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Intertidal shellfish monitoring in the northern North Island region, 2021–22

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New Zealand's coastal environments support a diverse range of marine species that are treasured in recreational fisheries and as kai moana. Their presence in coastal environments makes their populations vulnerable to human impacts, which may lead to localised population declines and depletion. In this context, regular monitoring of fishery species supports the management of their populations, ensuring long-term sustainability. For the recreational and customary take of intertidal cockles (*Austrovenus stuchburyi*) and pipi (*Paphies australis*), Fisheries New Zealand monitors their northern North Island populations through regular surveys in Fisheries Management Areas 1 and 9. This survey programme was first implemented in the early 1990s, and the survey methods became consistent in 1999–2000. Within this programme, the field surveys usually sample cockle and pipi populations at 12 northern sites each year and provide information about their abundance, density, and size structure in areas targeted by non-commercial fisheries.

Reported here are the findings from the northern North Island monitoring programme, updating survey data to the 2021–22 fishing year. The 16 sites in the 2021–22 assessment were (in alphabetical order): Bowentown Beach, Cockle Bay, Little Waihi Estuary, Mangawhai Harbour, Marsden Bank, Mill Bay, Ngunguru Estuary, Pataua Estuary, Raglan Harbour, Ruakākā Estuary, Tairua Harbour, Te Haumi, Te Mata and Waipatukahu (Te Mata Bay), Umupuia Beach, Whangateau Harbour, and Whitianga Harbour. Four of these sites (Mangawhai Harbour, Ngunguru Estuary, Ruakākā Estuary, Te Haumi) were intended to be sampled in the previous fishing year, but travel restrictions to counter COVID-19 prevented the survey of these sites in 2020–21.

Cockle populations were surveyed at 14 of the 16 sites, where they varied in their population size and density. Total abundance estimates varied from 8.04 million cockles at Ruakākā Estuary (where the coefficient of variation (CV) exceeded 20% at 25.94%) to 983.06 million (CV: 9.91%) individuals in Whangateau Harbour. The corresponding density estimates ranged from 141 cockles per m^2 (CV: 17.48%) at Little Waihi Estuary to 1774 cockles per m^2 (CV: 12.24%) at Ngunguru Estuary. Most sites supported relatively high cockle densities of several hundred individuals per square metre, but some of the high estimates were caused by a strong influx of recruits ($\leq$15 mm shell length). Apart from Ruakākā Estuary, where phase-2 sampling did not succeed in lowering the CV value below 20%, estimates at all other sites had CV values below this target percentage.

Only two of the cockle populations surveyed in 2021–22 included comparatively large numbers of large cockles ($\geq$30 mm shell length); they were at Mangawhai Harbour and Umupuia Beach. Estimated densities of this size class were 79 cockles and 72 individuals per m^2 at Mangawhai Harbour and Umupuia Beach, respectively. Cockle populations at all other sites had notably lower densities of large cockles.

Pipi populations were surveyed at 11 of the northern sites, excluding Marsden Bank, which no longer contained any pipi in 2021–22. Population sizes of this species ranged from small estimates of 0.46 million (CV: 23.00%) pipi at Bowentown Beach to 166.06 million (CV: 14.54%) pipi at Ruakākā Estuary. The pipi population at Ruakākā Estuary also had the highest density estimate at 4061 pipi per m^2, compared with the lowest density of 13 pipi per m^2 at Pataua Estuary. The low total population estimates at Bowentown Beach, Little Waihi Estuary, and Pataua Estuary had high uncertainty with CV values $>$20%, in spite of additional phase-2 sampling.

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There were few large pipi (≥50 mm shell length) included in the current populations. Instead, the pipi populations were largely determined by medium-sized individuals and recruits (≤20 mm shell length). The highest density of large pipi was at Te Mata Bay, estimated at 83 pipi per m^2 (CV: 14.65%).

Sediment samples from the cockle habitats across the northern sites indicated sediment that was low in organic content ($<$3.3%) and consisted predominantly of fine and medium sands (grain sizes $>$125 and $>$500 µm. The proportion of other grain size fractions varied across sites and included several sites with a relatively high proportion of sediment fines (silt and clay; $<$63 µm grain size).

In addition to providing population information, the current study explored the relationship between cockle abundance and sediment characteristics through principal component analysis. At most sites, there were no prominent patterns or temporal shifts in cockle abundances, most likely owing to relatively small changes in sediment granulometry over time. The exception was Umupuia Beach, which was characterised by a high proportion of sediment fines, particularly in recent surveys. At this site, total cockle abundance associated with all other (coarser) grain size fractions was high compared with sediment fines.

The current survey data were also used to update geostatistical models for predicting spatial and temporal patterns in cockle densities at the northern sites. Predictions of total cockle and of large cockle densities from the geostatistical models documented differences in spatio-temporal patterns between some of the sites. For example, the model outcomes highlighted the influence of strong recruitment events on the spatial distribution of predicted cockle densities and also illustrated the diminishment of high-density areas over time, dependent on the site.

1. INTRODUCTION

New Zealand's coastal environments support a diverse range of marine species that are treasured in recreational fisheries and as kai moana (Hauraki Māori Trust Board 2003, Ministry of Fisheries 2011). In coastal environments, fishery species include pāua (*Haliotis iris*), kina (*Evechinus chloroticus*), and intertidal bivalves, such as cockles/tuangi (*Austrovenus stutchburyi*) and pipi (*Paphies australis*). While recreational and customary fishing targets these species throughout New Zealand, fishing and other human activities in coastal environments may impact on their populations. Some of the impacts have been shown to lead to localised population declines and depletion.

In this context, regular monitoring of the spatial distribution and abundance of fishery species supports the management of their populations, ensuring long-term sustainability. For cockles and pipi, Fisheries New Zealand monitors northern North Island populations through regular surveys across Fisheries Management Areas 1 and 9. This survey programme was first implemented in the early 1990s, and the survey methods have been consistent since 1999–2000. Within this programme, the field surveys usually sample a subset of 12 sites each year, from an overall pool of over 30 sites. At each site, the field surveys provide data on the abundance, density, and population size compositions of cockles and pipi in areas that are targeted by non-commercial fisheries.

In addition to the bivalve populations, the field surveys also provide data about sedimentary habitat, in the form of sediment organic content and sediment grain size composition. The sediment sampling was added to the monitoring programme in 2013–14 and amended two years later to support formal analyses of sediment data (e.g., see Neubauer et al. 2015, Neubauer et al. 2021). This amendment in 2015–16 also restricted the sediment monitoring to cockle beds, because their locations are considered to be more permanent than the spatial distribution of pipi.

In addition to providing baseline information about the quality of the sediment habitat, recent analyses examined the relationship between cockles and sediment characteristics (Neubauer et al. 2021). This exploration included the application of a principal component analysis (PCA) to data on the different sediment grain size fractions.

This report provides the 2021–22 survey results from the northern North Island bivalve monitoring programme. In addition to information about cockle and pipi populations and general sediment characteristics, the current study also provided an update of the PCA of sediment data. It also updated the exploration of geostatistical estimators as an alternative approach to the survey-based estimations of population metrics.

The sampling sites included in this study were the 12 sites that were part of the 2021–22 assessment, and also four sites that had been selected for the previous survey in 2020–21. Travel restrictions in the Auckland area in February and March 2021 (relating to COVID-19 measures) prevented the sampling of these four sites (Berkenbusch et al. 2021), and they were added to the current assessment.

The 16 sites in the 2021–22 assessment were (in alphabetical order): Bowentown Beach, Cockle Bay, Little Waihi Estuary, Mangawhai Harbour, Marsden Bank, Mill Bay, Ngunguru Estuary, Pataua Estuary, Raglan Harbour, Ruakākā Estuary, Tairua Harbour, Te Haumi, Te Mata and Waipatukahu (Te Mata Bay), Umupuia Beach, Whangateau Harbour, and Whitianga Harbour (Figure 1).

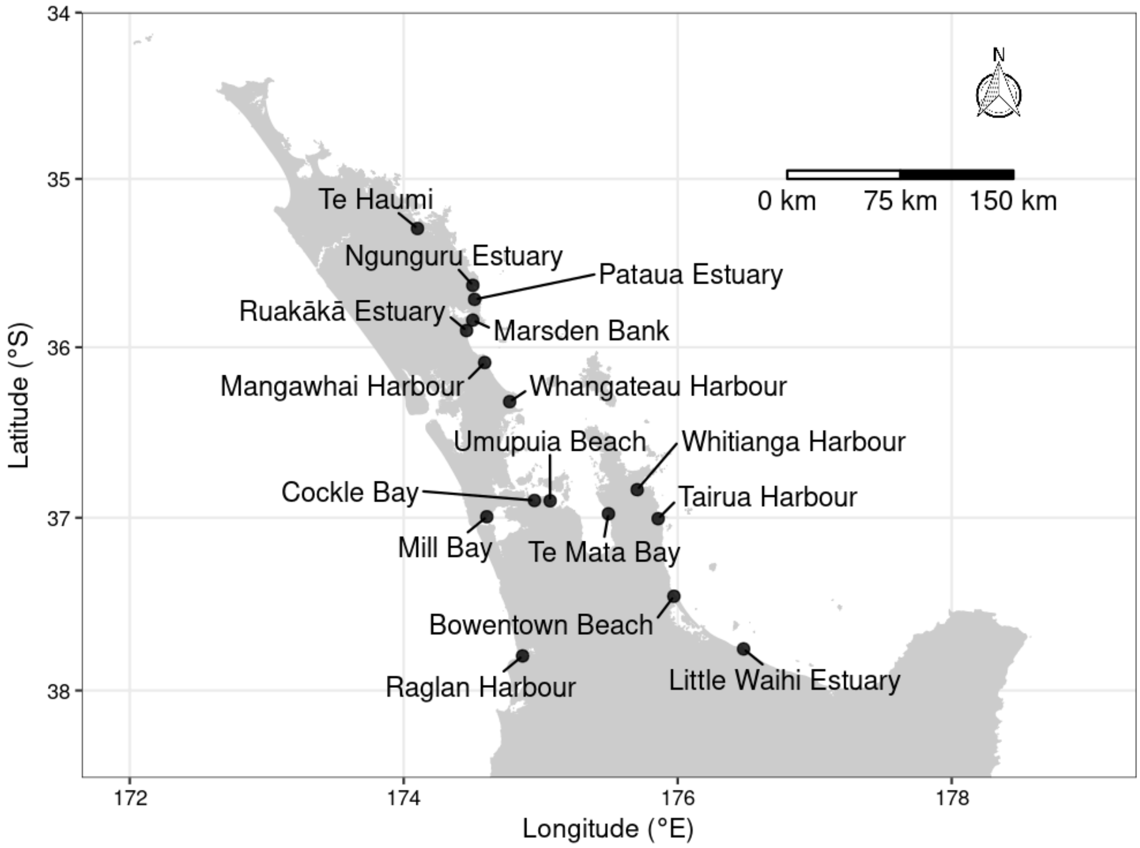


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2021–22.

2. METHODS

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

The methods used in recent surveys are described in detail by Berkenbusch & Neubauer (2016, 2017). For completeness, the methods are included here, following updates to reflect the 2021–22 assessment.

2.1 Survey methods

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

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

The number of sampling points for each bivalve population was determined by the population size and variability within each stratum, informed by data from previous surveys. For each stratum, a regular grid was generated, with the size and shape of the grid cells reflecting the desired sampling density and the orientation of the stratum. For strata with irregular 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. Based on recommendations by the Shellfish Fishery Working Group (at its meeting in November 2021), the number of allocated phase-2 points was limited to about 10% of the overall sampling effort (see also Francis 2006).

Owing to the importance of sediment properties for infaunal bivalves, recent previous surveys included a sediment sampling programme to determine the sediment organic content and grain size at each site (see Berkenbusch et al. 2015, Berkenbusch & Neubauer 2015). The initial sediment sampling provided general baseline information; subsequent improvements to the sediment sampling design in 2015–16 allowed the analysis of spatial patterns in sediment variables and of gradients in cockle abundance in relation to sediment properties (Neubauer et al. 2015, Berkenbusch & Neubauer 2016, Neubauer et al. 2021).

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

The most recent analysis of sediment properties was conducted in 2019–20, based on data from five years of monitoring (Neubauer et al. 2021). This analysis provided a spatial and temporal assessment of the relationship between cockles and sediment grain size properties. It included a principal component analysis, and the modelling of cockle population abundances as a function of different grain size fractions, for all cockles and also for individuals in the large size class (i.e., exceeding 30 mm shell length).

2.2 Field sampling – bivalves

The field survey across the 16 northern North Island sites was conducted in January and February 2022. During this period, bivalve populations at each site were sampled during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

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

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

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

2.3 Field sampling – sediment

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

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

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

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

2.4 Data analysis – bivalves

2.4.1 Survey-based population estimates

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

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

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

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

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

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

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

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

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

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

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

The numbers at length over all strata were then calculated according to equations 1a and 1b for each length class l. The same procedure was used to estimate the abundance of large-size individuals (defined as $\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.

2.4.2 Model-based population estimates

Since 2013–14, the field data have included high-resolution spatial data, providing the accurate position of each sampling point. Since 2015–16, these high-resolution spatial data have been used within geostatistical models of cockle densities to determine the optimal shape and location of cockle strata based on the spatial distribution and variability of previous samples (see Berkenbusch & Neubauer 2016). Although the re-stratification has been regularly applied since 2015–16 to determine cockle strata at each site prior to the field sampling, population estimates continue to be derived from sampling-based estimators to ensure comparability of population data throughout the survey series.

At some sites, unpredictable shifts in high-density cockle patches between surveys and resultant high uncertainty in the estimates prompted the exploration of geostatistical models to also derive population estimates (Tremblay-Boyer et al. 2021). Model-based geostatistical estimators interpolate between observations to generate site-wide predictions, while accounting for the correlation between observations as the distance increases between them.

The initial exploration provided a comparison between model-based geostatistical estimates and survey-based estimates for the northern sites included in the 2019–20 survey. It also included a temporal correlation structure, which allowed the inclusion of multiple years of survey data in spatio-temporal models. In general, these spatio-temporal models appeared more robust and provided more precise population estimates than single-year models for most sites (Tremblay-Boyer et al. 2021).

Based on the initial exploration of geostatistical models, the current analysis continued this modelling approach in parallel with the survey-based estimation. The spatio-temporal models were updated with the 2021–22 survey data from the current sites. These models were used to predict total cockle density and the density of large cockles over a spatial scale of one square metre. For each of the current sites with cockle populations, the predicted densities were mapped over time (see Appendix C). In comparison to the survey-based estimates that were derived for individual survey years throughout the monitoring series, the geostatistical estimates allowed examination of spatio-temporal patterns in predicted cockle densities at the northern sites.

2.5 Sediment data

For each site, sediment data from the sample processing provided information of the 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. These data were also summarised for a comparison across the sites included in the current survey.

Previous analyses have examined the relationship between cockle abundance and sediment characteristics (Neubauer et al. 2015, Neubauer et al. 2021). The most recent assessment used data to 2019–20 in principal component analyses to explore relationships of the total cockle population and of large cockles with sediment grain size (see Neubauer et al. 2021). The principal component analysis was updated here with sediment data from the current field sampling from 2021–22.

3. RESULTS

3.1 Bowentown Beach

Bowentown Beach is part of Tauranga Harbour, located in Bay of Plenty. Cockle and pipi populations at this site were first surveyed in 2001–02, with six subsequent assessments since then, including the current survey (see Appendix A, Tables A-1, A-2). The sampling extent has been consistent across survey years and encompassed three strata in 2021–22, with the field survey sampling a total of 98 points across these strata, including eight points in phase 2.

Sediment samples were collected in all strata, and sediment characteristics were similar across the sampling extent (Figure 2; and see details in Appendix B, Table B-1). Sediment organic content was low (i.e., $<$4.3%), and the sediment consisted mostly of fine and medium sands (grain sizes $>$125 µm and $>$250 µm); there was only a small proportion of sediment fines (grain size $<$63 µm), but this grain size fraction exceeded 10% in two of the samples.

Cockles were distributed across the entire sampling extent at Bowentown Beach, with highest numbers in stratum C (Figure 3, Table 1). The population estimates included a total abundance of 16.00 million (CV: 7.35%) cockles and an average density of 1068 cockles per m^2 (Table 2). Included in the population was a small number of large individuals ($\geq$30 mm shell length), with 0.09 million (CV: 22.32%) cockles in this size class, at an estimated density of 6 large individuals per m^2. Owing to their low abundance, large individuals were only a minor component (0.58%) of the total population (Table 3). Throughout most of the survey series, the proportion of large individuals was negligible (i.e., less than 0.5%), and general increases in the total population were not reflected in concomitant increases in large cockles. In comparison, recruits ($\leq$15 mm shell length) made up 14.19% of the 2021–22 cockle population, and this size class made up almost a quarter of the population (23.06%) in 2017–18. Length-frequency distributions revealed a similar population size structure across recent surveys, with a single strong cohort of medium-sized cockles (Figure 4). Mean and modal sizes showed relatively little change over time and were 20.47 mm and 22 mm, respectively in 2021–22.

Principal component analysis of cockle and sediment grain size data showed a general pattern of higher cockle abundance (total population and large cockles) associated with sediment fines and with finer sand fractions, although less so with fine sand (Figure 5).

The pipi population at Bowentown Beach was mostly concentrated in stratum B, directly adjacent to one of the side channels, with smaller numbers in the other two strata (Figure 6, Table 4). The population estimate for this species was 0.46 million (CV: 23.00%) pipi, and their estimated density was 30 pipi per m^2 (Table 5). Compared with the preceding survey in 2019–20, these population estimates signified a marked population increase; however, the associated CV was high (i.e., $>$20%), in spite of increased sampling effort through phase-2 sampling. Part of this increase was related to a considerable recent influx of recruits ($\leq$20 mm shell length), with almost a third of the current population consisting of these small-sized individuals (Table 6). Their overall proportion increased from 17.85% of the total population in 2019–20 to 32.58% in 2021–22. Their current estimates, and high CV, were similar to estimates in 2017–18, when a large proportion (38.78%) of recruits also indicated a strong recruitment event preceding the field survey.

In contrast, large pipi ($\geq$50 mm shell length) were consistently scarce at Bowentown Beach, and there was usually high uncertainty (i.e., CV exceeding 50%) associated with their population estimates. For example, in 2021–22, there were an estimated 0.01 million large pipi at this site, but the CV was 63.45%. The general scarcity of this size class and the influence of a relatively large proportion of recruits was also evident in the mean and modal sizes of the current population, which decreased from shell lengths of 30.62 mm and 30 mm in 2019–20 to 26.27 mm and 12 mm in 2021–22. Although medium-sized pipi continued to dominate the population in 2021–22, their cohort was smaller than in the preceding two surveys, corresponding with a shift from a unimodal to the current bimodal population size structure (Figure 7).

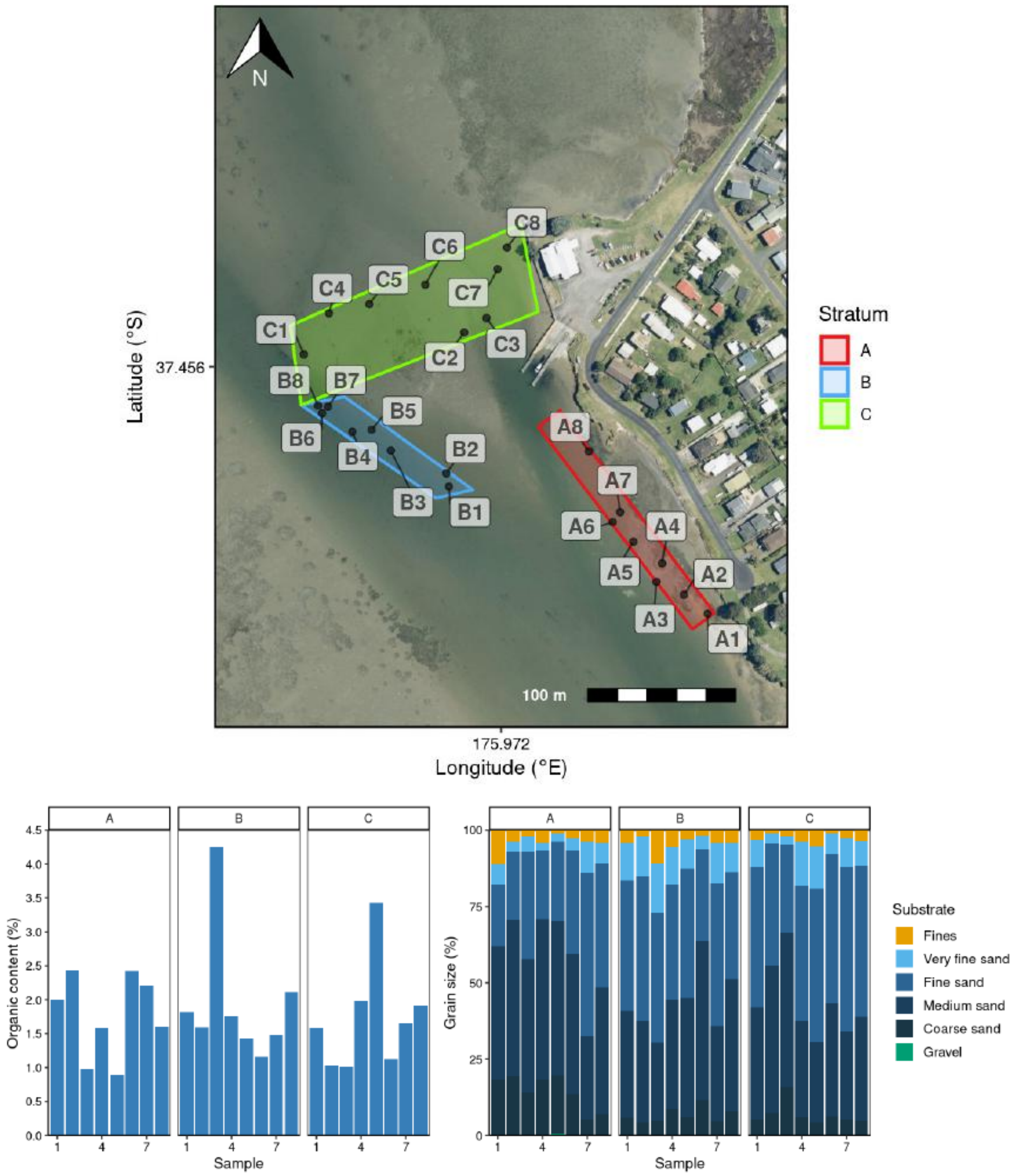


Figure 2: Sediment sample locations and characteristics at Bowentown Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Bowentown Beach

