	4.3	0.0
	A	8	-36.08446	174.59135	0.4	0.0	1.1	72.9	25.8	0.2	0.0
	A	6	-36.08378	174.59106	0.3	0.6	1.2	44.1	49.4	4.7	0.0
	A	7	-36.08491	174.59094	0.4	0.3	1.1	80.6	16.8	1.2	0.0
	A	3	-36.08546	174.59028	1.0	1.7	0.8	46.8	47.2	3.4	0.0
	A	1	-36.08538	174.58995	0.8	0.7	0.8	70.2	27.7	0.6	0.0
	A	2	-36.08496	174.59034	0.5	0.8	0.9	41.0	54.4	2.8	0.0
	A	4	-36.08424	174.59090	0.9	3.0	2.0	70.6	22.5	1.8	0.0
	B	4	-36.08629	174.59056	0.7	0.4	2.7	71.4	22.2	3.4	0.0
	B	1	-36.08644	174.59041	0.3	0.6	0.8	67.4	30.8	0.3	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	3	-36.08610	174.59061	0.6	0.8	2.1	63.5	32.0	1.6	0.0
	B	2	-36.08667	174.59043	0.5	0.2	1.1	55.4	41.9	1.4	0.0
	C	6	-36.08830	174.59037	0.5	0.0	1.8	47.2	46.1	3.6	1.3
	C	3	-36.08901	174.59026	0.3	0.0	0.9	50.5	47.8	0.8	0.0
	C	2	-36.08839	174.59007	0.3	0.7	1.6	54.8	42.1	0.8	0.0
	C	1	-36.08785	174.59018	0.3	0.1	1.1	48.6	49.1	1.0	0.0
	C	4	-36.08767	174.59028	0.3	0.0	2.0	48.8	44.2	2.4	2.6
	C	5	-36.08785	174.59045	0.5	0.6	1.9	54.1	40.3	2.7	0.3
	D	1	-36.09699	174.59172	0.5	0.7	1.5	67.1	30.1	0.6	0.0
	D	4	-36.09678	174.59234	0.4	0.2	2.6	74.5	22.6	0.1	0.0
	D	6	-36.09870	174.59266	0.3	0.2	1.7	60.4	35.5	2.2	0.0
	D	5	-36.09864	174.59231	0.5	0.8	2.2	69.6	26.1	1.3	0.0
	D	3	-36.09753	174.59209	0.5	0.2	1.2	69.7	28.6	0.3	0.0
	D	2	-36.09726	174.59155	0.4	0.0	0.4	64.5	34.0	1.0	0.0
Mill Bay	A	1	-36.99311	174.60536	1.7	2.7	6.4	18.5	17.0	41.6	13.8
	A	3	-36.99305	174.60631	2.2	7.1	9.7	22.7	15.7	28.9	16.0
	A	6	-36.99387	174.60626	1.7	8.7	9.4	23.9	20.2	35.7	2.1
	A	5	-36.99394	174.60606	1.3	6.9	7.5	50.6	17.9	13.1	4.1
	A	4	-36.99358	174.60563	1.2	6.5	8.2	32.3	16.6	25.4	11.1
	A	2	-36.99309	174.60552	1.1	1.7	1.7	13.8	29.2	44.5	9.0
	A	7	-36.99427	174.60619	1.6	8.7	17.0	31.4	19.1	22.0	1.8
	A	8	-36.99495	174.60722	0.9	5.1	4.2	39.8	26.1	23.4	1.4
	B	3	-36.99405	174.60712	2.6	14.0	9.6	36.1	24.2	14.3	1.9
	B	7	-36.99432	174.60758	1.6	7.5	5.3	34.5	26.3	24.7	1.8
	B	5	-36.99414	174.60773	1.5	8.8	6.2	33.8	23.0	24.8	3.3
	B	4	-36.99453	174.60683	1.6	7.2	7.7	36.0	26.0	21.4	1.7
	B	2	-36.99421	174.60659	1.7	7.8	13.1	40.8	20.8	16.7	0.7

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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
	B	1	-36.99426	174.60624	1.0	9.1	9.1	37.4	18.8	18.8	6.9
	B	8	-36.99500	174.60709	1.1	6.4	5.3	41.6	23.2	21.3	2.2
	B	6	-36.99479	174.60690	1.9	12.5	12.3	36.1	20.3	17.3	1.5
	C	5	-36.99425	174.60742	1.8	6.4	6.2	40.0	21.4	23.9	2.1
	C	1	-36.99422	174.60709	2.6	14.0	10.0	30.0	22.7	21.8	1.5
	C	8	-36.99499	174.60684	1.3	7.2	13.7	37.6	18.0	19.2	4.2
	C	6	-36.99483	174.60656	1.5	5.6	6.0	29.5	32.8	24.5	1.6
	C	7	-36.99499	174.60659	1.9	6.2	4.9	36.5	24.1	22.3	6.0
	C	4	-36.99492	174.60639	0.9	5.2	9.2	38.2	31.2	15.1	1.0
	C	3	-36.99481	174.60636	1.3	6.0	8.9	32.1	26.7	23.4	2.9
	C	2	-36.99471	174.60643	0.6	1.2	3.3	49.1	22.6	22.7	1.0
Ngunguru Estuary	A	7	-35.63329	174.50198	1.2	1.4	9.3	58.7	16.3	14.1	0.3
	A	6	-35.63299	174.50226	0.8	0.6	6.6	51.0	19.8	20.4	1.7
	A	1	-35.63271	174.50236	1.0	1.1	9.8	56.0	16.2	13.4	3.5
	A	5	-35.63239	174.50261	1.2	1.0	11.9	50.1	10.6	15.7	10.7
	A	11	-35.63524	174.50079	1.5	3.0	10.9	71.3	10.3	4.5	0.0
	A	10	-35.63509	174.50076	1.0	1.9	10.0	57.6	18.6	11.9	0.0
	A	9	-35.63479	174.50100	1.1	2.5	19.0	64.5	10.3	3.7	0.0
	A	4	-35.63462	174.50101	1.2	2.7	12.0	67.4	12.4	5.4	0.0
	A	2	-35.63435	174.50115	1.3	0.0	14.7	71.4	7.6	6.3	0.0
	A	3	-35.63450	174.50108	2.0	2.8	14.1	65.8	10.2	6.8	0.2
	A	8	-35.63420	174.50135	1.1	0.0	11.6	80.2	6.4	1.9	0.0
	B	5	-35.63683	174.50455	1.3	3.1	11.3	80.2	4.7	0.8	0.0
	B	3	-35.63681	174.50446	0.8	0.7	8.0	80.4	9.1	1.8	0.0
	B	4	-35.63644	174.50468	1.0	4.4	8.9	77.6	7.9	1.2	0.0
	B	1	-35.63570	174.50478	0.9	0.2	4.9	54.6	26.1	11.5	2.7
	B	2	-35.63620	174.50468	0.7	0.9	6.4	73.3	14.0	5.4	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
	C	7	-35.63471	174.50285	1.1	1.6	4.9	87.0	6.3	0.3	0.0
	C	4	-35.63534	174.50254	1.6	4.7	11.1	81.8	2.2	0.2	0.0
	C	8	-35.63573	174.50256	2.0	4.9	16.3	77.0	1.5	0.3	0.0
	C	6	-35.63652	174.50213	1.1	0.0	13.8	84.9	0.6	0.7	0.0
	C	5	-35.63602	174.50212	1.6	4.6	16.2	78.2	0.8	0.2	0.0
	C	3	-35.63686	174.50169	1.1	2.1	15.7	78.8	1.8	1.6	0.0
	C	1	-35.63630	174.50165	1.2	0.7	13.1	80.9	3.2	2.1	0.0
	C	2	-35.63467	174.50240	0.8	0.2	3.6	87.6	7.9	0.7	0.0
Ohiwa Harbour	A	4	-38.00888	177.13928	1.4	0.0	17.6	81.0	1.0	0.5	0.0
	A	7	-38.00887	177.13938	1.5	5.4	16.1	75.7	1.6	1.2	0.0