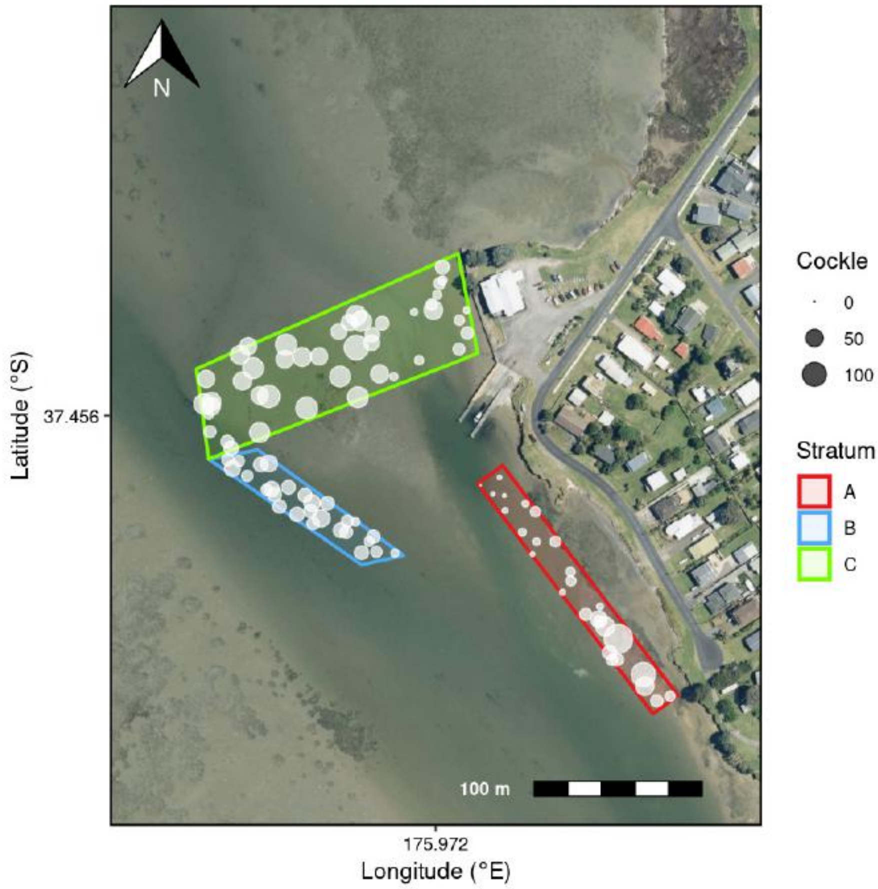


Figure 3: Map of sample strata and individual sample locations for cockles at Bowentown Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Bowentown Beach, by stratum, for 2021–22. 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	27	660	2.22	698	25.96
B	0.2	27	752	1.76	796	7.14
C	1.0	44	1 931	12.01	1 254	8.47

Table 2: Estimates of cockle abundance at Bowentown Beach for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	1.6	4.75	301	5.42	1.41	89	7.61
2010–11	1.6	18.56	1 175	9.18	0.08	5	33.18
2012–13	1.6	25.05	1 586	5.59	0.07	4	42.60
2015–16	1.5	26.95	1 799	5.17	0.03	2	34.77
2017–18	1.5	30.07	2 008	6.25	0.16	10	20.55
2019–20	1.5	24.80	1 656	5.97	0.12	8	17.30
2021–22	1.5	16.00	1 068	7.35	0.09	6	22.32

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Bowentown Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	18.99	20	5–35	23.06	0.52
2019–20	21.01	23	5–34	9.49	0.48
2021–22	20.47	22	5–37	14.19	0.58

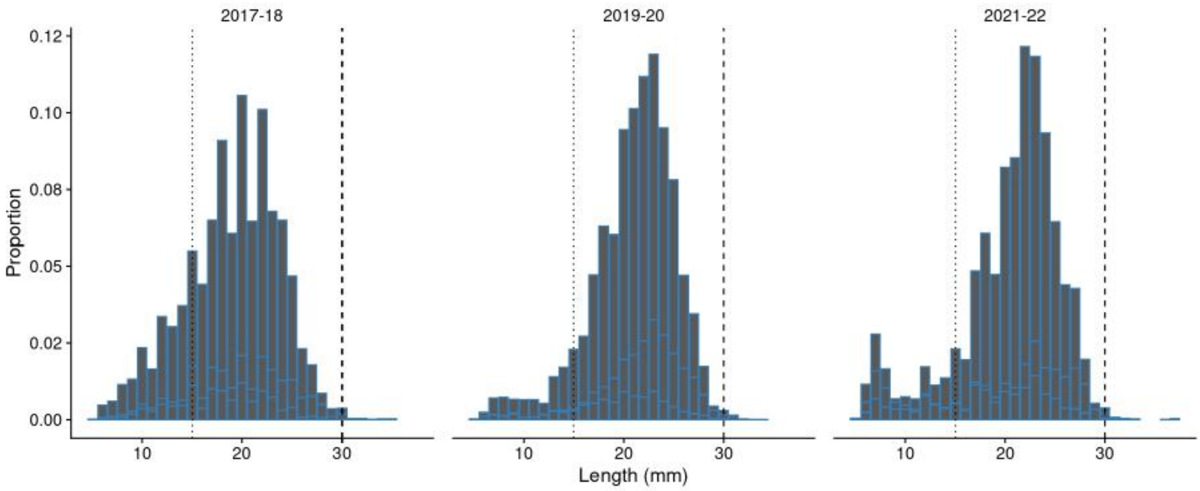


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

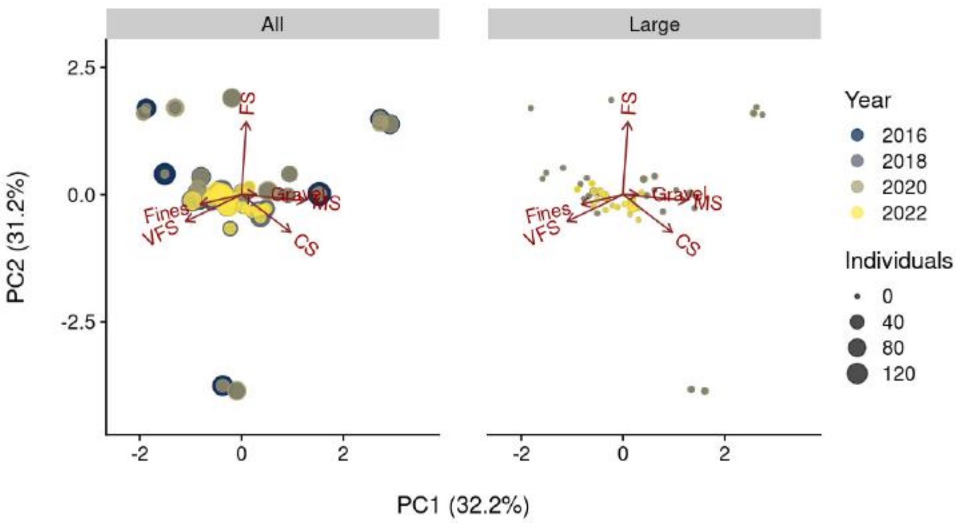


Figure 5: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Bowentown Beach. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.1.2 Pipi at Bowentown Beach

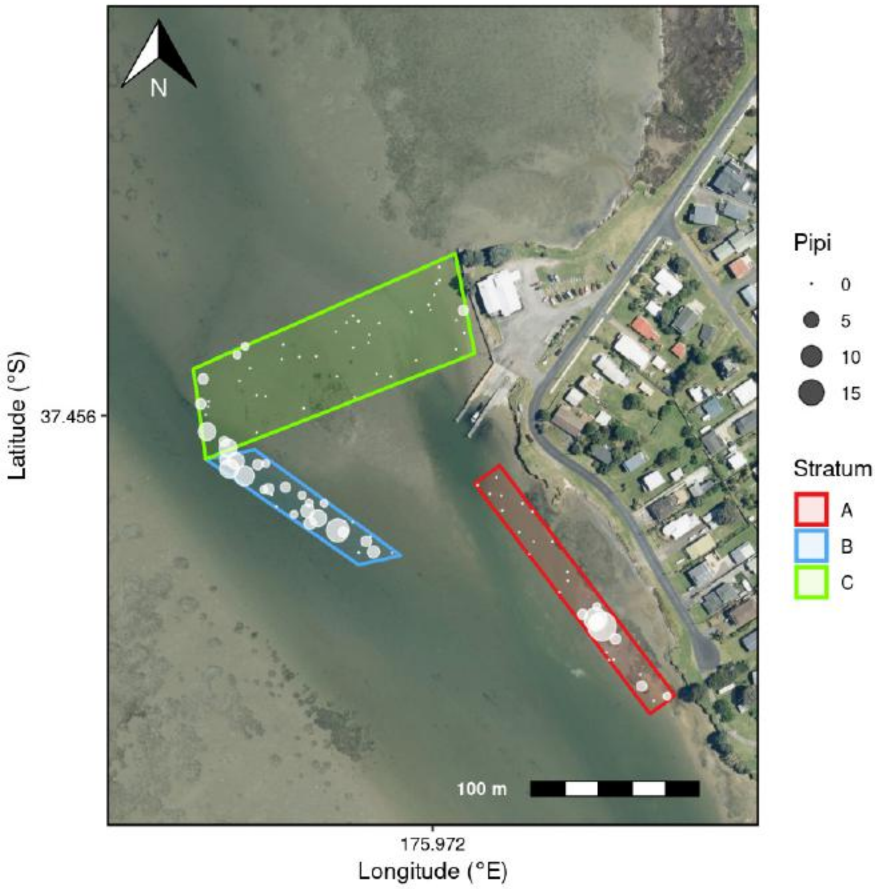


Figure 6: Map of sample strata and individual sample locations for pipi at Bowentown Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of pipi abundance at Bowentown Beach, by stratum, for 2021–22. 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	27	43	0.14	46	51.19
B	0.2	27	69	0.16	73	23.29
C	1.0	44	24	0.15	16	42.76

Table 5: Estimates of pipi abundance at Bowentown Beach for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	1.6	0.01	<1	25.46	0.00	<1	0
2010–11	1.6	0.18	12	22.86	0.00	<1	>100
2012–13	1.6	0.34	21	82.82	0.00	0	
2015–16	1.5	0.15	10	16.60	0.01	<1	72.82
2017–18	1.5	0.48	32	32.31	0.00	<1	>100
2019–20	1.5	0.29	19	15.16	0.01	<1	75.2
2021–22	1.5	0.46	30	23.00	0.01	<1	63.45

Table 6: Summary statistics of the length-frequency (LF) distribution of pipi at Bowentown Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	23.96	15	12–50	38.78	0.53
2019–20	30.62	30	8–56	17.85	1.77
2021–22	26.27	12	10–52	32.58	1.54

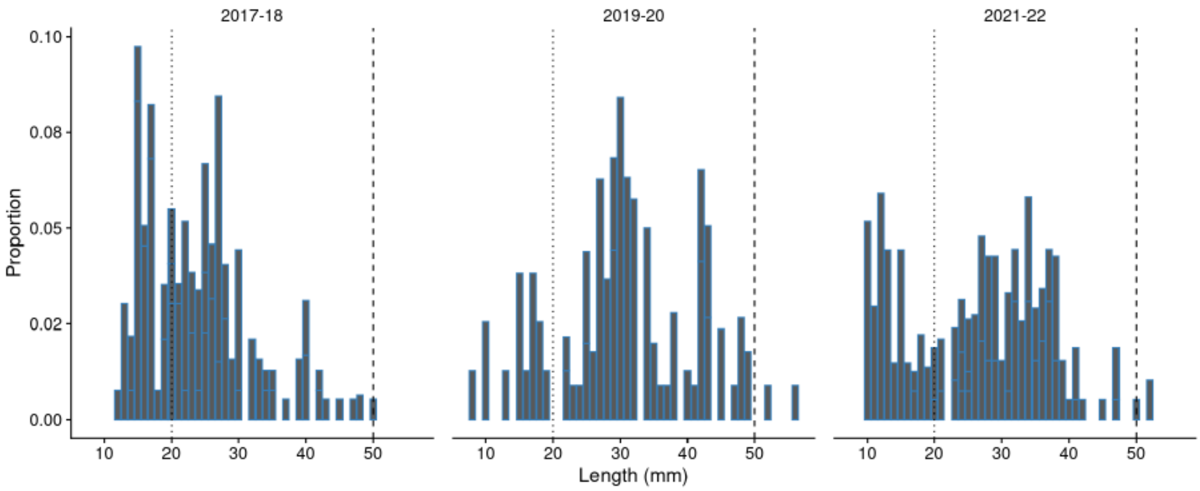


Figure 7: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Cockle Bay

Cockle Bay/Tūwakamana is a small, suburban beach in the south-eastern part of Auckland. The beach was closed to the seasonal (summer) take of all shellfish in 2008, and this measure was extended in 2021 to a year-round closure (Department of Internal Affairs 2021). This site was included in eight surveys as part of the monitoring series to date (see Appendix A, Tables A-1, A-2). The population assessments were focused on cockles because there is no pipi population at this beach. The cockle surveys were consistently conducted across the same spatial extent, and the 2021–22 survey sampled a total of 80 points across two strata within this sampling extent. During the 2021–22 field sampling, there were small, localised patches of recently-dead cockles in some parts of the sampling extent.

The sediment organic content was generally low at less than 2.0% (Figure 8, and see details in Appendix B, Table B-1). Similarly, the proportion of sediment fines (grain size <63 μm) was low (between 1 and 5%), but exceeded 37% in one of the samples. Overall, the sediment was dominated by fine and very find sand fractions (grain sizes >63 and >125 μm).

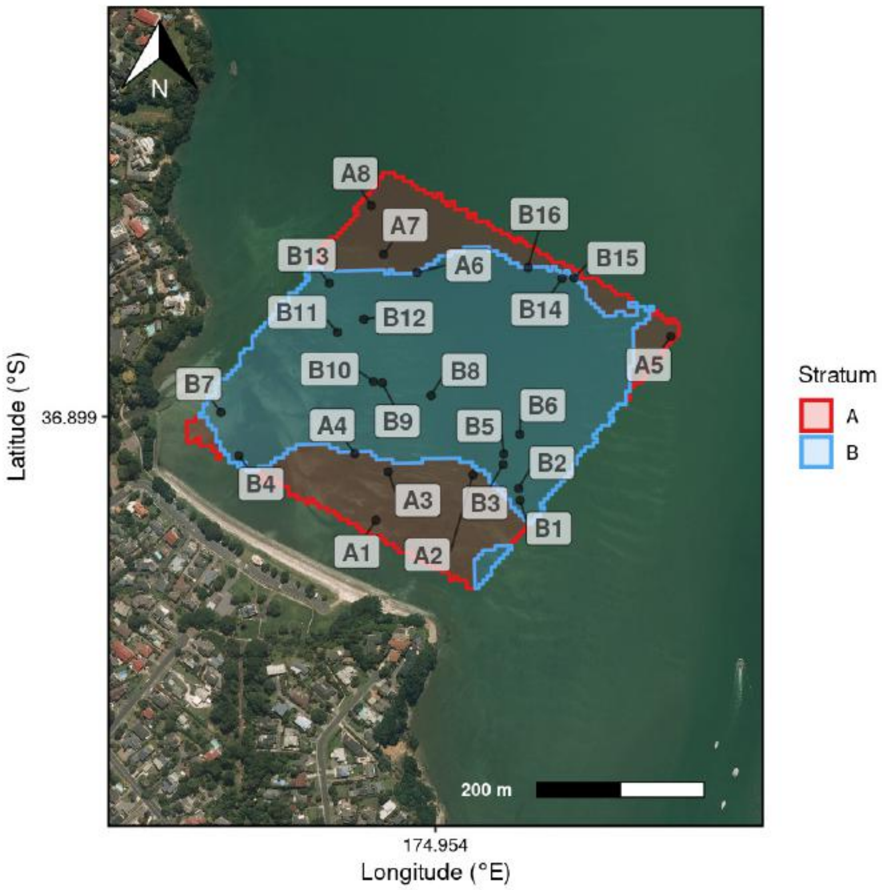
Cockles at this site were predominantly in the upper- to mid-shore area, with few individuals in the low tide zone (Figure 9, Table 7). The total population size was estimated at 34.58 million (CV: 14.93%) cockles in 2021–22, with an estimated density of 222 cockles per m^2 (Table 8). the cockle population in comparison with the two immediately preceding surveys in 2017–18 and 2019–20; for example, the 2019–20 estimates were 44.41 million (CV: 13.84%) cockles, occurring at a density of 282 cockles per m^2.

A similar decline was evident in the population of large cockles ($\geq$30 mm shell length): the abundance of individuals in this size class decreased from an estimated 11.75 million (CV: 15.81%) large cockles in 2019–20 to 4.99 million (CV: 15.57%) large individuals in 2021–22; their corresponding density declined from 75 to 32 large individuals per m^2.

The decline in large cockles was also reflected in the population structure, with the large size class contributing 14.44% of individuals to the total population in 2021–22, compared with 40.30% in 2017–18, and 26.46% in 2019–20 (Table 9). The proportion of recruits ($\leq$15 mm shell length) was similar in the three most recent surveys; in 2021–22, it was 11.13% of the total cockle population.

Over the same period, there were small reductions in mean and modal sizes across surveys, and the current shell lengths for these metrics were 22.77 mm and 17 mm, respectively. The decrease in the population of large cockles and in mean and modal sizes was also evident in the three most recent length-frequency distributions: the population size structure shifted from a distinctly bimodal population in 2017–18 to the current unimodal population dominated by medium-sized cockles (Figure 10).

Cockle abundance in relation to sediment composition showed relatively high abundances of all cockles and of large individuals associated with the very fine to medium sand grain size fractions (Figure 11). This pattern was particularly evident in 2021–22, with PC1 distinguishing these sand fractions from gravel and explaining 46.6% of the variance.



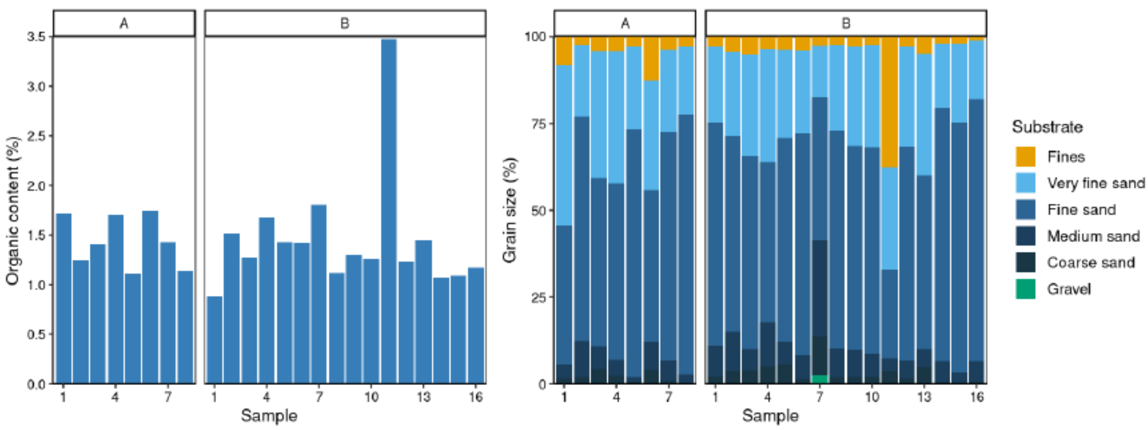


Figure 8: Sediment sample locations and characteristics at Cockle Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm;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

3.2.1 Cockles at Cockle Bay

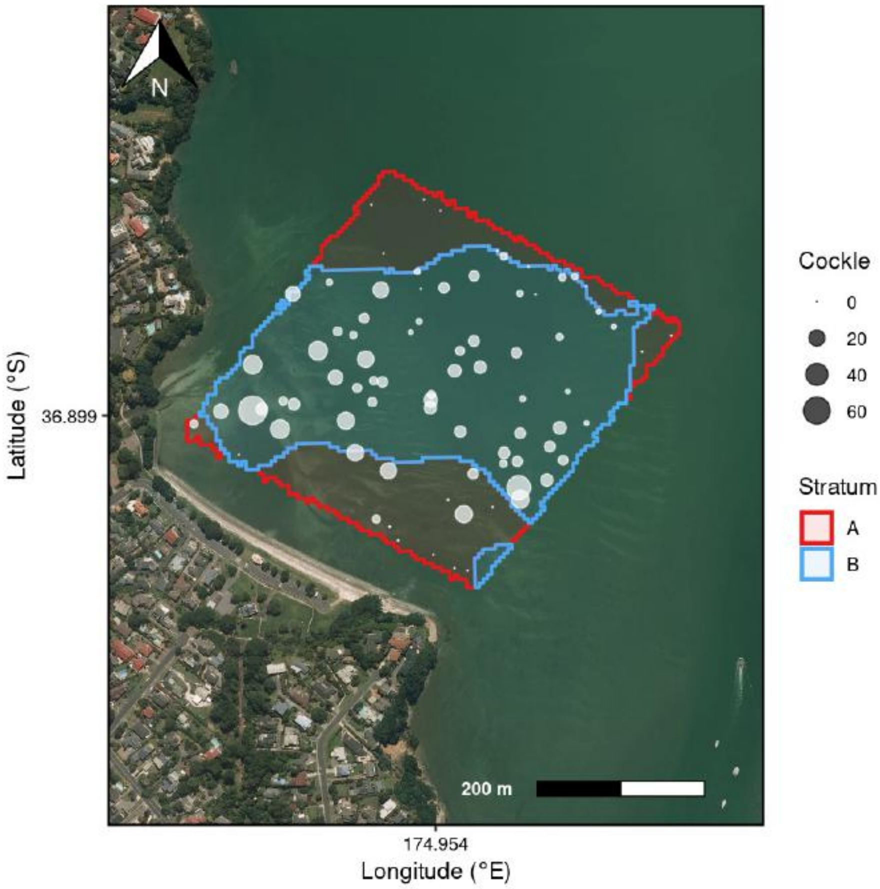


Figure 9: Map of sample strata and individual sample locations for cockles at Cockle Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Cockle Bay, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	5.0	20	80	5.66	114	42.42
B	10.6	60	571	28.92	272	15.81

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	16.0	59.54	372	5.60	6.27	39	12.48
2010–11	16.0	72.20	451	5.61	21.29	133	8.15
2012–13	16.0	54.67	342	7.51	36.46	228	8.78
2013–14	15.8	33.68	214	8.14	21.02	133	9.50
2015–16	15.8	21.46	136	8.48	15.37	98	10.77
2017–18	15.8	43.37	275	11.62	17.48	111	13.87
2019–20	15.8	44.41	282	13.84	11.75	75	15.81
2021–22	15.6	34.58	222	14.93	4.99	32	15.57