	A	9	-38.00893	177.13957	0.9	3.2	5.7	82.3	4.0	4.8	0.0
	A	6	-38.00861	177.13941	1.5	7.2	10.3	79.2	1.5	1.8	0.0
	A	5	-38.00829	177.13928	1.5	7.9	13.8	75.1	2.3	0.8	0.0
	A	3	-38.00803	177.13915	1.5	6.5	9.0	83.4	0.8	0.3	0.0
	A	8	-38.00763	177.13936	1.0	4.0	5.5	88.1	2.2	0.2	0.0
	A	2	-38.00771	177.13909	1.4	11.2	10.2	76.8	1.4	0.4	0.0
	A	10	-38.00939	177.13961	1.7	9.4	16.6	69.0	2.2	2.7	0.0
	A	11	-38.00942	177.13962	1.1	0.0	5.4	88.9	2.6	3.1	0.0
	A	1	-38.00730	177.13906	1.1	4.8	7.9	85.8	1.5	0.1	0.0
	A	12	-38.00990	177.13974	1.6	2.0	9.0	82.5	3.6	3.0	0.0
	B	4	-38.01346	177.13894	1.6	8.2	14.7	73.6	3.1	0.4	0.0
	B	9	-38.01481	177.13790	1.1	5.2	10.8	80.6	3.2	0.3	0.0
	B	12	-38.01471	177.13813	1.9	0.0	17.9	78.7	3.1	0.2	0.0
	B	11	-38.01460	177.13822	1.8	3.5	14.1	80.4	1.9	0.1	0.0
	B	8	-38.01444	177.13814	1.1	0.7	6.6	90.1	2.3	0.3	0.0
	B	7	-38.01437	177.13822	1.2	3.3	10.8	83.5	1.9	0.4	0.0
	B	6	-38.01432	177.13824	1.0	2.1	7.7	87.2	2.5	0.5	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	10	-38.01429	177.13840	1.6	7.3	11.6	79.1	1.5	0.5	0.0
	B	5	-38.01417	177.13835	1.1	5.0	10.3	81.1	2.8	0.8	0.0
	B	3	-38.01407	177.13839	1.2	0.0	6.9	90.8	2.0	0.3	0.0
	B	2	-38.01395	177.13844	1.2	2.8	14.7	81.1	1.2	0.2	0.0
	B	1	-38.01381	177.13859	1.5	1.9	14.8	82.6	0.6	0.1	0.0
Otūmoetai	A	2	-37.66450	176.15021	0.7	0.7	3.0	62.7	20.8	12.7	0.1
	A	3	-37.66457	176.15052	1.4	1.4	6.8	63.2	17.8	10.5	0.4
	A	4	-37.66462	176.15068	0.9	0.2	5.5	66.2	19.1	9.1	0.0
	A	1	-37.66431	176.15026	0.8	0.6	4.8	56.7	24.6	13.2	0.0
	A	5	-37.66422	176.15144	1.2	0.7	6.8	73.6	15.1	3.6	0.2
	A	8	-37.66448	176.15146	1.2	0.8	6.9	73.8	14.9	3.6	0.0
	A	7	-37.66431	176.15146	0.9	0.2	8.6	73.3	14.6	3.4	0.0
	A	9	-37.66429	176.15163		1.4	7.8	63.1	16.7	11.0	0.0
	A	12	-37.66450	176.15209	1.2	0.5	5.4	67.3	20.4	6.3	0.0
	A	13	-37.66426	176.15215	0.9	0.3	4.0	72.5	17.9	5.2	0.0
	A	11	-37.66427	176.15195	0.8	0.2	5.4	61.7	24.3	8.3	0.0
	A	10	-37.66416	176.15186	1.1	0.9	5.5	68.0	21.8	3.7	0.1
	A	6	-37.66416	176.15157	1.2	0.9	6.9	73.3	16.5	2.4	0.0
	B	2	-37.66387	176.15013	1.3	1.7	9.3	71.4	15.7	1.9	0.0
	B	1	-37.66397	176.15000	1.4	0.4	10.3	75.5	12.4	1.5	0.0
	B	3	-37.66396	176.15031	1.5	0.8	10.1	73.4	14.2	1.6	0.0