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	25.85	20	7–48	13.25	40.30
2019–20	23.58	18	5–47	12.27	26.46
2021–22	22.77	17	7–39	11.13	14.44

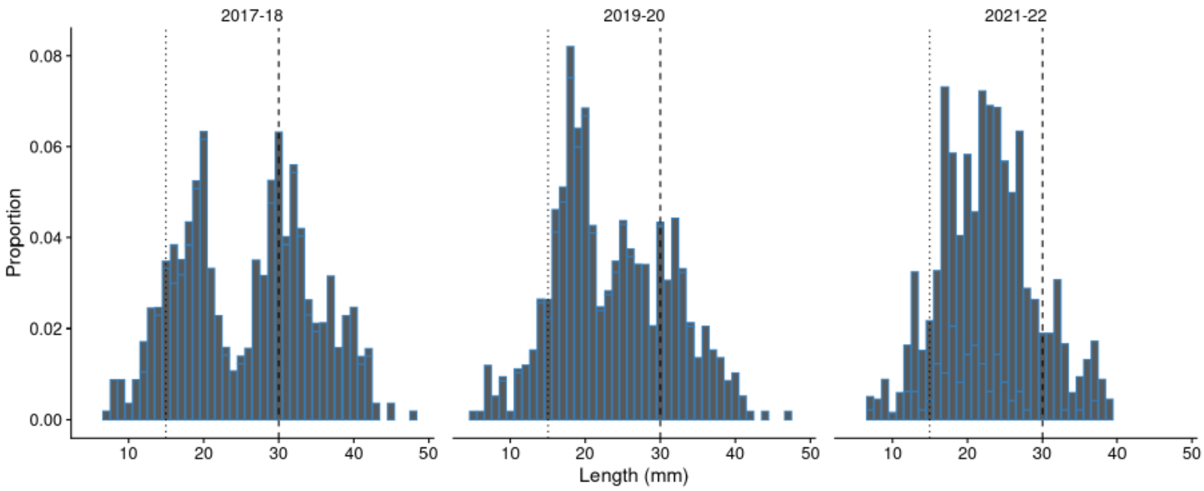


Figure 10: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

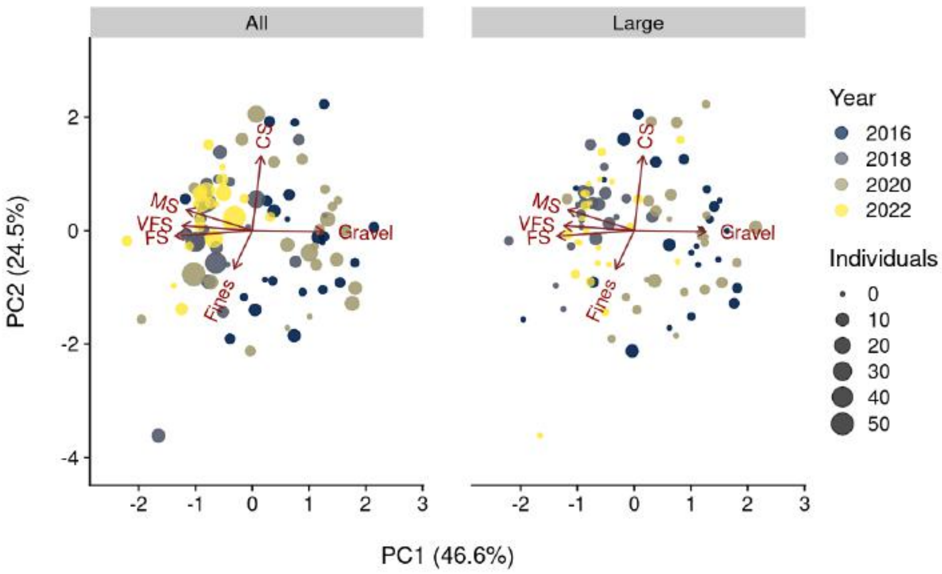


Figure 11: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Cockle Bay. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.3 Little Waihi Estuary

Little Waihi Estuary is in the Bay of Plenty region, east of Tauranga. Within the current monitoring series, the estuary has been surveyed 12 times (see Appendix A, Tables A-1, A-2). The field survey provides information of cockle and pipi populations at this site, and the sampling extent covers the entire area in the lower part of the estuary. In 2021–22, the field survey sampled 176 points across three strata within this sampling extent, including 15 points that were sampled in phase 2.

Sediment characteristics at Little Waihi Estuary included a low organic content and a small proportion of sediment fines (grain size <63 µm) at about 2% and 3%, respectively (Figure 12, and see details in Appendix B, Table B-1). The sediment was predominantly fine and medium sand (grain sizes >125 µm and >250 µm), with only small proportions of other grain size fractions.

Within the estuary, cockles exhibited a distinct distribution across the intertidal areas of stratum A (Figure 13, Table 10). Current population estimates documented a total abundance of 23.45 million (CV: 17.48%) cockles and an estimated average density of 141 cockles per m^2 (Table 11). These estimates were a marked reduction from the preceding survey in 2019–20, when total cockle abundance was an estimated 39.37 million (CV: 18.00%) individuals, and their density was 235 cockles per m^2. Nevertheless, the cockle population at this site has been characterised by considerable fluctuation over time, in part corresponding with differences in the proportion of recruits (≤15 mm shell length) across surveys: in 2019–20, almost half (43.93%) of the population consisted of individuals in this size class, compared with 31.62% in 2021–22 (Table 12). At the same time, the population of large cockles (≥30 mm shell length) was consistently small throughout the survey series, contributing few individuals to the overall population (see Table 11). In 2021–22, their population size estimate was 0.44 million individuals, and their density was 3 large cockles per m^2 (with a high CV of 45.75% for these estimates, similar to previous estimates for this size class).

Length-frequency distributions for the three most recent surveys highlighted the influence of recruits on the overall population size structure (Table 12, Figure 14). The strong recruitment event in 2019–20 led to a bimodal population structure, with a strong cohort of recruits in addition to the cohort of medium-sized cockles. Subsequently, less recruitment in 2021–22 resulted in the return to a unimodal population structure, as recruits contributed to the medium size class. This shift was evident in the concomitant increase in modal shell length from 7 mm in 2019–20 to 17 mm in 2021–22.

In the principal component analysis, total cockle abundance tended to be higher in relatively coarse sediment fractions, especially when compared with sediment fines (Figure 15). Nevertheless, there was no clear pattern in recent surveys, e.g., in 2019–20 and 2021–22.

Pipi at Little Waihi Estuary were mainly distributed throughout the channel areas in the middle of the lower estuary, in strata A and B (Figure 16, Table 13). The total population estimate of this species was 65.19 million (CV: 20.37%) individuals in 2021–22, which signified a substantial decline in population size from an estimated 142.30 million (CV: 13.35%) pipi in 2019–20 (Table 14). Similarly, the density estimate declined from 849 pipi per m^2 to the current estimate of 392 individuals per m^2. The recent changes in the population estimates were consistent with fluctuations exhibited by the pipi population throughout the survey series, which in turn were associated with marked changes in the population of large pipi (≥50 mm shell length). In 2021–22, this size class showed a notable decline to about 10% of their preceding abundance and density estimates, from 15.59 million (CV: 18.74%) large pipi in 2019–20 to 1.45 million (CV: 45.27%) large individuals in 2021–22.

Their contribution to the total population declined concomitantly, from about 11% in 2019–20 to 2.22% in 2021–22 (Table 15, Figure 17). In comparison, the proportion of recruits (≤20 mm shell length) was relatively stable across the three recent surveys, with 22.03% of the 2021–22 population consisting of these small-sized individuals. In 2021–22, recruits continued to form a comparatively small second cohort to the strong cohort of medium-sized pipi. There was little change in mean and modal sizes in recent surveys, with a modal shell length of 42 mm, and a mean size of 31.77 mm in this assessment.

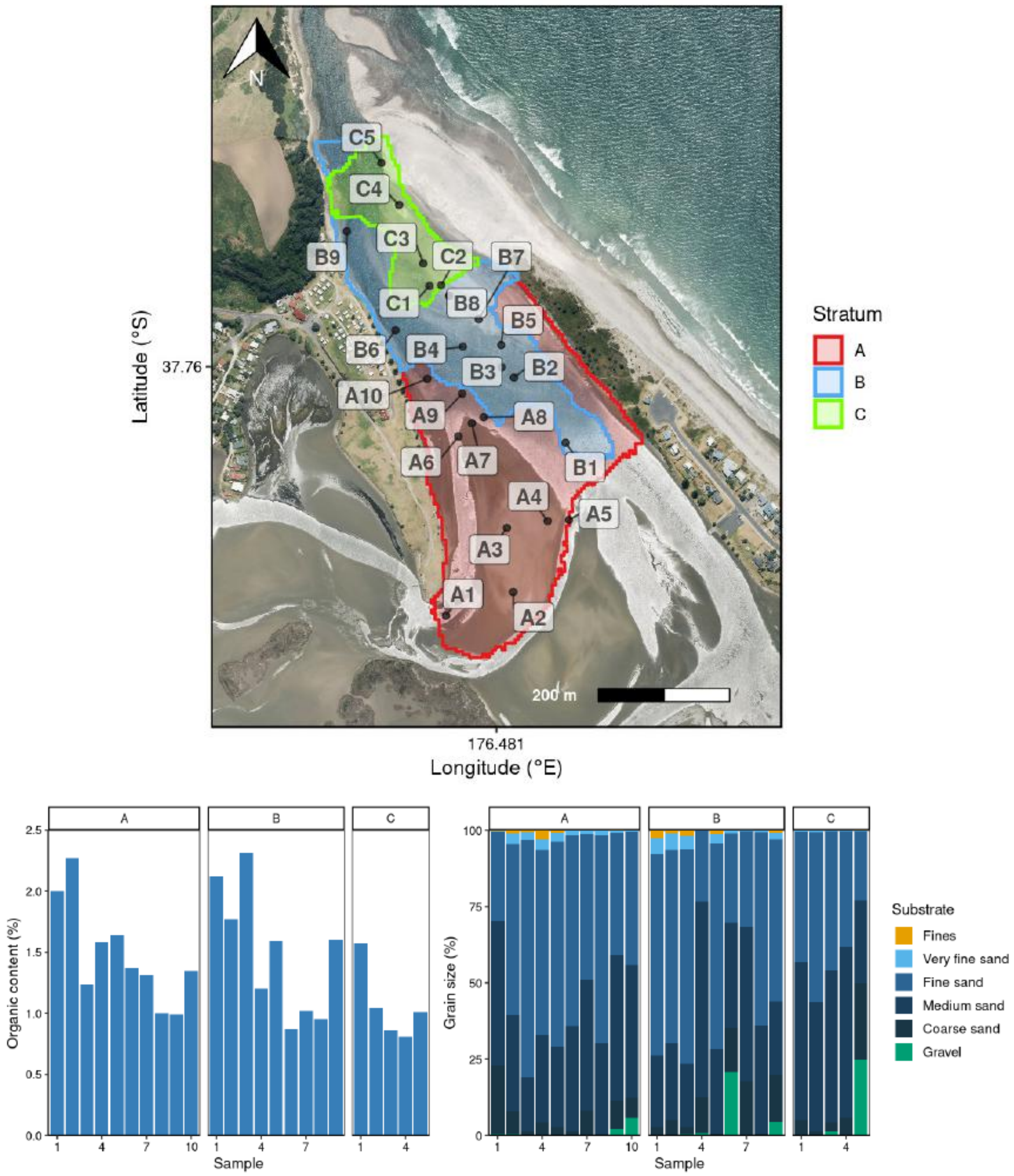


Figure 12: Sediment sample locations and characteristics at Little Waihi Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.3.1 Cockles at Little Waihi Estuary

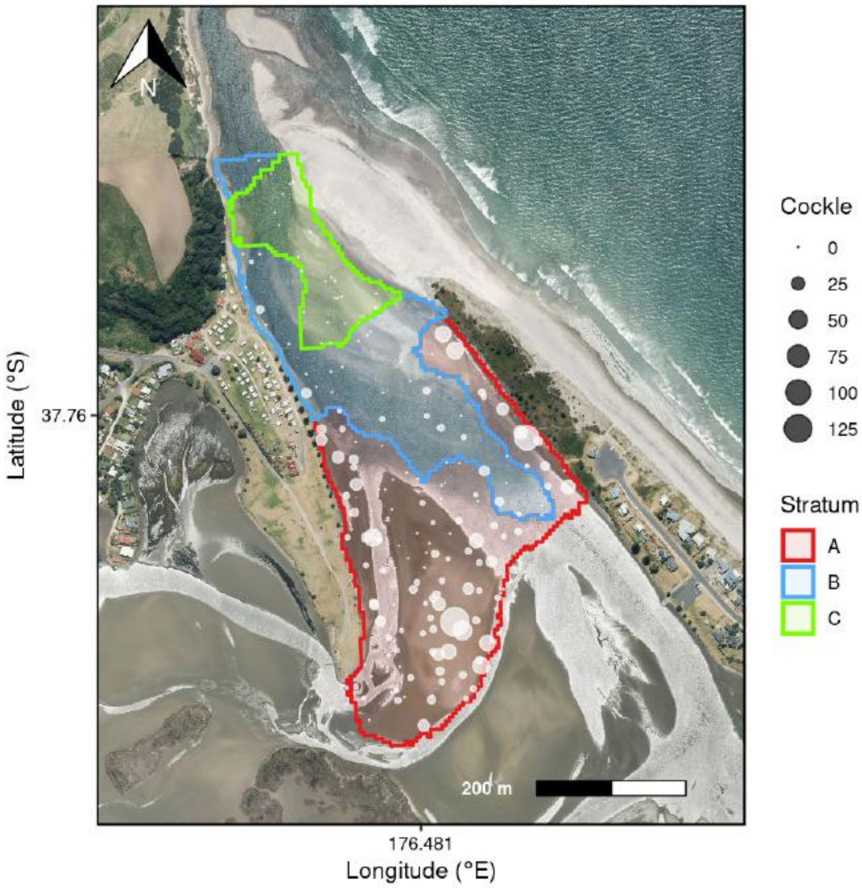


Figure 13: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2021–22. 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	9.1	121	999	21.50	236	18.79
B	5.2	33	43	1.95	37	35.74
C	2.3	22	0	0.00	0	

Table 11: Estimates of cockle abundance at Little Waihi Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	4.44	148	11.06	0.95	32	9.2
2002–03	3.0	0.96	32	5.98	0.07	2	20.47
2003–04	3.1	3.92	125	8.01	0.40	13	15.92
2004–05	3.8	3.73	99	9.65	0.17	4	18.32
2006–07	3.2	2.09	66	18.32	0.01	<1	>100
2009–10	13.9	20.55	148	16.57	0.08	<1	76.43
2012–13	15.4	17.77	115	18.58	0.20	1	56.95
2013–14	17.1	27.32	160	16.62	0.35	2	59.9
2015–16	18.4	30.40	165	12.74	0.26	1	51.69
2017–18	18.4	15.50	84	26.09	0.36	2	>100
2019–20	16.8	39.37	235	18.00	0.26	2	42.8
2021–22	16.6	23.45	141	17.48	0.44	3	45.75

Table 12: Summary statistics of the length-frequency (LF) distribution of cockles at Little Waihi Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	19.03	20	6–32	25.17	2.33
2019–20	16.70	7	5–31	43.93	0.66
2021–22	18.18	17	5–40	31.62	1.88

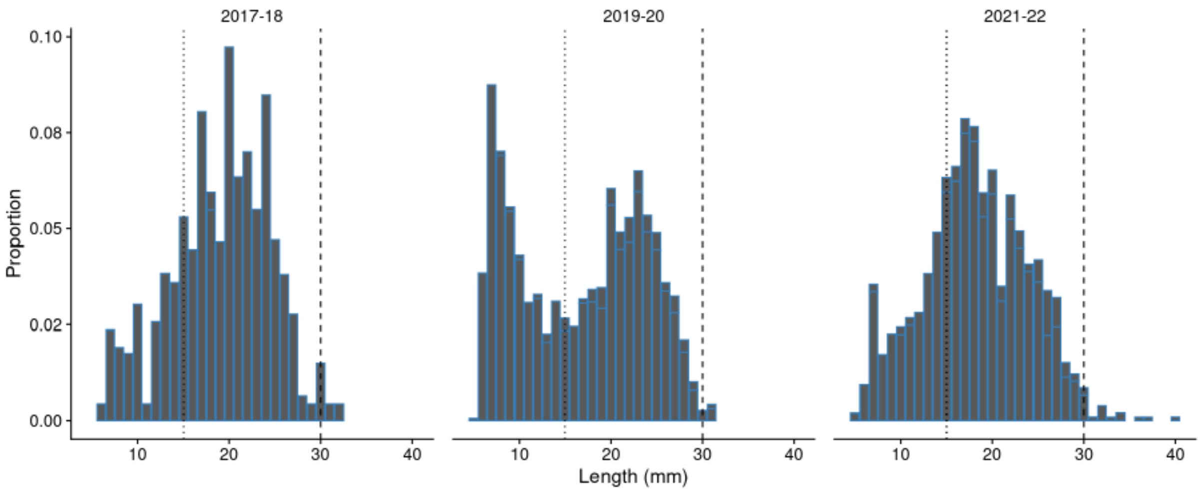


Figure 14: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

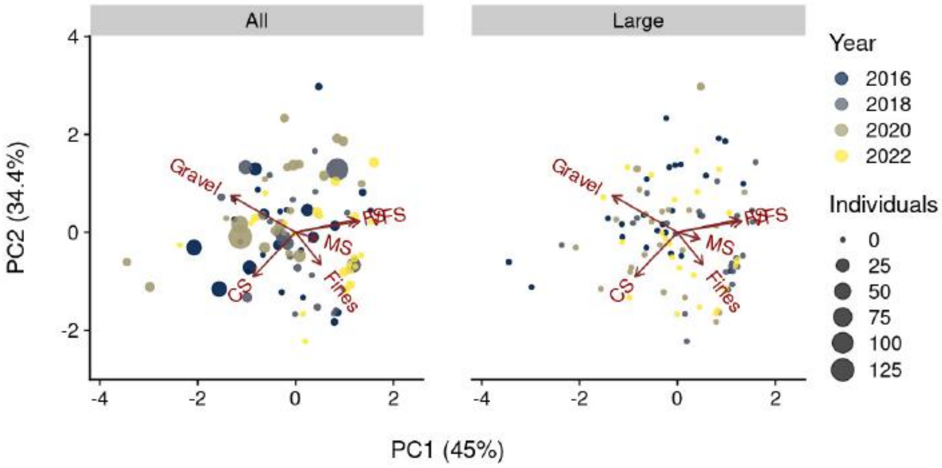


Figure 15: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Little Waihi Estuary. Sediment grain size fractions are defined as fines (silt and clay) <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.

3.3.2 Pipi at Little Waihi Estuary

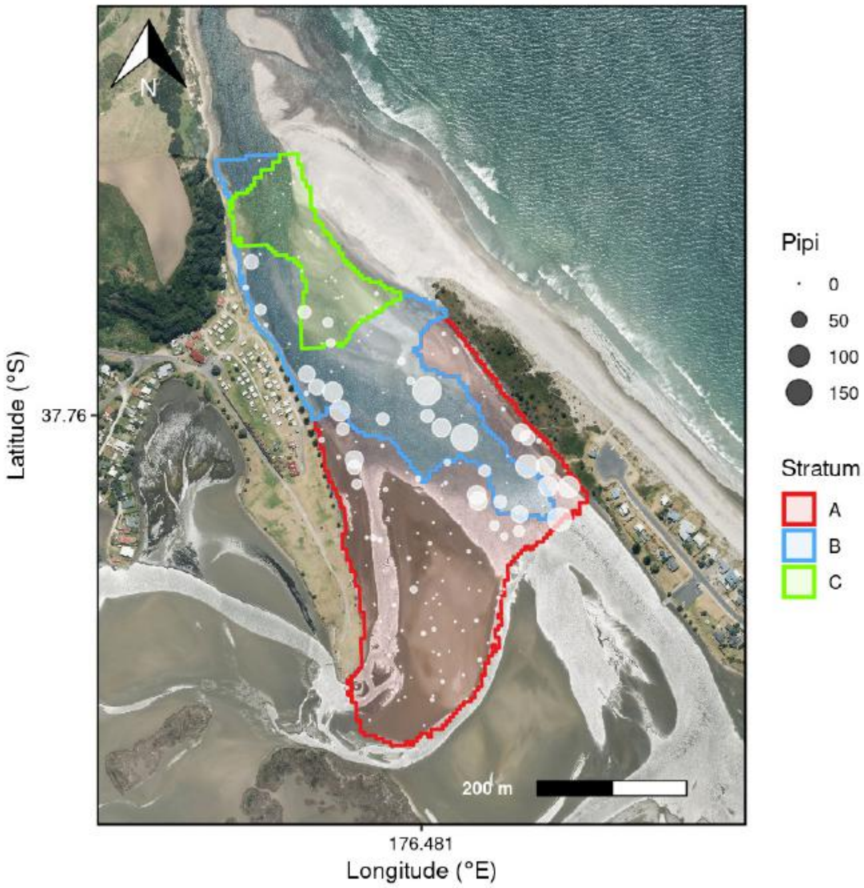


Figure 16: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2021–22. 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	9.1	121	1 124	24.19	265	24.44
B	5.2	33	863	39.10	747	30.29
C	2.3	22	64	1.90	83	58.36

Table 14: Estimates of pipi abundance at Little Waihi Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	28.69	956	8.78	3.74	125	8.46
2002–03	3.0	5.82	194	7.38	0.48	16	9.56
2003–04	3.1	7.05	226	9.15	0.84	27	13.52
2004–05	3.8	48.00	1 280	6.16	1.90	51	10.25
2006–07	3.2	44.52	1 409	7.47	2.00	63	10.76
2009–10	13.9	271.99	1 954	11.54	10.12	73	20.25
2012–13	15.4	219.43	1 423	7.88	10.26	67	27.03
2013–14	17.1	170.82	1 000	12.70	4.58	27	31.30
2015–16	18.4	83.84	456	16.62	2.35	13	43.62
2017–18	18.4	79.10	430	26.04	5.44	30	64.08
2019–20	16.8	142.30	849	13.35	15.59	93	18.74
2021–22	16.6	65.19	392	20.37	1.45	9	45.27

Table 15: Summary statistics of the length-frequency (LF) distribution of pipi at Little Waihi Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	35.48	40	7–58	14.53	6.88
2019–20	35.41	44	1–58	16.45	10.95
2021–22	31.77	42	6–57	22.03	2.22

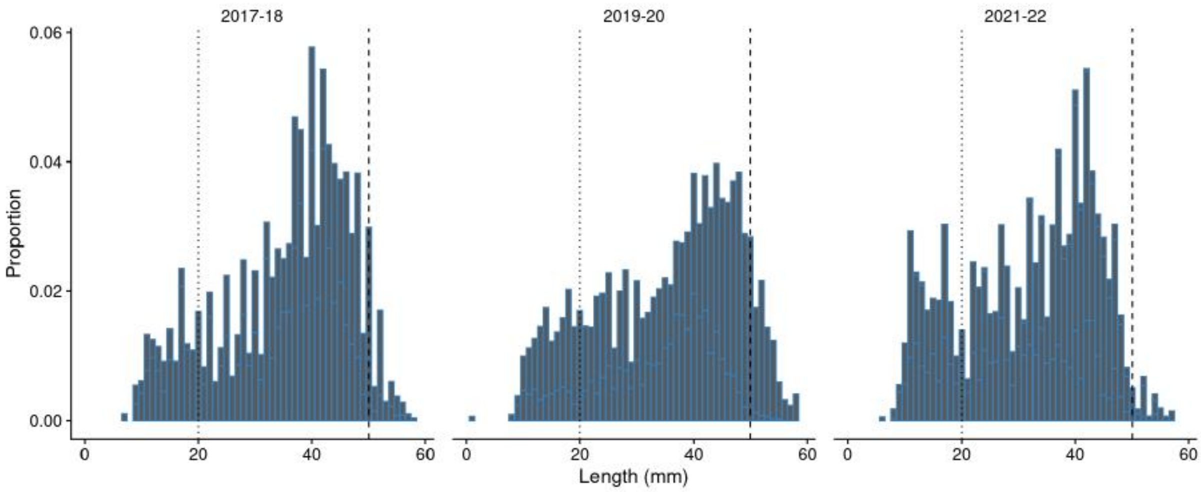


Figure 17: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.4 Mangawhai Harbour

Mangawhai Harbour is a large estuary north of Auckland that opens into Hauraki Gulf. The harbour was first surveyed in 1999–2000, and the present study was the tenth bivalve assessment within the northern monitoring series (see Appendix A, Tables A-1, A-2). Previous surveys included both cockles and pipi, with recent assessments of the latter species focused on beds associated with the main channel. The immediately-preceding survey in 2018–19 only included a small pipi bed characterised by small-sized recruits, and there was a general scarcity of other pipi size classes in recent surveys. The reconnaissance for the current survey (conducted in 2020 and 2021) failed to find pipi beds that were accessible to intertidal sampling. For this reason, the assessment here focused on cockle beds only. Cockles were assessed in two separate areas that were divided into four strata and constituted the same sampling extent as used previously (i.e., since 2016–17). There were 135 sampling points across the four strata.

The sediment organic content in the cockle strata was less than 1.3%, and there was only a small proportion (i.e., less than 3%) of sediment fines (grain size <63 µm) across all samples (Figure 18, and see details in Appendix B, Table B-1). The prevalent grain size fractions were fine and medium sands (grain sizes >125 µm and >250 µm), whereas the other fractions were small.

Cockles were distributed across all strata in both areas, but their numbers were low in stratum C, close to the harbour entrance (Figure 19, Table 16). Current population estimates indicated a total abundance of 65.64 million (CV: 8.84%) cockles and a mean density of 915 cockles per m^2 (Table 17). Included in the population were 5.68 million (CV: 17.56%) large cockles ($\geq$30 mm shell length), and their density was 79 large cockles per m^2. The population of large cockles more than doubled between the most recent surveys in 2018–19 and 2021–22, even though the total population showed a decrease over the same period.

Considering different size classes, large cockles made up 8.66% of the population and contributed to the single cohort that was largely determined by medium-sized pipi (Table 18, Figure 20). The proportion of recruits ($\leq$15 mm shell length) was 10.62% in 2021–22, which was a notable difference to the preceding surveys, when they contributed almost a third of the total population. Across the three most recent surveys, there was a shift in growth of recruits into the medium size class, strengthening the latter cohort in 2021–22. Following the strong recruitment event in 2018–19, small individuals grew beyond the lower-size threshold and contributed to the medium size class. At the same time, there was some growth of medium-sized cockles into the large size class. These shifts were reflected in increases in mean and modal shell lengths in 2021–22 to 22.33 mm and 23 mm, respectively. These findings also highlighted that the recent population decrease in the cockle population at Mangawhai Harbour was largely determined by a comparatively small recruitment event preceding the survey, resulting in fewer recruits than in the preceding two surveys in 2016–17 and 2018–19.

Exploring the relationship between cockle abundance and sediment grain size fractions indicated that total cockle abundance was higher in medium and coarse sand fractions, particularly in recent surveys (Figure 21). There was a similar pattern for the large-cockle size class, although these individuals were generally scarce.

Bivalves, including cockles and pipi, were also part of a habitat assessment in Mangawhai Harbour by Northland Regional Council, conducted in 2019 (Griffiths et al. 2020). The areas included a northern area that overlapped with strata A to C of the current study and a mid-harbour area adjacent to (with slight overlap) stratum D. Although the survey methods and data analysis were markedly different to the current assessment, average cockle densities from the regional council's survey were within the estimates of the current study: total cockles had a mean density of 955 (SE: 178.7) individuals per m^2 in the northern area, and it was 816 (SE: 80.1) cockles per m^2 in the mid-harbour area. Pipi were sampled across the same intertidal areas but were generally scarce, so that recorded average densities had high standard errors.

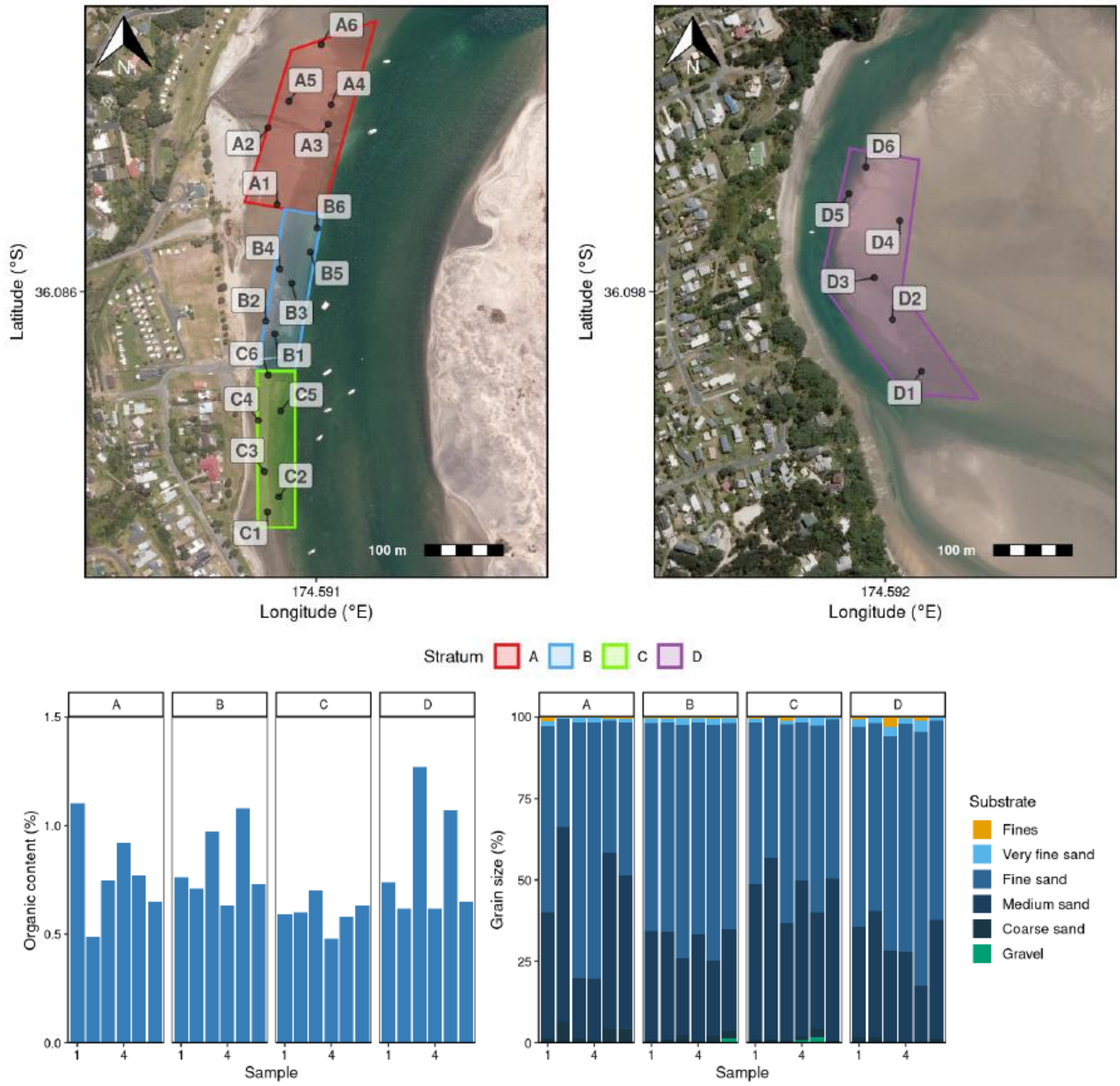


Figure 18: Sediment sample locations and characteristics at Mangawhai Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.4.1 Cockles at Mangawhai Harbour

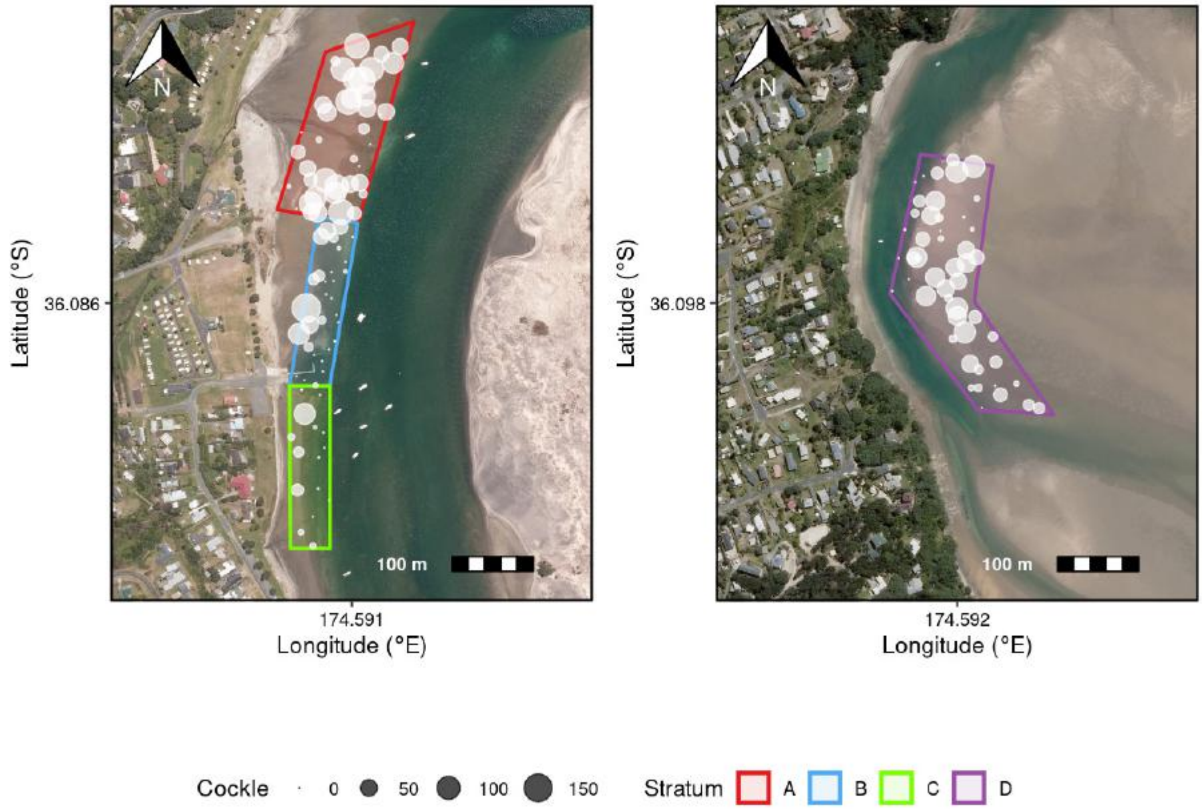


Figure 19: Map of sample strata and individual sample locations for cockles at Mangawhai Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of cockle abundance at Mangawhai Harbour, by stratum, for 2021–22. 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	40	2 165	34.43	1 546	11.86
B	1.0	30	490	4.69	467	36.70
C	1.0	15	130	2.41	248	61.08
D	3.0	50	1 422	24.10	813	14.26

Table 17: Estimates of cockle abundance at Mangawhai Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	9.4	98.71	1 050	4.54	28.56	304	7.17
2000–01	8.4	76.61	912	4.35	45.27	539	4.35
2001–02	8.4	28.54	340	5.80	8.75	104	7.48
2002–03	8.4	46.14	549	5.46	20.46	244	6.47
2003–04	8.4	50.77	604	4.71	17.43	207	6.24
2010–11	9.0	61.78	686	9.15	8.28	92	17.41
2014–15	8.6	52.73	617	7.58	2.05	24	15.95
2016–17	7.4	58.97	794	13.89	1.46	17	28.67
2018–19	7.2	78.89	1 091	8.56	2.48	34	17.36
2021–22	7.2	65.64	915	8.84	5.68	79	17.56

Table 18: 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 (%)
2016–17	19.19	22	5–47	29.01	2.48
2018–19	18.55	20	5–36	33.73	3.14
2021–22	22.33	23	6–39	10.62	8.66

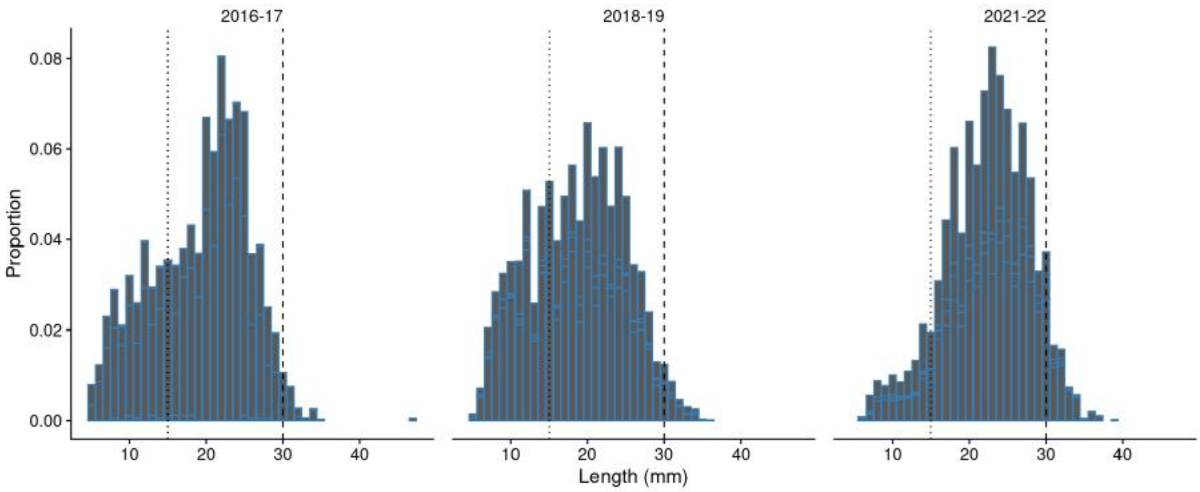


Figure 20: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

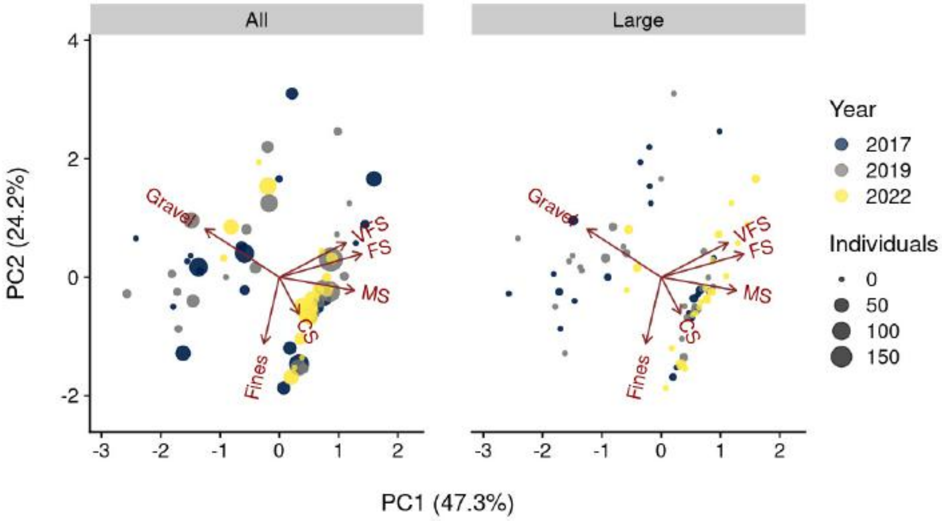


Figure 21: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Mangawhai Harbour. Sediment grain size fractions are defined as fines (silt and clay) <63 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.

3.5 Marsden Bank

Marsden Bank is south of Whangārei and one of the Northland monitoring sites. The bank is directly adjacent to the Marsden Point oil refinery, with nearby Mair Bank on its seaward side. Both banks are currently closed to the collection of all shellfish (Department of Internal Affairs 2020a). Monitoring surveys at Marsden Bank have surveyed pipi only, because there is no cockle population at this site. There have been four previous pipi population surveys, starting in 2009–10. In addition to the Fisheries New Zealand monitoring, pipi surveys have also been carried out by Te Patuharakeke Te Iwi Trust Board (Williams et al. 2017, Shirkey 2019).

Throughout the survey series, the sampling extent has varied considerably, determined by changes in the location and distribution of the pipi bed. The current sampling extent was similar to that in the 2017–18 survey, extending along the side channel between Marsden and Mair banks. Within this sampling extent, the 2021–22 field survey sampled a total of 60 points (Figure 22, Table 19).

Pipi were absent at Marsden Bank in 2021–22, and none of the 60 samples contained any pipi. Their renewed decline at this site followed signs of recovery in 2017–18, when the pipi population had an estimated abundance of 10.93 million (CV: 19.17%) indidviduals, which occurred at an average density of 1284 pipi per m^2 (Table 20). Previous to this earlier survey, there were marked declines in the pipi population in 2012–13 and 2013–14, following high estimates at the start of the survey series in 2009–10. Coinciding with the declines was the prevalence of recruits ($\leq$ 20 mm shell length) within the population. In recent surveys in 2013–14 and 2017–18, recruits represented 69.10% and 22.52% of all individuals, respectively (Table 21).

In the most recent preceding survey in 2017–18, the pipi population mostly consisted of medium-sized individuals, indicating that some of the earlier recruits had grown into this size class (Figure 23). It is unknown why the pipi population did not persist at this site. Localised patches of moribund and decaying pipi, noted during the 2017–18 field survey at Marsden Bank (Berkenbusch & Neubauer 2018), may have contributed to the loss of pipi that was observed in the current sampling.

This notion is supported by findings from the 2019 population assessment by Te Patuharakeke Te Iwi Trust Board, which documented a restricted distribution of pipi and the prevalence of small-sized individuals (Shirkey 2019). The population estimate from this survey was about 16 million pipi, but the associated uncertainty was high with a CV of 97%. The high uncertainty was attributed to the patchy distribution of pipi, because only one of sixty sampling stations had a high number of individuals, whereas the remaining stations contained no or few individuals. In addition, the majority of pipi were small, with most of their sizes between 8 and 25 mm shell length.

3.5.1 Pipi at Marsden Bank

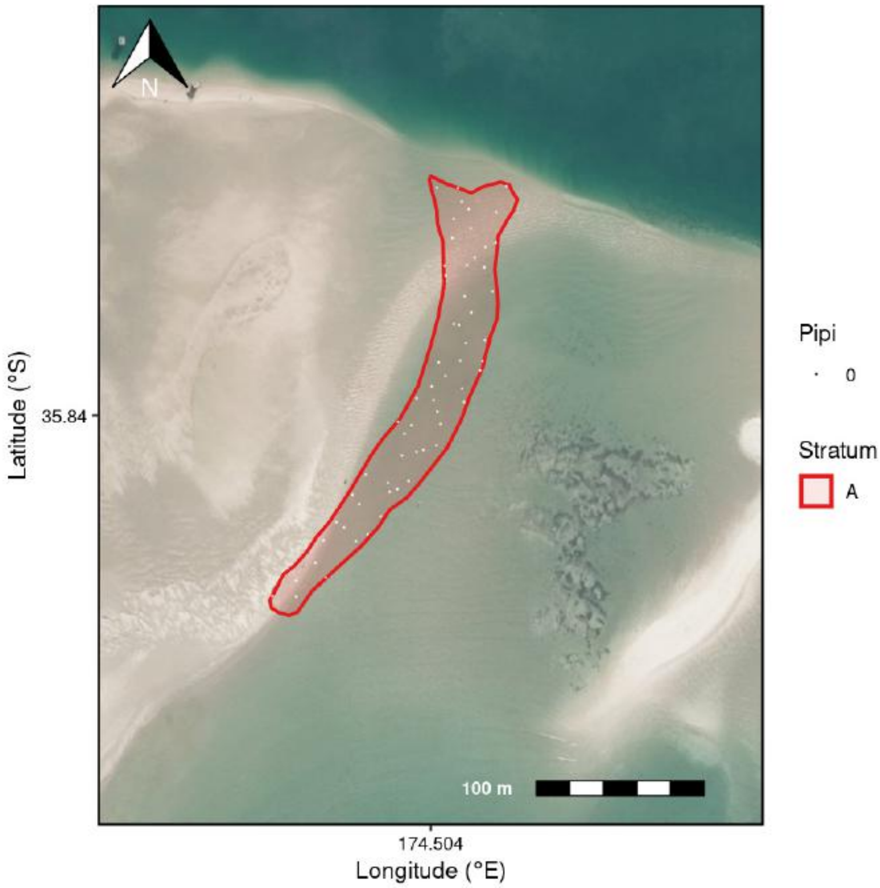


Figure 22: Map of sample strata and individual sample locations for pipi at Marsden Bank, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of pipi abundance at Marsden Bank, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.9	60	0	0.00	0	

Table 20: Estimates of pipi abundance at Marsden Bank for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	11.5	210.88	1 833	20.28	8.00	69	41.49
2012–13	6.3	60.53	959	19.79	0.00	0	
2013–14	15.4	3.88	25	51.70	0.00	0	
2017–18	0.9	10.93	1 284	19.17	0.00	0	
2021–22	0.9	0.00	0		0.00	0	

Table 21: Summary statistics of the length-frequency (LF) distribution of pipi at Marsden Bank. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2013–14	16.18	9	6–40	69.10	0.00
2017–18	26.47	32	8–47	22.52	0.00

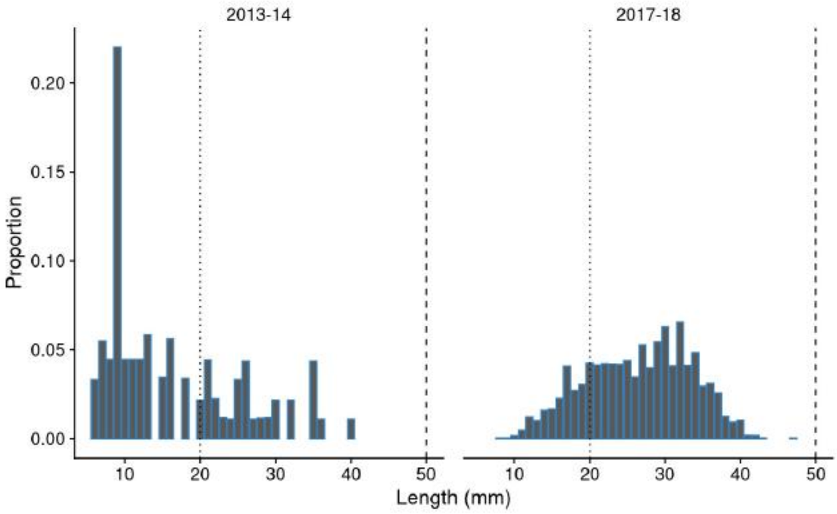


Figure 23: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Marsden Bank. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Mill Bay

Mill Bay is a small bay in Manukau Harbour, consisting of a sheltered tidal sandflat close to the harbour entrance. Bivalve monitoring surveys at this site started in 1999–2000, with ten subsequent surveys since then, including the current assessment (see Appendix A, Tables A-1, A-2). The field sampling at Mill Bay has been consistently within the same sampling extent throughout the survey series, covering most of the bay. The surveys assess the population of cockles only, because there is no discernible pipi population at this site. In 2021–22, the sampling design was based on four strata and a total of 82 sampling points.