	B	7	-37.66383	176.15132	1.2	1.4	10.6	75.8	11.2	1.0	0.0
	B	8	-37.66394	176.15135	1.3	0.2	8.4	78.0	12.5	0.9	0.0
	B	6	-37.66394	176.15091	0.6	3.6	10.9	71.0	13.2	1.2	0.0
	B	5	-37.66384	176.15068	1.3	0.7	6.8	74.4	16.0	2.1	0.0
	B	4	-37.66377	176.15041	1.3	1.9	8.9	72.9	15.5	0.7	0.0
	B	10	-37.66408	176.15211	0.8	0.7	5.3	77.4	14.7	1.9	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	9	-37.66409	176.15161	1.0	0.8	5.7	81.1	11.5	0.9	0.0
Ruakaka Estuary	A	4	-35.90186	174.45708	0.4	0.0	1.3	72.8	25.2	0.7	0.0
	A	1	-35.90175	174.45701	0.5	0.2	1.3	91.1	7.2	0.2	0.0
	A	8	-35.90184	174.45719	0.7	1.5	4.1	85.3	8.6	0.5	0.0
	A	7	-35.90176	174.45727	0.5	0.2	0.6	43.7	50.4	5.1	0.0
	A	3	-35.90143	174.45732	0.4	0.1	0.2	42.3	54.8	2.5	0.0
	A	6	-35.90130	174.45756	0.4	0.8	0.5	61.8	35.1	1.9	0.0
	A	2	-35.90121	174.45756	0.3	0.4	0.2	33.9	61.0	4.4	0.0
	A	5	-35.90094	174.45784	0.4	0.2	0.4	57.6	39.3	2.6	0.0
	B	4	-35.90226	174.45619	0.4	0.0	0.5	50.7	47.1	1.7	0.0
	B	3	-35.90222	174.45603	0.3	0.3	0.2	34.8	63.0	1.7	0.0
	B	1	-35.90218	174.45573	0.4	0.6	0.5	53.9	43.8	1.2	0.0
	B	2	-35.90216	174.45588	0.4	0.1	0.9	64.7	33.6	0.6	0.0
	B	5	-35.90224	174.45628	0.2	0.2	0.4	43.7	53.3	2.5	0.0
	B	6	-35.90261	174.45625	0.3	0.1	1.0	77.3	21.1	0.5	0.0
	B	8	-35.90275	174.45650	0.4	1.1	2.2	76.0	20.2	0.6	0.0
	B	7	-35.90257	174.45639	0.3	0.3	0.5	43.0	53.9	2.3	0.0
	D	8	-35.89789	174.46115	0.7	4.6	1.3	62.6	30.0	1.4	0.0
	D	6	-35.89784	174.46093	0.6	3.5	1.2	58.1	35.9	1.4	0.0
	D	7	-35.89792	174.46100	1.0	3.8	2.7	71.9	20.8	0.9	0.0
	D	5	-35.89792	174.46091	1.1	5.3	2.9	69.6	21.1	1.0	0.0
	D	4	-35.89788	174.46084	1.3	5.7	1.9	58.7	32.8	1.0	0.0
	D	3	-35.89793	174.46078	1.0	4.2	2.8	66.7	25.4	1.0	0.0
	D	2	-35.89797	174.46047	0.7	2.6	2.8	70.8	23.4	0.4	0.0
	D	1	-35.89803	174.46041	0.6	2.3	2.1	75.5	19.7	0.4	0.0
Te Haumi	A	3	-35.29665	174.10030	3.0	0.1	1.2	26.6	52.6	0.0	19.6
	A	4	-35.29608	174.10141	1.7	0.0	0.6	0.0	37.6	34.7	27.1

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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	-35.29617	174.10173	1.7	0.1	4.1	0.0	69.6	25.0	1.2
	A	1	-35.29576	174.09936	1.5	0.0	0.0	59.2	30.5	9.0	1.2
	A	2	-35.29587	174.09988	0.9	0.0	0.0	36.2	49.3	13.9	0.6