The most recent previous survey was in 2018–19. It was conducted a year after the population assessment in 2017–18 which had coincided with a significant mortality event, evident in large numbers of recently-dead and moribund cockles. The current field sampling collected some decaying and anoxic cockles, but these recently-dead individuals were scarce.

Sediment characteristics at Mill Bay included a low organic content ($<$5.5%), with most of the sediment consisting of fine to coarse sand fractions (grain sizes $>$125 to $>$500 µm) (Figure 24, and see details in Appendix B, Table B-1). There was a varying proportion of sediment fines (grain size $<$63 µm), ranging from 3 to 13% across samples.

Cockles occurred throughout the sampling extent at Mill Bay but were mostly in the mid-intertidal area, in parts of stratum B and in stratum D (Figure 25, Table 22). The 2021–22 total population estimates were 46.68 million (CV: 12.00%) cockles and a mean density of 964 cockles per m^2 (Table 23). These estimates were the highest estimates throughout the survey series and documented a substantial increase (doubling) of the population between the preceding survey in 2018–19 and the current assessment. Nevertheless, there were few large cockles ($\geq$30 mm shell length) within the population, with current estimates for this size class of 0.29 million individuals and a mean density of six large cockles per m^2. The uncertainty associated with these estimates was high, with a CV of 37.80%.

In contrast to large cockles, recruits ($\leq$15 mm shell length) made up 64.00% of the population in 2021–22, shifting the single cohort within the modal population below the small size threshold (Table 24, Figure 26). In the two preceding surveys, this size class made up 31.00% (2017–18) and 43.80% (2018–19) of the total population, highlighting its consistent influence on the total population. In 2021–22, the strong influx of recruits largely determined the observed increase in the cockle population. At the same time, the size class of medium-sized cockles diminished. The prevalence of recruits was also evident in current mean and modal sizes of 14.14 mm and 13 mm shell length.

In relation to sediment grain size fractions, total cockle abundance tended to be higher in finer sediment, compared with coarse sand and gravel (Figure 27). The abundance of large individuals showed a similar pattern, even thought this size class was generally small.

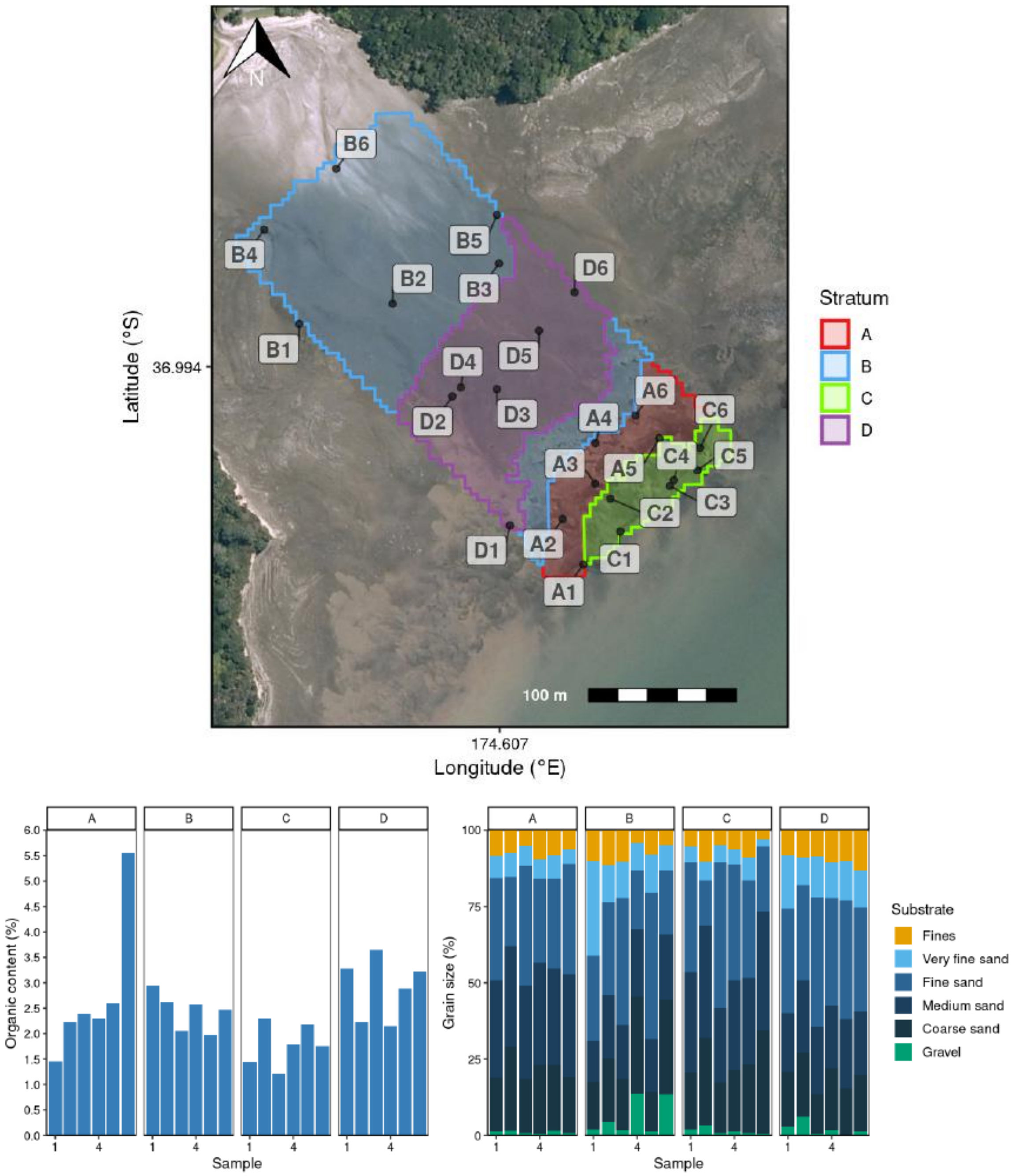


Figure 24: Sediment sample locations and characteristics at Mill Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.6.1 Cockles at Mill Bay

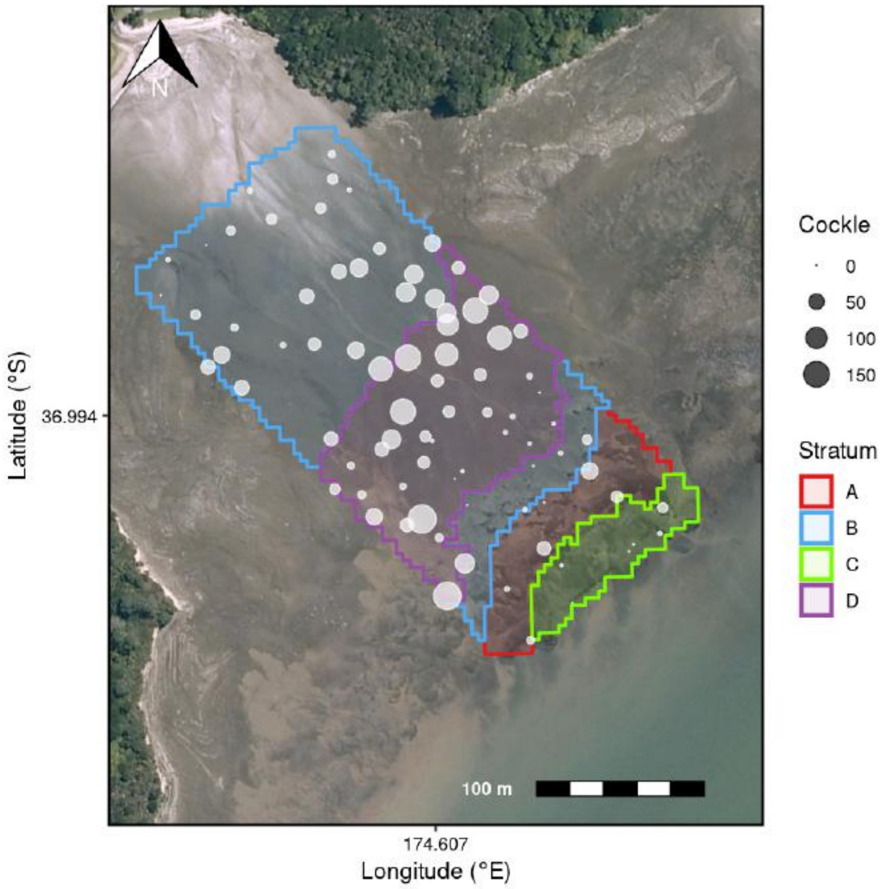


Figure 25: Map of sample strata and individual sample locations for cockles at Mill Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of cockle abundance at Mill Bay, by stratum, for 2021–22. 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	0.5	6	133	3.36	633	41.55
B	2.5	35	1 145	23.26	935	16.39
C	0.4	6	20	0.36	95	82.58
D	1.4	35	1 667	19.70	1 361	19.53

Table 23: Estimates of cockle abundance at Mill Bay for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	4.6	4.91	107	7.87	0.74	16	12.06
2000–01	4.8	10.24	213	6.32	1.23	26	9.50
2001–02	4.5	5.21	116	6.89	0.38	8	13.26
2003–04	4.5	5.33	118	7.69	0.32	7	14.64
2004–05	4.5	4.23	94	7.30	0.30	7	14.45
2005–06	4.5	6.72	149	6.66	0.39	9	11.89
2009–10	5.0	11.31	229	8.92	0.18	4	31.80
2014–15	4.9	16.66	342	9.56	0.07	1	42.43
2017–18	4.9	7.78	160	25.18	0.21	4	41.00
2018–19	4.9	23.04	475	14.68	0.67	14	20.30
2021–22	4.8	46.68	964	12.00	0.29	6	37.80

Table 24: 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 (%)
2017–18	18.02	17	6–33	31.00	2.67
2018–19	17.37	14	5–35	43.80	2.90
2021–22	14.14	13	5–32	64.00	0.62

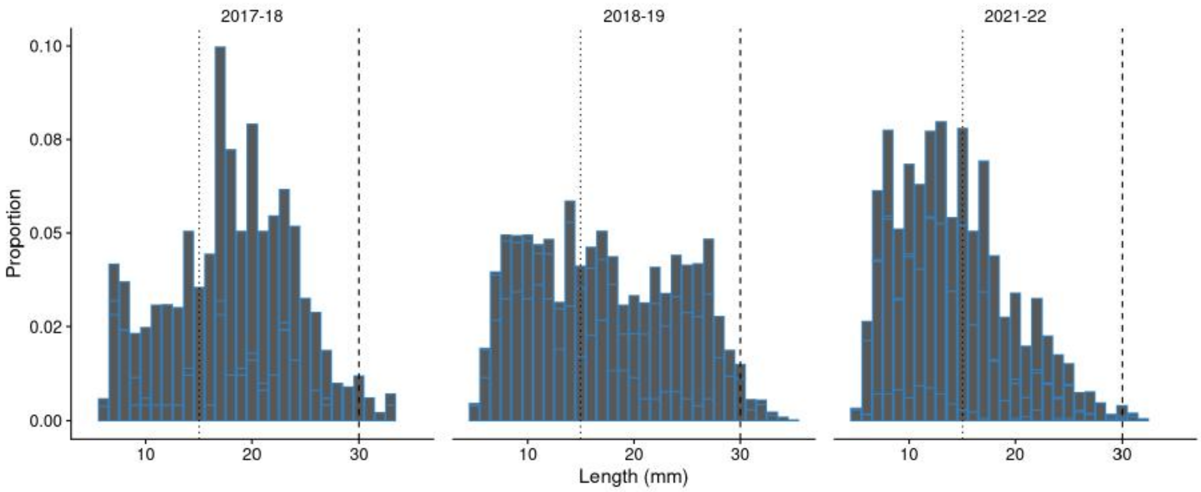


Figure 26: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mill Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

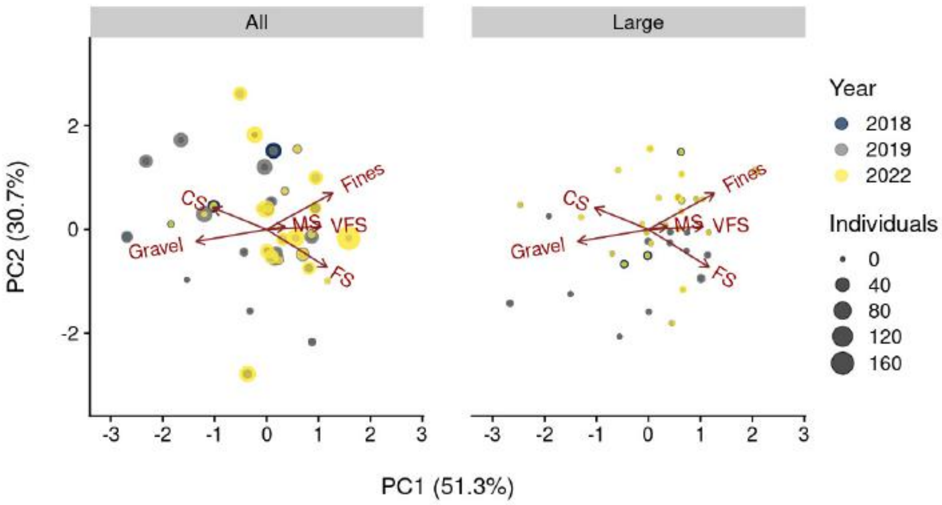


Figure 27: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Mill Bay. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.7 Ngunguru Estuary

Ngunguru Estuary is on Northland's east coast, near Whangārei. The estuary has been closed to the collection of cockles and pipi since January 2016 (Department of Internal Affairs 2015a). Starting in 2009–10, there have been seven bivalve surveys in this estuary, including the present assessment in 2021–22 (see Appendix A, Tables A-1, A-2). Throughout this period, the sampling extent has remained similar in recent assessments, i.e., since 2014–15. Population estimates here were based on the field sampling of 100 points across four separate strata, which included one pipi stratum.

The sampling documented a low sediment organic content of less than 3% across all samples in the cockle strata (Figure 28, and see details in Appendix B, Table B-1). The sediment grain size composition was dominated by fine sand (grain size >125 µm), and other grain size fractions made up only small proportions overall. Sediment fines (grain size <63 µm) varied between 0.5 and 5% of the sediment across samples.

Cockles occurred throughout all strata but were only in the high-intertidal section of the pipi bed in stratum D (Figure 29, Table 25). Their estimated total abundance was 112.60 million (CV: 12.24%) cockles, and they occurred at an average density of 1774 cockles per m^2 (Table 26). There was a comparatively small number of large cockles (≥30 mm shell length) included in the population, with 0.72 million (CV: 46.61%) individuals in this size class; their density was 11 large cockle per m^2. The small number of large individuals meant that this size class represented only a minor proportion (0.61%) of the cockle population (Table 27, Figure 30). In comparison, recruits (≤15 mm shell length) made up 26.39% of the current population, with medium-sized cockles dominating the population size structure.

Considering abundance and density estimates throughout the survey series, there was a steady increase in the cockle population excepting the current assessment, which indicated a decrease compared with preceding estimates in 2018–19 (Table 26). Nevertheless, the high estimates in the latter survey were related to a strong size class of recruits, with 42.75% of all individuals at shell lengths of less than 15 mm (Table 27). This aspect was also evident in the length-frequency distributions of the three most recent surveys, which showed a consistently single cohort of medium-sized cockles, including in 2021–22. The reduction in recruits was reflected in a small increase in mean and modal sizes to 18.35 mm and 17 mm shell length, respectively.

There was no clear pattern in cockle abundance in relation to sediment grain size fractions, as evident in the principal component analysis (Figure 31).

The pipi population at Ngunguru Estuary was concentrated in stratum D, with few individuals in the other strata (Figure 32, Table 28). Based on the field data, estimates derived for this species were a total of 34.54 million (CV: 9.81%) pipi and a density of 544 pipi per m^2 (Table 29). Included in the population were 2.74 million (CV: 21.58%) large individuals (≥50 mm shell length), and their density was 43 large pipi per m^2. The current estimates for the total population signified a decrease from the preceding survey in 2018–19, but they were still relatively high compared with other previous surveys. Furthermore, the estimates for large pipi corresponded with a recent increase in this size class.

This increase was also evident in its contribution to the total population, which increased from 0.94% in 2018–19 to 7.93% of individuals in 2021–22 (Table 30). Overall, the current pipi population continued to be dominated by medium-sized pipi, although a significant proportion of recruits (≤20 mm shell length) in 2018–19 and 2021–22 (33.19% and 40.49%) strongly influenced the population estimates and size structure (Figure 33). In 2021–22, the decline in medium-sized pipi reduced the strength of their cohort, while the large size class of recruits formed a second cohort, leading to a bimodal population, at a modal size of 14 mm.

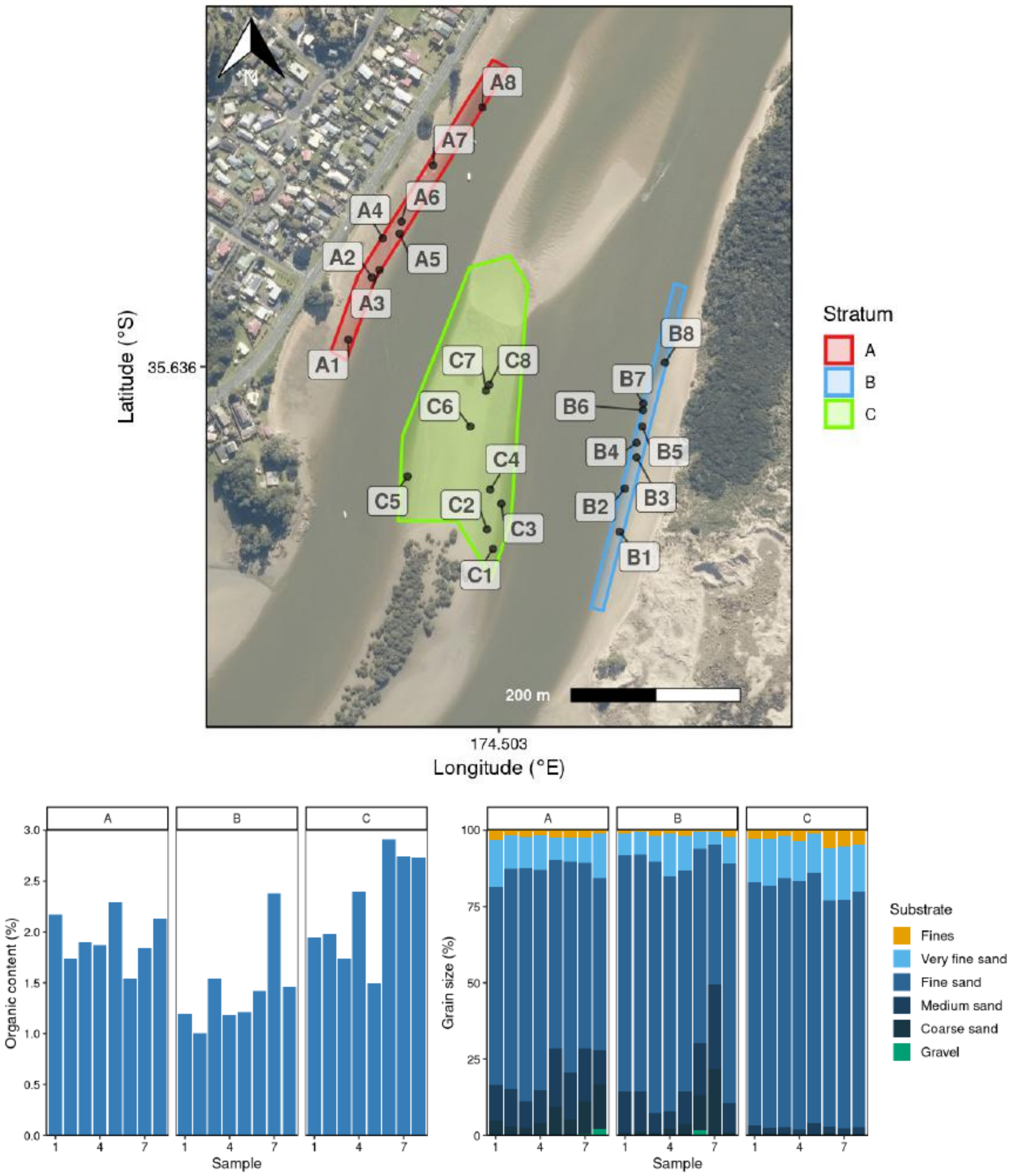


Figure 28: Sediment sample locations and characteristics at Ngunguru Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine,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

3.7.1 Cockles at Ngunguru Estuary

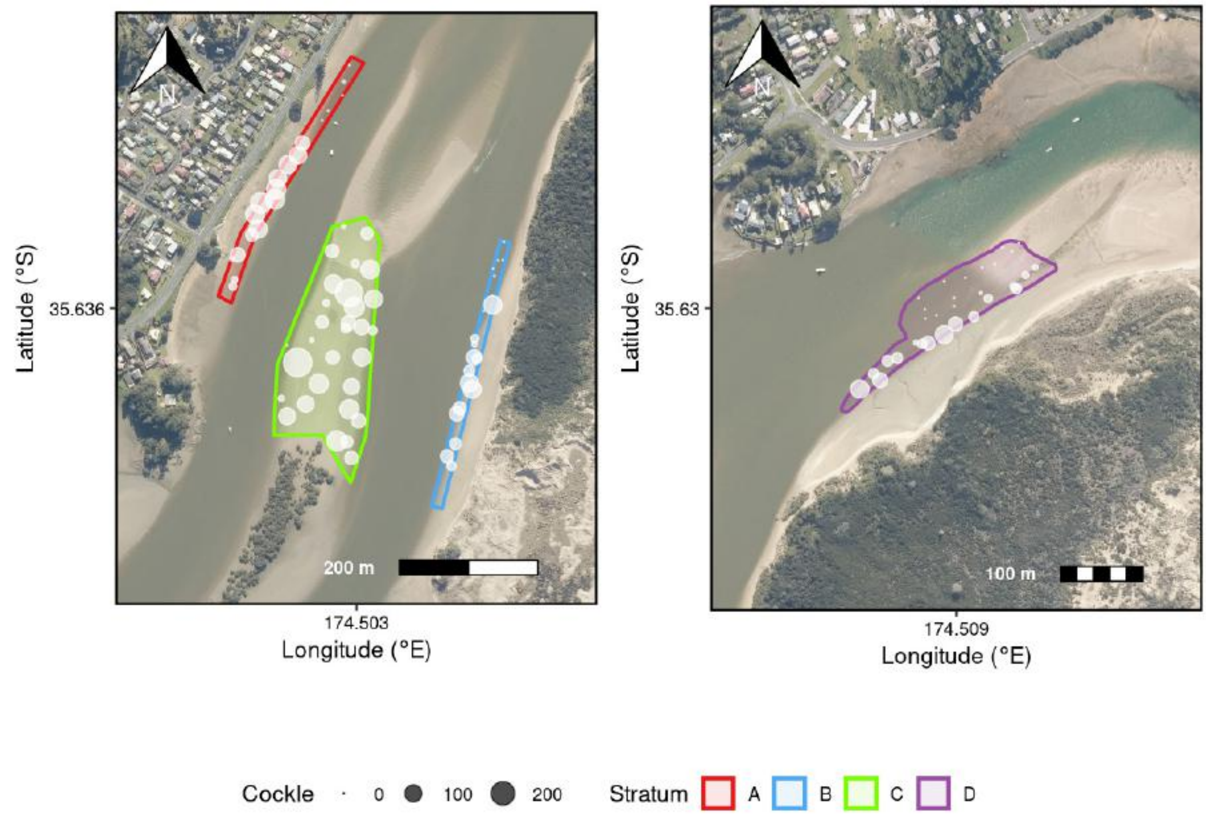


Figure 29: Map of sample strata and individual sample locations for cockles at Ngunguru Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Ngunguru Estuary, by stratum, for 2021–22. 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	1 174	13.37	1 677	21.38
B	0.6	20	742	6.20	1 060	24.75
C	3.6	30	2 435	84.58	2 319	15.61
D	1.3	30	673	8.45	641	26.33

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	8.63	508	6.71	0.64	38	11.70
2004–05	1.8	9.79	544	7.77	0.34	19	18.85
2010–11	1.8	19.55	1 086	10.72	0.07	4	35.49
2014–15	5.5	92.67	1 696	7.53	0.38	7	32.11
2016–17	6.3	91.81	1 461	7.19	0.22	3	48.15
2018–19	6.5	129.23	1 997	6.57	0.28	4	51.20
2021–22	6.3	112.60	1 774	12.24	0.72	11	46.61

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 (%)
2016–17	17.88	20	4–34	27.30	0.24
2018–19	16.52	15	4–45	42.75	0.22
2021–22	18.35	17	5–34	26.39	0.61

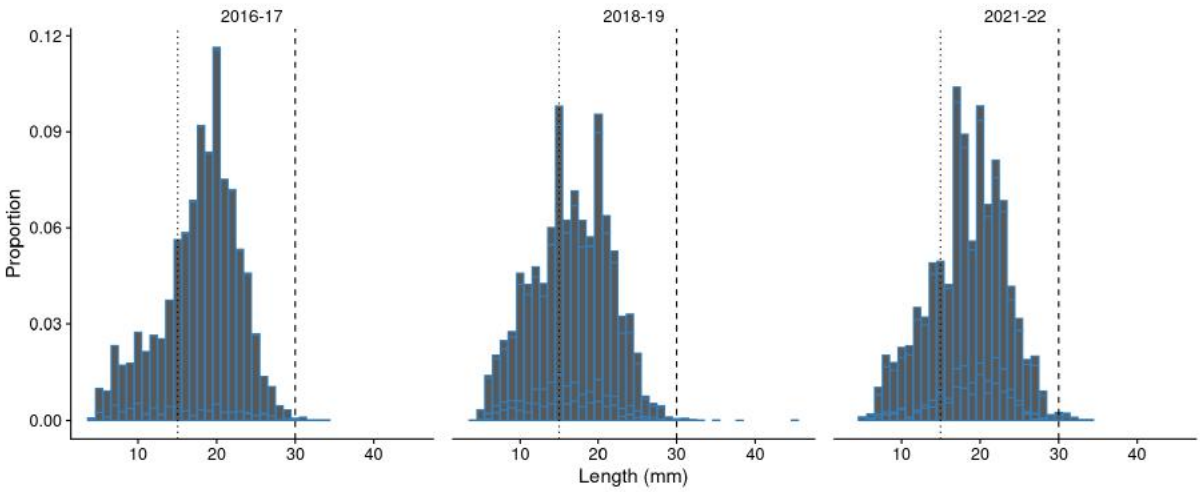


Figure 30: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

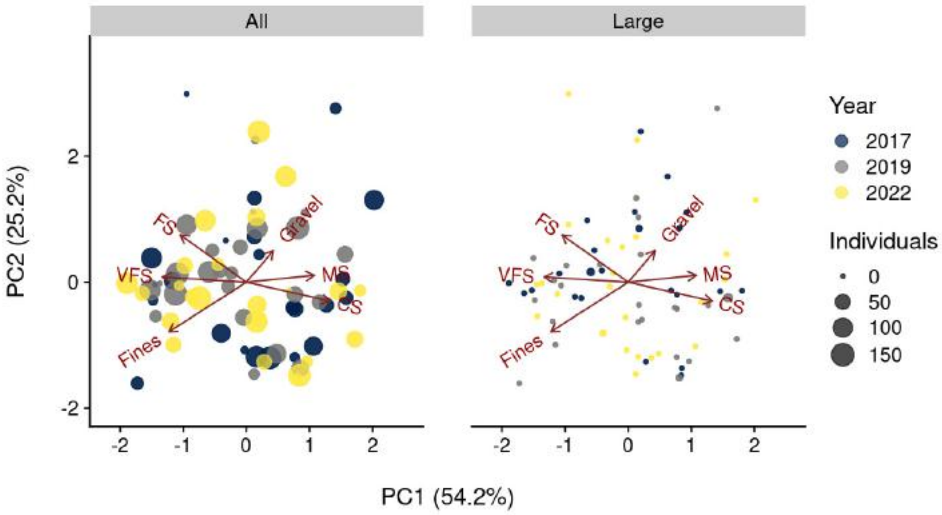


Figure 31: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Ngunguru Estuary. Sediment grain size fractions are defined as fines (silt and clay) <63 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.

3.7.2 Pipi at Ngunguru Estuary

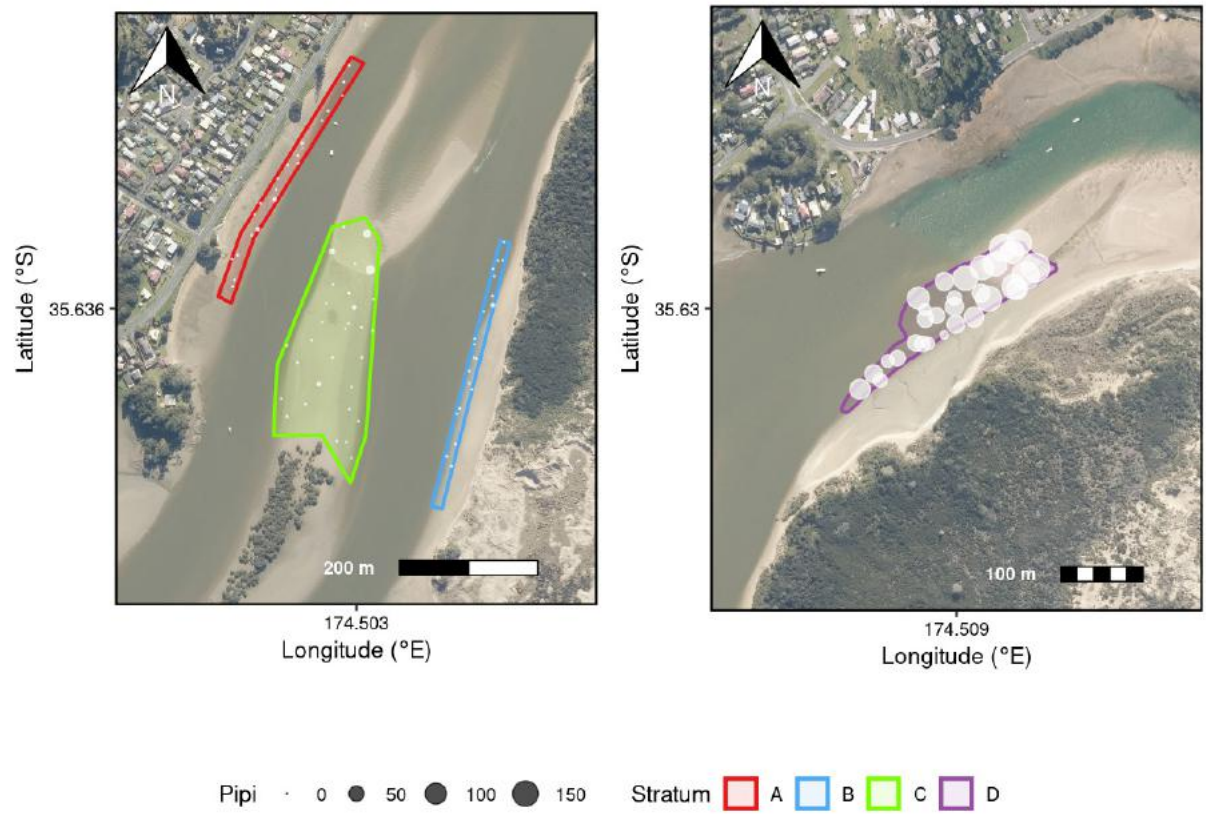


Figure 32: Map of sample strata and individual sample locations for pipi at Ngunguru Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Ngunguru Estuary, by stratum, for 2021–22. 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	2	0.02	3	68.82
B	0.6	20	1	0.01	1	>100
C	3.6	30	20	0.69	19	54.46
D	1.3	30	2 692	33.81	2 564	9.96

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	1.87	110	8.73	0.87	51	9.04
2004–05	1.8	2.23	124	5.37	0.95	53	7.83
2010–11	1.8	0.73	40	16.60	0.25	14	19.25
2014–15	5.5	0.74	14	34.26	0.00	0	
2016–17	6.3	28.43	453	6.03	0.23	4	31.61
2018–19	6.5	42.39	655	11.76	0.40	6	43.99
2021–22	6.3	34.54	544	9.81	2.74	43	21.58

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 (%)
2016–17	38.61	42	4–56	7.72	0.79
2018–19	26.75	18	6–53	33.19	0.94
2021–22	29.79	14	7–59	40.49	7.93

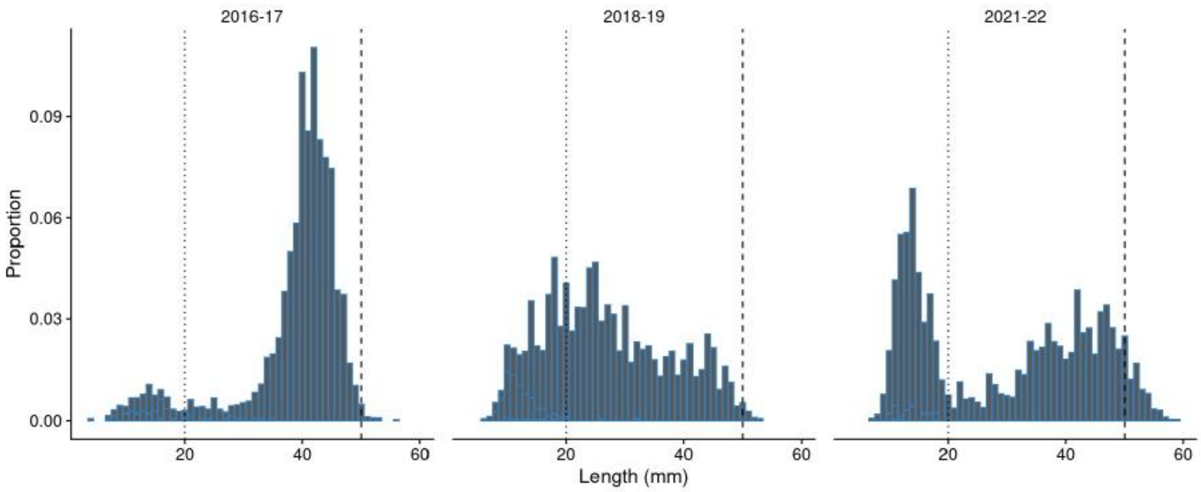


Figure 33: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Pataua Estuary

Pataua Estuary is a small Northland estuary, just north of Whangārei. The northern bivalve surveys first included the estuary in 2002–03, and there have been eight assessments in the survey series to date (see Appendix A, Tables A-1, A-2). The survey area encompassed an extensive intertidal sandflat, intersected by the estuary channel, and a separate pipi bed in the lower estuary, associated with the channel. Apart from some variation in the extent and size of the pipi bed, the field surveys have focused on the same sampling extent since 2013–14. The sampling effort in 2021–22 was spread across three strata, with a total of 99 sampling points, including nine points in phase 2.

Sediment in the cockle strata was low in organic content (1 to 3%), with a varying proportions of sediment fines (up to 8.3%; grain size <63 µm) (Figure 34, and see details in Appendix B, Table B-1). Most of the sediment was fine sand (grain size >250 µm), but some of the samples contained over 30% of different coarser grain size fractions, including gravel (grain size >2000 µm).

The cockle population in the estuary was restricted to the intertidal sandflat area, in strata A and B (Figure 35, Table 31). Their population consisted of an estimated 356.31 million (CV: 12.83%) cockles, and their average density was estimated at 1278 cockles per m^2 (Table 32). Large individuals (≥30 mm shell length) were scarce in the population, with a low estimated abundance of 2.25 million (CV: 50.01%) individuals; their average density was eight large cockles per m^2. This size class has been small since 2013–14, with ongoing decreases since then.

In contrast to the small proportion (0.63%) of large cockles, recruits (≤15 mm shell length) contributed about a third (31.59%) of all individuals in 2021–22, similar to the two preceding surveys (Table 33, Figure 36). Together with medium-sized cockles, this size class consistently formed a single cohort, with uniform mean and modal sizes of 17 to 18 mm shell length since 2017–18. In each of these recent surveys, strong recruitment events augmented the relatively stable population of medium-sized cockles, but the latter individuals failed to grow to larger sizes beyond the 30 mm threshold. At the same time, decreases in the number of medium-sized cockles led to the overall population declines, documented for this population since 2017–18.

Exploring the relationship between cockle abundance and sediment grain sizes showed no clear pattern for any particular grain size fraction, although the principal component analysis showed a relatively lower total cockle abundance associated with gravel (Figure 37).

Pipi at Pataua Estuary were distributed throughout stratum D but concentrated in its central intertidal area (Figure 38, Table 34). Abundance and density estimates for the total population were 3.53 million pipi and 13 pipi per m^2, with a relatively high CV of 23.14% (Table 35). The current estimates were markedly lower than estimates in 2019–20 (9.45 million pipi at a density of 34 pipi per m^2; CV: 18.50%); however, this population was characterised by notable fluctuations in earlier surveys also. The population of large pipi (≥50 mm shell length) fluctuated also, with a recent increase to 0.23 million (CV: 35.33%) large individuals, following a decline in the preceding survey. Nevertheless, their density remained consistently low; e.g., it was <1 large pipi per m^2 in recent assessments (generally with high CV values of >50%). The recent population fluctuations were not explained by varying recruitment, even though the proportion of recruits (≤20 mm shell length) varied considerably across recent surveys (Table 36, Figure 39). For example, the small total population size in 2021–22 coincided with 24.56% of recruits in the total population, compared with 8.16% in 2019–20 (when total abundance was 9.45 million pipi; CV: 18.50%). Within the same period, the proportion of large pipi, albeit small, increased from 0.48% to 6.44%. These findings confirm the consistent influence of medium-sized pipi, which largely determined changes in the population estimates. In 2021–22, the decline of medium-sized pipi was also evident in the population size structure, which shifted from a unimodal population dominated by this size class in 2019–20 to a bimodal population, with a second cohort of recruits. At the same time, the cohort of medium-sized pipi was markedly smaller, although mean and modal sizes remained similar at 33.20 mm and 37 mm shell length.

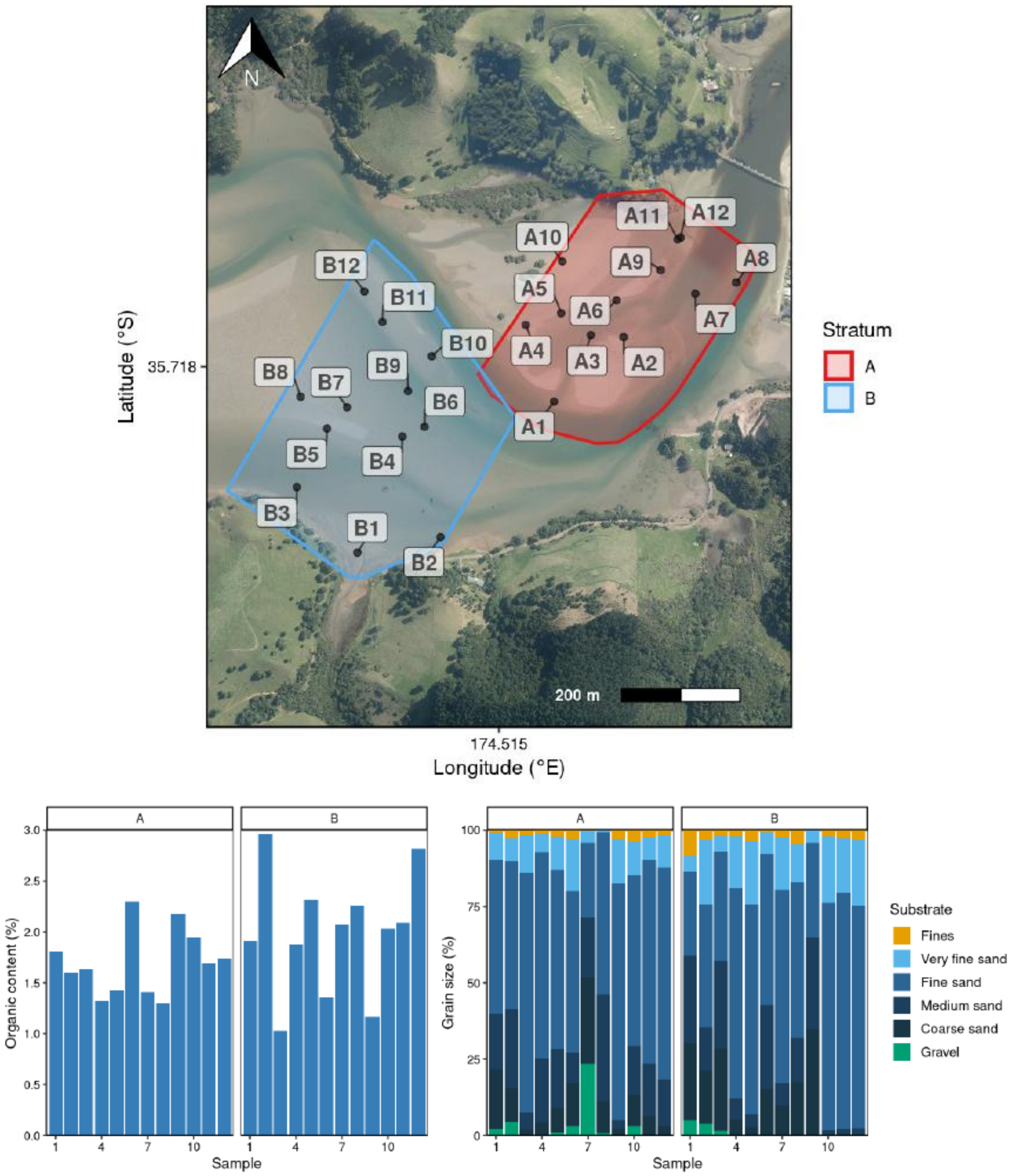


Figure 34: Sediment sample locations and characteristics at Pataua Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.8.1 Cockles at Pataua Estuary