	A	6	-35.29553	174.10156	1.5	0.0	0.0	38.4	30.2	23.1	8.3
	A	5	-35.29503	174.10127	2.1	0.0	0.0	81.9	15.5	2.3	0.2
	B	1	-35.29470	174.09902	1.2	5.4	16.0	61.4	8.4	8.9	0.0
	B	2	-35.29495	174.09915	1.6	11.9	9.7	54.2	15.4	8.1	0.7
	B	4	-35.29451	174.09929	1.1	4.2	13.2	64.7	10.5	7.4	0.1
	B	3	-35.29452	174.09921	1.1	5.0	14.4	64.8	8.3	7.3	0.3
	B	5	-35.29459	174.10000	1.2	4.7	5.7	77.1	11.2	1.2	0.0
	B	7	-35.29621	174.10228	1.2	0.1	7.8	0.0	40.1	39.2	12.9
	B	6	-35.29575	174.10202	1.3	0.0	8.8	0.0	46.1	32.4	12.6
	C	2	-35.29444	174.10063	1.1	8.6	7.2	74.4	7.4	2.4	0.0
	C	1	-35.29414	174.10045	1.3	0.0	15.2	79.2	4.0	1.6	0.0
	C	3	-35.29420	174.10076	1.2	0.0	12.6	79.6	7.8	0.0	0.0
	C	5	-35.29526	174.10213	1.2	0.0	0.0	76.8	13.1	9.6	0.4
	C	4	-35.29470	174.10158	1.4	0.0	0.0	86.4	9.7	3.9	0.0
	D	1	-35.29403	174.10119	1.2	0.0	11.1	82.3	6.6	0.0	0.0
	D	3	-35.29440	174.10157	1.1	0.0	10.0	83.1	6.9	0.0	0.0
	D	2	-35.29417	174.10139	1.1	0.0	8.6	82.7	8.6	0.0	0.0
	D	4	-35.29405	174.10166	1.5	0.0	19.8	75.3	4.8	0.0	0.0
	D	5	-35.29456	174.10189	1.5	0.0	10.6	80.7	7.5	1.2	0.0
Whangamatā Harbour	A	10	-37.19753	175.87460	0.8	0.0	3.5	69.6	24.7	2.1	0.0
	A	5	-37.19326	175.87145	1.3	1.1	3.0	28.6	33.5	32.4	1.4
	A	6	-37.19333	175.87176	1.7	2.1	5.0	45.0	24.3	21.0	2.6
	A	7	-37.19360	175.87237	1.5	0.8	3.7	42.4	9.7	34.9	8.5
	A	9	-37.19432	175.87285	1.4	0.8	3.5	85.0	9.7	1.0	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
	A	8	-37.19402	175.87269	1.2	0.5	4.7	82.7	11.2	0.9	0.0
	A	1	-37.19255	175.86979	2.1	10.1	9.9	47.2	13.3	19.1	0.6
	A	2	-37.19270	175.86979	2.4	11.3	11.8	55.2	7.9	13.7	0.0
	A	3	-37.19267	175.87009	1.4	3.6	9.1	51.2	17.9	16.9	1.3
	A	4	-37.19311	175.87081	1.8	4.5	4.3	31.7	30.5	26.0	3.2
	B	10	-37.19693	175.87432	1.2	2.8	4.8	64.6	25.6	2.3	0.0
	B	5	-37.19658	175.87265	1.6	2.7	8.2	56.2	29.7	2.8	0.4
	B	11	-37.19717	175.87525	1.4	2.1	3.6	60.5	27.2	6.5	0.1
	B	9	-37.19616	175.87404	1.1	0.7	2.6	47.0	39.9	9.8	0.0
	B	7	-37.19629	175.87307	1.3	4.7	5.5	51.9	34.7	3.1	0.0
	B	4	-37.19597	175.87225	0.9	2.0	4.5	66.7	22.4	4.2	0.3
	B	6	-37.19531	175.87303	1.9	4.4	3.6	64.6	21.7	5.2	0.5
	B	8	-37.19525	175.87335	1.3	0.5	1.8	57.8	30.2	9.6	0.2