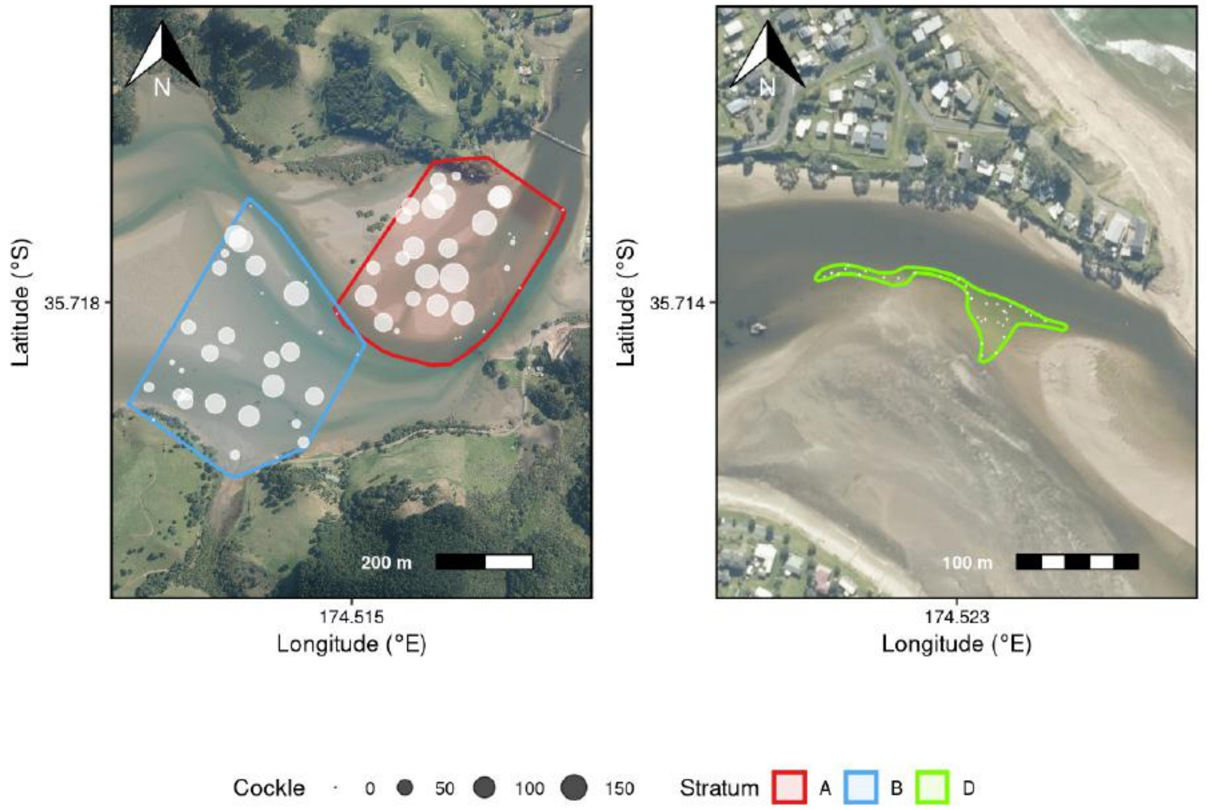


Figure 35: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	12.3	33	1 767	187.73	1 530	17.88
B	15.3	33	1 270	168.57	1 100	18.42
D	0.3	33	0	0.00	0	

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	88.64	832	4.45	21.63	203	6.94
2003–04	10.4	123.54	1 182	3.02	13.56	130	8.90
2005–06	10.4	108.08	1 034	5.18	19.87	190	7.57
2013–14	26.3	410.54	1 561	5.30	6.54	25	15.94
2015–16	27.8	380.13	1 368	7.58	4.89	18	29.68
2017–18	27.7	406.39	1 467	11.78	4.54	16	44.37
2019–20	27.9	362.52	1 299	12.71	3.96	14	44.65
2021–22	27.9	356.31	1 278	12.83	2.25	8	50.01

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	17.73	17	4–35	30.76	1.12
2019–20	18.41	17	5–48	28.48	1.09
2021–22	18.07	17	5–38	31.59	0.63

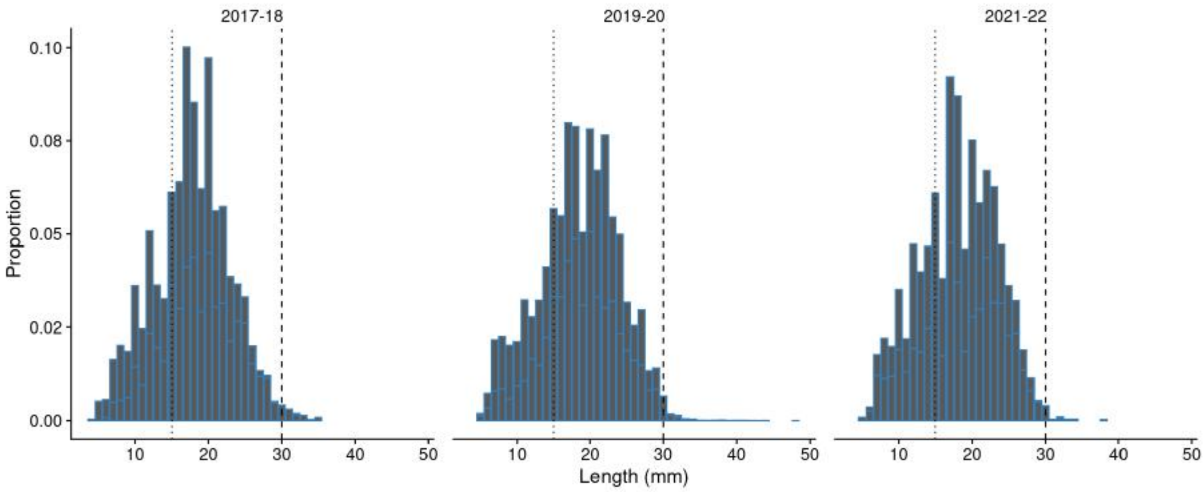


Figure 36: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

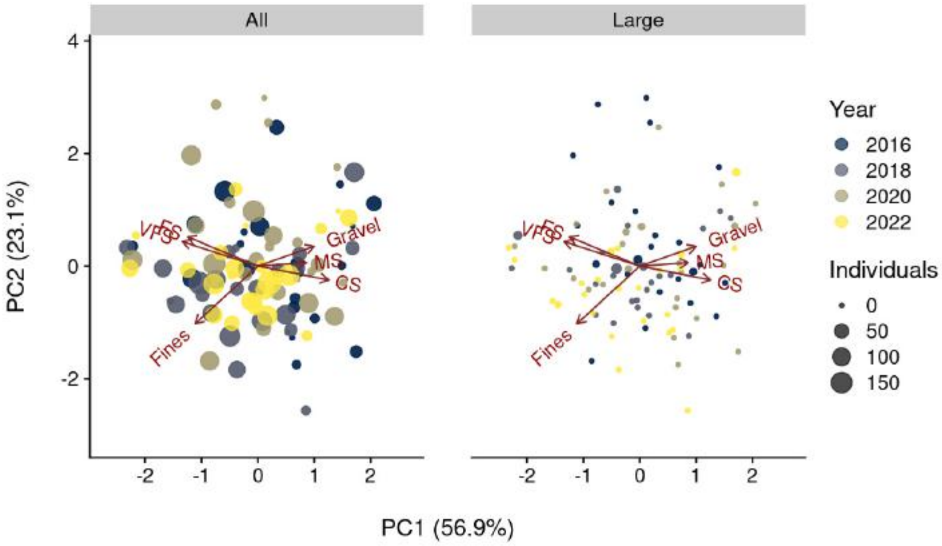


Figure 37: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Pataua Estuary. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.8.2 Pipi at Pataua Estuary

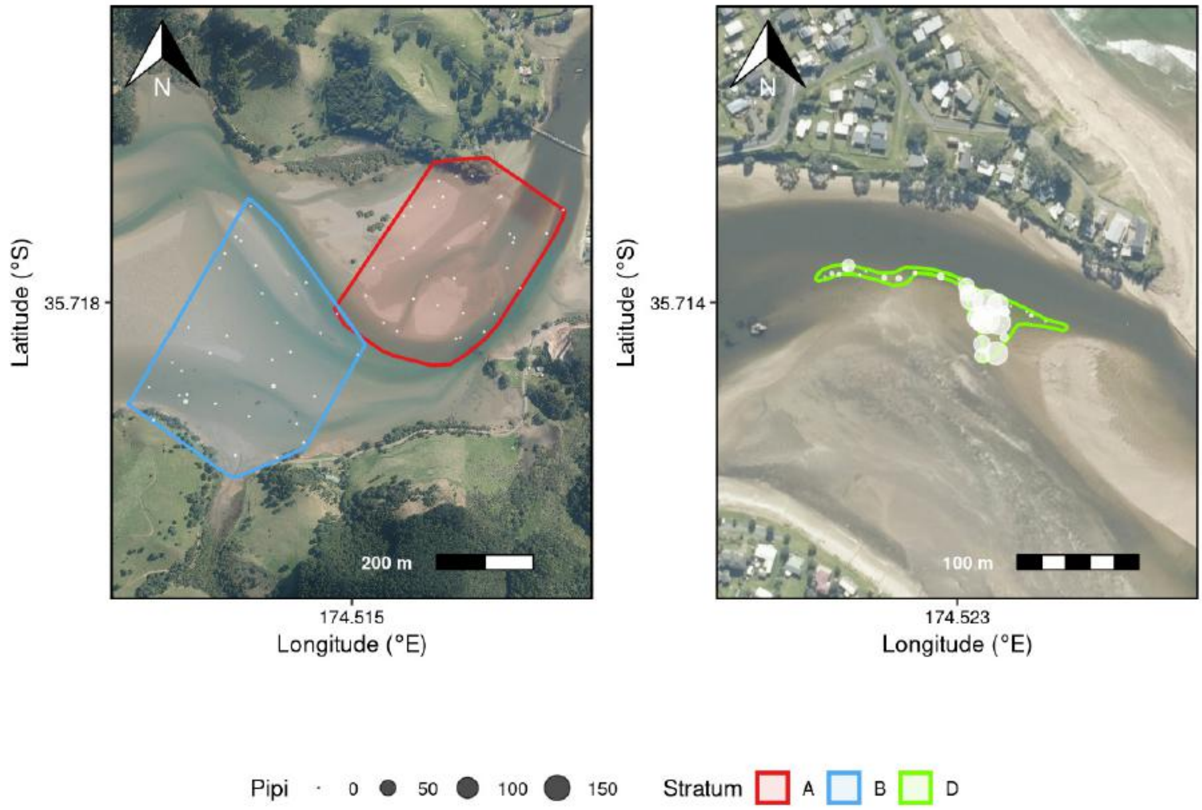


Figure 38: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	12.3	33	0	0.00	0	
B	15.3	33	2	0.27	2	69.60
D	0.3	33	1 349	3.27	1 168	24.37

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	16.58	156	14.00	0.02	<1	>100
2003–04	10.4	2.21	21	11.72	0.43	4	7.94
2005–06	10.4	1.18	11	9.73	0.45	4	32.47
2013–14	26.3	7.52	29	17.28	0.47	2	60.35
2015–16	27.8	6.45	23	14.67	0.19	<1	79.86
2017–18	27.7	2.04	7	35.38	0.19	<1	>100
2019–20	27.9	9.45	34	18.50	0.05	<1	52.35
2021–22	27.9	3.53	13	23.14	0.23	<1	35.33

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	28.17	15	11–59	30.87	9.24
2019–20	34.82	38	8–60	8.16	0.48
2021–22	33.20	37	8–58	24.56	6.44

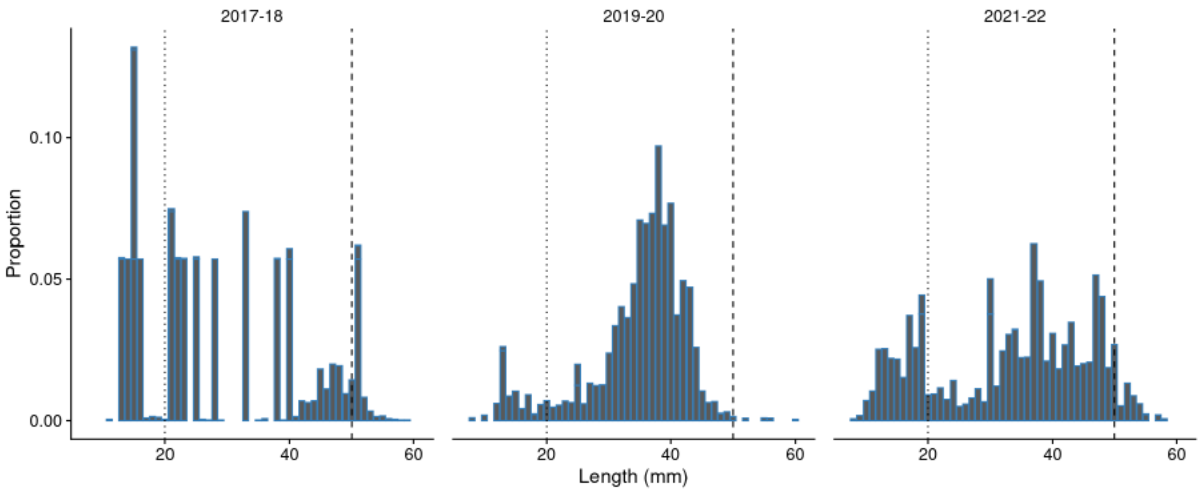


Figure 39: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Raglan Harbour

Raglan Harbour is one of the Waikato sites, and was first added to the monitoring series in 1999–2000 (see Appendix A, Tables A-1, A-2). Since then, it has been surveyed ten times, including the current assessment and a survey in 2019–20 immediately preceding it. Since 2014–15, cockles and pipi have been sampled across the same sampling extent in two separate areas, in the lower part of the harbour. Within this sampling extent, there were 90 sampling points in two cockle and one pipi strata in 2021–22.

The sediment had a low organic content of less than 4%, with the proportion of sediment fines (grain size <63 µm) ranging from 2 to 17% (Figure 40, and see details in Appendix B, Table B-1). The sediment was predominantly fine sand (grain size >125 µm), with small proportions of sediment in the remaining grain size fractions.

The cockle population was distributed throughout the two cockle strata, with lower numbers in the pipi bed (Figure 41, Table 37). The overall population estimate for 2021–22 was 115.66 million (CV: 8.25%) cockles. Cockles occurred at an average density of 1579 individuals per m^2 (Table 38). There were few large individuals ($\geq$30 mm shell length) included in the population, with 1.65 million (CV: 26.29%) large cockles in 2021–22; their average density was low at 23 large individuals per m^2. Throughout the survey series, there was some fluctuation in the cockle population and, although the current population estimates reflected a decrease from the preceding estimates in 2019–20, they were within these fluctuations.

Similarly, the proportions of large cockles and of recruits ($\leq$15 mm shell length) remained similar across recent surveys, with 1.43% and 12.23% of the population in these size classes, respectively in 2021–22 (Table 39, Figure 42). The overall population size structure at Raglan Harbour was dominated by medium-sized cockles, which formed a single cohort at a modal size at about 20 mm shell length in the three most recent surveys. Although there was consistent recruitment to this cockle population, there was no discernible trend of medium-sized cockles contributing to the large size class over time.

Principal component analysis showed a shift in cockle abundance from coarse sediment fractions over time (Figure 43). In earlier surveys, total cockle abundance associated with gravel was high; however, this pattern changed in the most recent survey in 2021–22, when high abundance was associated with the coarse to fine sand fractions.

Pipi at Raglan Harbour were concentrated in the pipi bed along the side channel, in stratum C (Figure 44, Table 40). Their current abundance and density estimates were a total of 1.52 million (CV: 15.39%) pipi, and 21 pipi per m^2 (Table 41). Although the current estimates marked an almost 50% decrease from estimates in the immediately preceding survey in 2019–20, they were within the population fluctuations evident at this site in recent survey years (e.g., the current estimates were similar to abundance and density estimates in 2017–18). At the same time, the population of large individuals ($\geq$50 mm shell length) remained similar across surveys, even though this size class was consistently small: in 2021–22, there were an estimated 0.14 million (CV: 18.83%) large pipi, and their average density was 2 large pipi per m^2.

The recent decrease in the total population led to a greater contribution of large individuals to the total population: the proportion of individuals in this size class increased from 3.95% in 2019–20 to 9.26% in 2021–22 (Table 42, Figure 45). At the same time, the proportion of recruits ($\leq$20 mm shell length) remained similar at 12.14%, indicating consistent recruitment at this site. The current influence of large pipi on the population structure was evident in increases in the length-frequency distributions, with increases in mean and modal sizes from 34.12 mm and 32 mm shell lengths in 2019–20 to 40.00 mm and 43 mm shell lengths in 2021–22, respectively. The size increases were evident in the consolidation of a strong pipi cohort at medium sizes that were close to the 50 mm size class threshold.

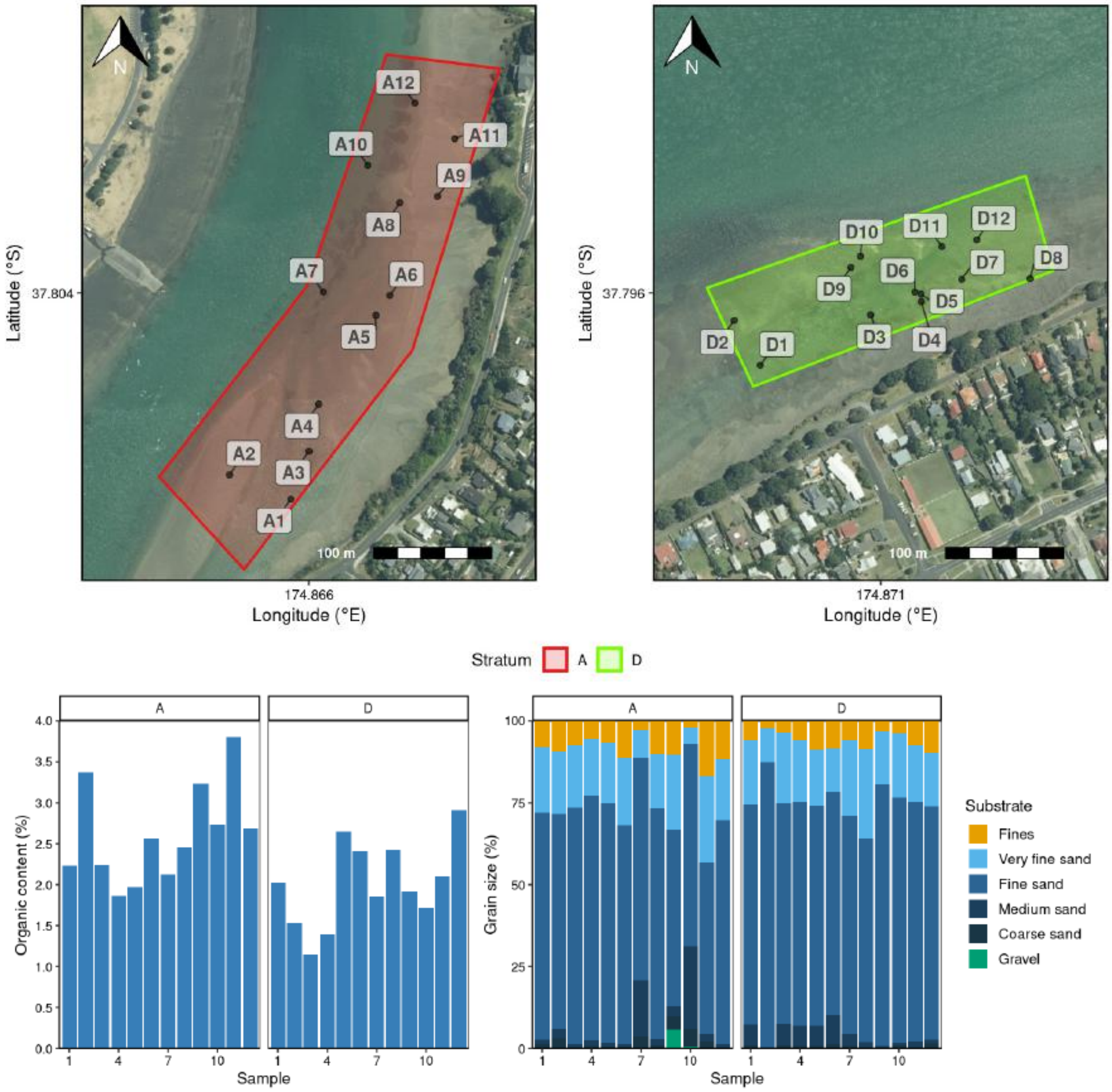


Figure 40: Sediment sample locations and characteristics at Raglan Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.9.1 Cockles at Raglan Harbour

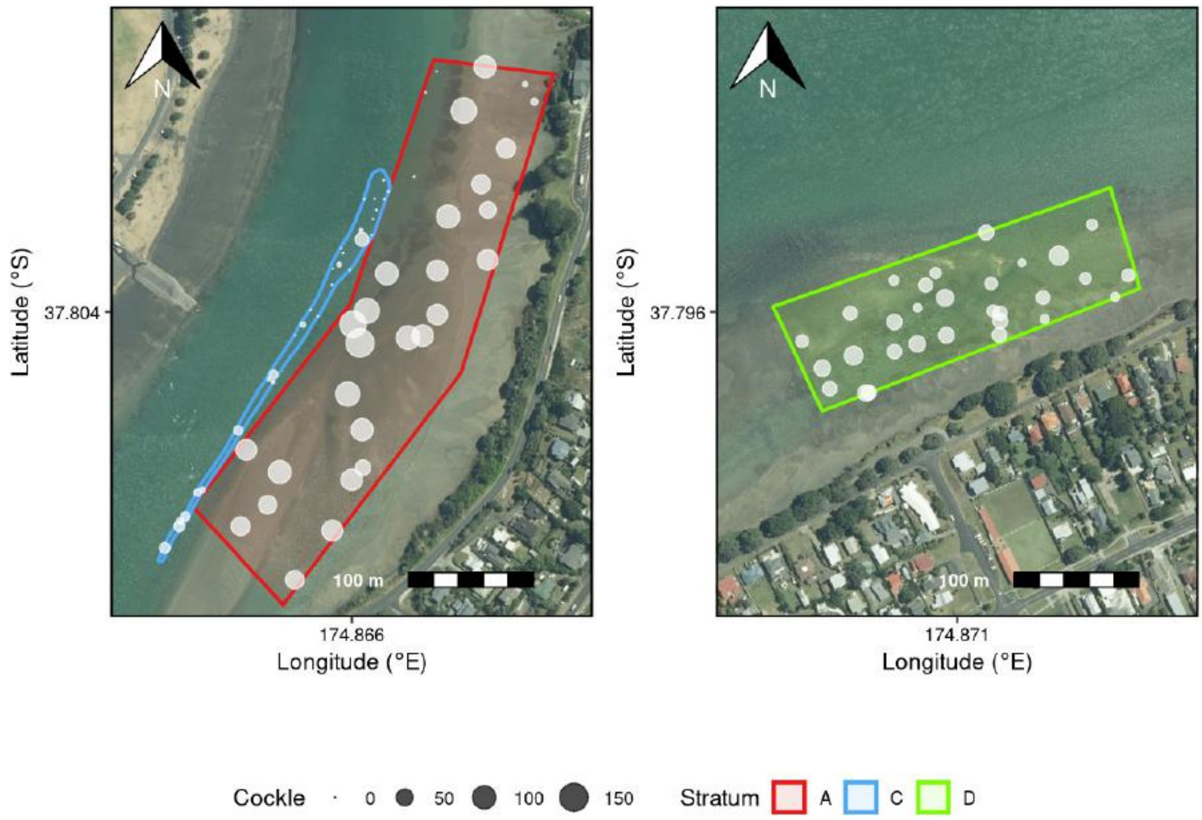


Figure 41: Map of sample strata and individual sample locations for cockles at Raglan Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of cockle abundance at Raglan Harbour, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.6	30	2 142	92.87	2 040	10.07
C	0.3	30	126	0.37	120	31.67
D	2.5	30	955	22.42	910	8.39