	B	2	-37.19372	175.87120	1.8	4.2	8.4	68.8	11.0	7.5	0.2
	B	3	-37.19384	175.87207	3.1	3.1	9.5	76.2	10.3	0.8	0.0
	B	1	-37.19302	175.86977	3.3	12.0	20.6	54.3	6.2	7.0	0.0
	C	1	-37.19364	175.87288	1.4	1.1	2.2	82.3	13.9	0.5	0.0
	C	3	-37.19382	175.87334	1.3	0.1	1.0	60.2	38.3	0.4	0.0
	C	2	-37.19392	175.87300	1.2	0.3	1.6	75.4	22.3	0.3	0.0
Whangapoua Harbour	A	6	-36.73859	175.64924	1.1	1.4	1.6	47.0	46.4	3.5	0.0
	A	8	-36.73874	175.65012	0.6	1.6	1.3	41.3	51.4	4.4	0.0
	A	9	-36.73877	175.65032	0.9	3.0	1.1	39.8	50.8	5.3	0.0
	A	7	-36.73861	175.64982	1.0	1.9	1.0	34.9	58.0	4.2	0.0
	A	5	-36.73849	175.64921	0.7	1.7	1.1	37.5	54.7	5.0	0.0
	A	4	-36.73860	175.64912	0.7	1.6	1.0	53.1	41.9	2.4	0.0
	A	3	-36.73851	175.64884	0.7	0.7	1.6	46.1	47.8	3.7	0.0
	A	2	-36.73843	175.64865	0.7	1.5	1.9	46.4	45.8	4.4	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
	A	1	-36.73850	175.64849	0.8	1.1	1.8	43.4	47.3	6.4	0.0
	B	4	-36.73348	175.63766	1.3	1.9	15.4	80.5	1.7	0.5	0.0
	B	3	-36.73337	175.63734	1.1	1.6	10.0	85.1	2.9	0.3	0.0
	B	2	-36.73316	175.63701	0.6	0.3	4.8	90.1	4.5	0.4	0.0
	B	7	-36.73434	175.63989	0.9	0.9	8.4	73.4	14.9	2.3	0.0
	B	6	-36.73400	175.63906	1.2	1.4	9.0	76.2	11.9	1.4	0.0
	B	1	-36.73302	175.63662	0.7	0.3	3.9	74.6	18.8	2.4	0.0
	B	5	-36.73362	175.63828	1.0	1.4	12.4	81.7	3.9	0.6	0.0
	C	1	-36.72545	175.61644	1.4	2.3	24.2	69.3	2.8	0.9	0.6
	C	3	-36.72540	175.61660	1.2	1.8	10.4	83.8	3.3	0.7	0.0
	C	4	-36.72544	175.61665	1.3	2.0	9.9	82.4	5.0	0.7	0.0
	C	8	-36.72551	175.61672	0.9	0.7	9.0	79.3	9.6	1.5	0.0
	C	5	-36.72589	175.61650	1.2	1.0	11.0	80.3	6.9	0.8	0.0
	C	6	-36.72620	175.61628	1.4	2.3	7.9	82.9	4.8	1.8	0.2
	C	7	-36.72635	175.61623	1.8	1.4	7.7	86.3	3.9	0.7	0.0
	C	2	-36.72610	175.61607	1.3	1.9	8.1	84.4	5.0	0.6	0.0

APPENDIX C: Sampling areas at Hokianga Harbour

Figure C-1: Bivalve sampling areas at Koutu Beach (star) and Pākanae (circle), Hokianga Harbour, Northland.

Figure C-2: Intertidal sampling area at Pākanae, Hokianga Harbour. General sampling area (left) and close up of the sediment surface (right).

Figure C-3: Intertidal sampling area at Koutu Beach, Hokianga Harbour. General sampling area (left) and close up of the sediment surface (right).