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

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.1	184.49	1 827	3.64	6.56	65	12.56
2000–01	10.0	220.43	2 195	3.34	17.28	172	6.50
2002–03	8.2	92.26	1 120	3.78	4.17	51	9.47
2003–04	8.2	89.79	1 090	3.50	3.76	46	7.49
2009–10	9.2	125.59	1 365	5.23	5.90	64	20.79
2012–13	8.2	129.04	1 566	6.84	6.08	74	19.74
2014–15	7.2	109.56	1 513	4.95	2.44	34	15.20
2017–18	7.2	109.16	1 508	7.11	3.21	44	22.20
2019–20	7.4	126.74	1 716	6.07	2.15	29	22.01
2021–22	7.3	115.66	1 579	8.25	1.65	23	26.29

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	19.04	20	4–40	26.08	2.94
2019–20	20.02	20	4–36	17.71	1.70
2021–22	20.69	23	6–37	12.23	1.43

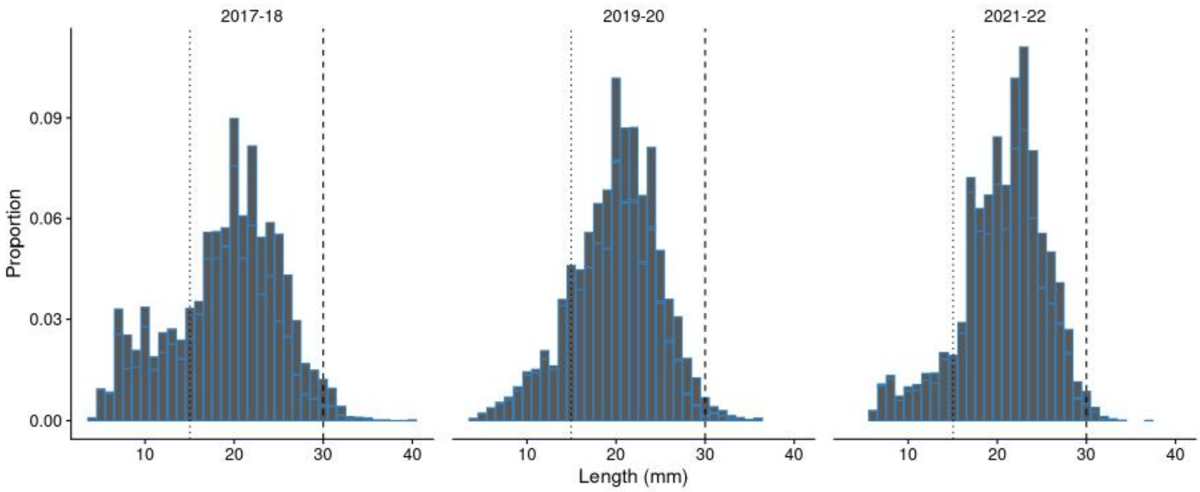


Figure 42: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

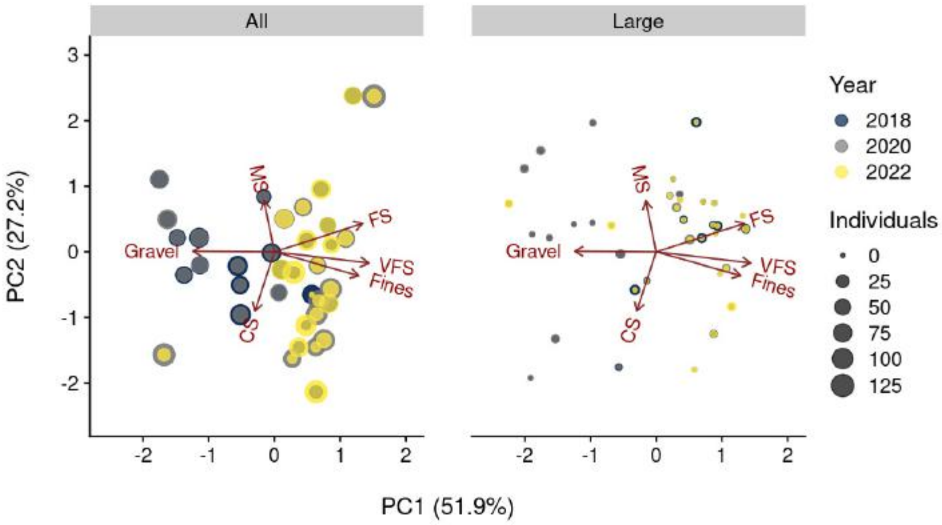


Figure 43: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Raglan Harbour. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.9.2 Pipi at Raglan Harbour

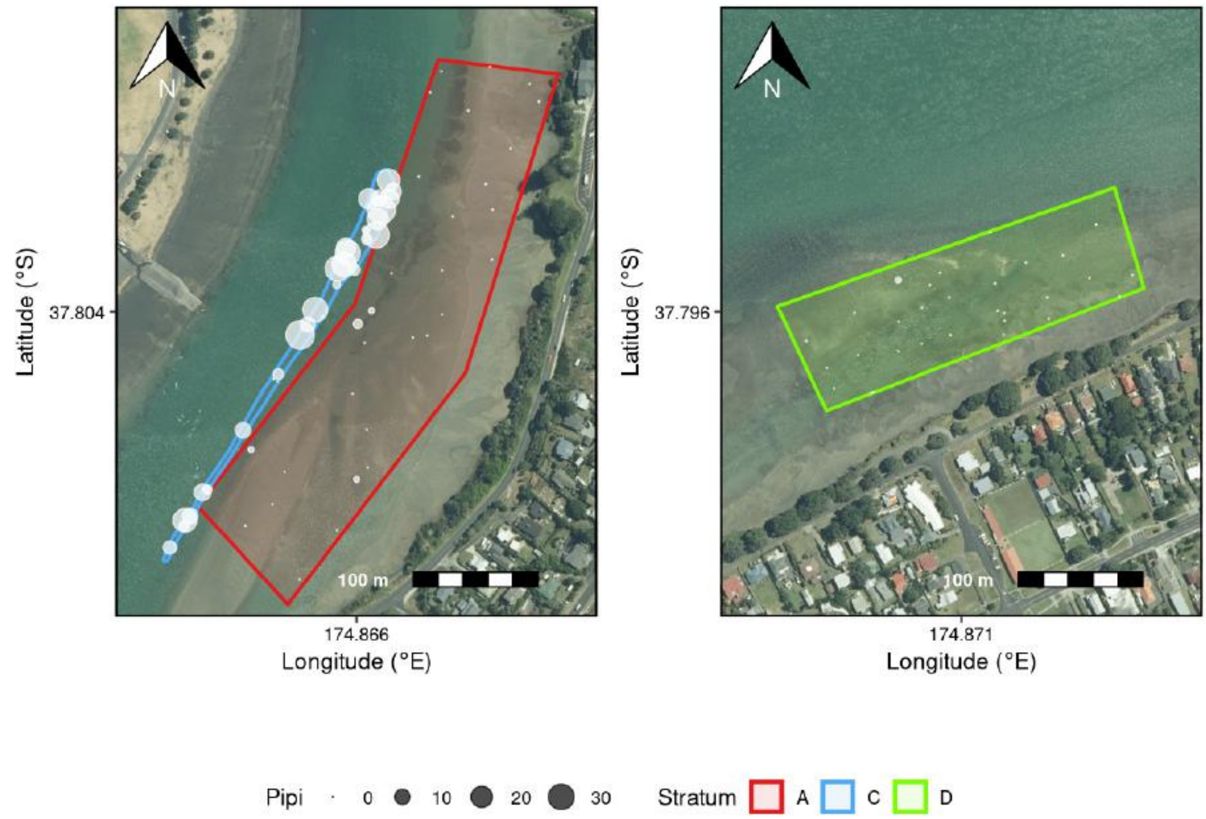


Figure 44: Map of sample strata and individual sample locations for pipi at Raglan Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of pipi abundance at Raglan Harbour, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.6	30	6	0.26	6	55.71
C	0.3	30	427	1.24	407	14.76
D	2.5	30	1	0.02	<1	>100

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.1	0.31	3	15.14	0.00	0	
2000–01	10.0	1.46	15	11.75	0.23	2	8.33
2002–03	8.2	0.47	6	13.18	0.08	<1	17.69
2003–04	8.2	0.43	5	13.70	0.02	<1	20.92
2009–10	9.2	0.60	7	19.17	0.15	2	12.61
2012–13	8.2	1.78	22	14.51	0.13	2	43.37
2014–15	7.2	2.35	32	15.53	0.14	2	40.45
2017–18	7.2	1.74	24	12.29	0.10	1	24.15
2019–20	7.4	3.03	41	13.52	0.12	2	55.64
2021–22	7.3	1.52	21	15.39	0.14	2	18.83

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	36.07	37	8–56	16.55	5.81
2019–20	34.12	32	10–57	11.09	3.95
2021–22	40.00	43	8–56	12.14	9.26

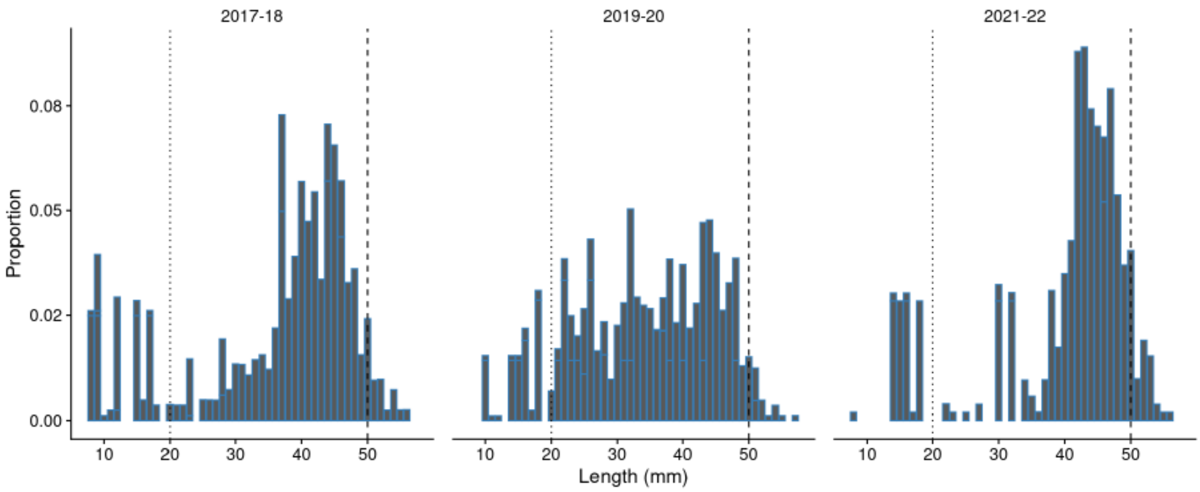


Figure 45: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Ruakākā Estuary

Ruakākā Estuary is in the Northland region, south of Whangārei. There have been six bivalve assessments in this estuary since 2006–07, including the current survey in 2021–22 (see Appendix A, Tables A-1, A-2). Significant changes in the course and size of the main estuary channel have led to changes in the sampling extent throughout the survey series. In 2021–22, the sampling area was similar to that in the preceding survey and consisted of three strata. Bivalves were sampled in a total of 98 points, including eight phase-2 sampling points.

The sediment sampling at this site documented a low organic content of less than 3%, with most of the sediment consisting of fine and medium sand fractions (grain sizes >125 and >250 µm) (Figure 46, and see details in Appendix B, Table B-1). The proportion of sediment fines (grain size <63 µm) was less than 7.5% across all samples.

Cockles were sampled across all three strata, but their distribution was restricted to the upper channel area of the pipi bed in stratum C (Figure 47, Table 43). Their total abundance was estimated at 8.04 million (CV: 25.94%) individuals, marking a substantial increase from the 2018–19 estimate of 3.46 million (CV: 12.25%) cockles (Table 44). Similarly, their density increased from 88 to 197 cockles per m^2 over the same period. Nevertheless, the current estimates had a high CV (>20%), in spite of increased sampling effort, and there were few large individuals (≥30 mm shell length) included in the population. This size class has been consistently scarce across surveys, with high uncertainty around their population estimates, including in 2021–22. Population size data confirmed the general lack of large cockles, with most of the population consisting of medium-sized individuals and a substantial proportion of recruits (≤15 mm shell length) in recent surveys (Table 45, Figure 48). In 2021–22, the latter size class represented 39.42% of the population. The influence of recruits was also evident in recent length-frequency distributions; after contributing to a single cohort of largely medium-sized cockles in 2018–19, recruits formed a second cohort in the current population, although modal length increased by about 6 mm to 23 mm shell length.

In relation to sediment grain sizes, total cockle abundance associated with sand fractions and sediment fines was relatively high in recent surveys but not with gravel (Figure 49).

Pipi at Ruakākā Estuary were sampled in all strata, with their highest abundance and density recorded in the main channel, in stratum C (Figure 50, Table 46). The current population estimates for this species were the highest values in the survey series, with a total of 166.06 million (CV: 14.54%) pipi and a density of 4061 pipi per m^2 in 2021–22 (Table 47). The population contained few large pipi (≥50 mm shell length), and their current estimates of 0.02 million large pipi and <1 large individuals per m^2 had a high uncertainty (CV: >100%). In contrast to large pipi, recruits (≤20 mm shell length), had a strong influence on the population in recent assessments. In 2021–22, the proportion of recruits was 64.21%, reflecting a continued increase from 37.25% in 2016–17 and 51.11% in 2018–19 (Table 48, Figure 51). This influx of recruits led to a recent size shift in length-frequency distributions, from the preceding mode of 15 mm shell length to 12 mm shell length in 2021–22. Although there was some growth of recruits to medium sizes over time, it was insufficient to shift modal sizes above the 15 mm threshold.

In addition to the monitoring surveys by Fisheries New Zealand, Te Patuharakeke Te Iwi Trust Board also assesses the pipi population in Ruakākā Estuary regularly (Shirkey 2019). Their most recent-available survey data from 2019 showed high numbers of pipi throughout the main estuary channel, but large individuals (defined as ≥40 mm and ≥50 mm shell length) were scarce. The population was dominated by small-sized individuals, with a modal length of 21 mm. The overall population estimate was 130 million (CV: 15%) pipi. These findings were similar to the 2018–19 results from the current survey series. Ruakākā Estuary was also part of a habitat mapping project by Northland Regional Council (Griffiths et al. 2019). The intertidal mapping in 2018 identified different bivalve habitats, based on low- and high-density thresholds, but did not provide population estimates. For cockles, there were discrete localised areas of mostly low-density cockles, whereas pipi were on the fringes of the main channel and in small isolated patches in other areas.

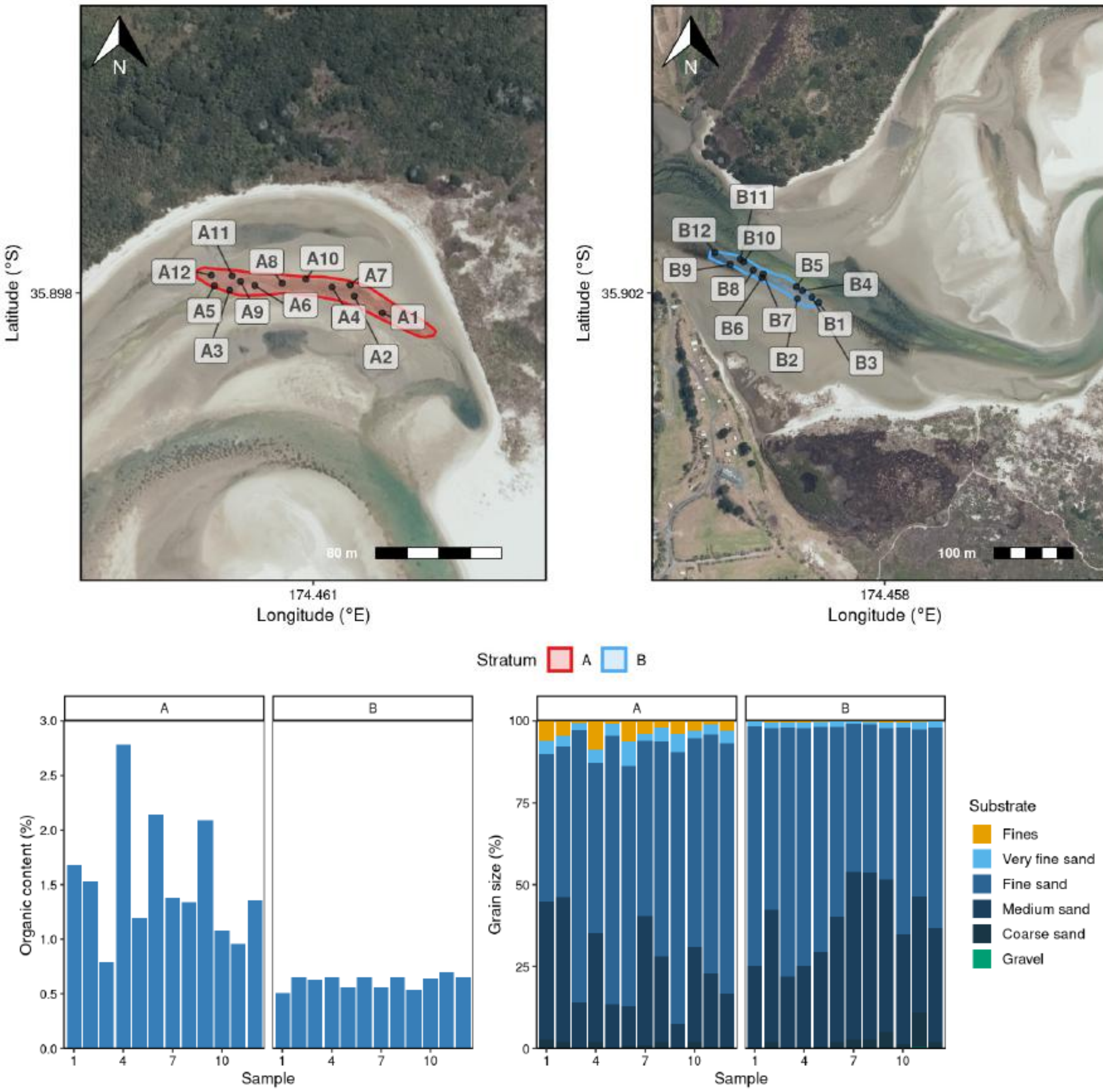


Figure 46: Sediment sample locations and characteristics at Ruakākā Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125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

3.10.1 Cockles at Ruakākā Estuary

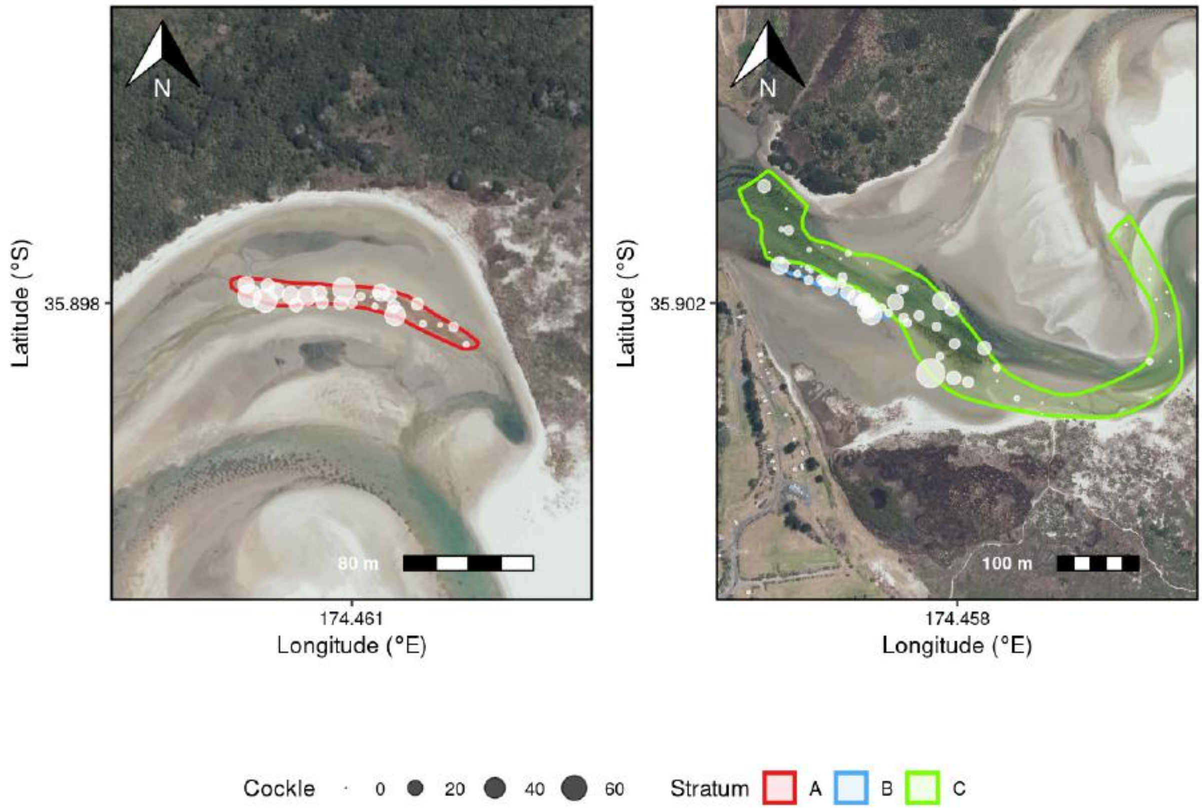


Figure 47: Map of sample strata and individual sample locations for cockles at Ruakākā Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of cockle abundance at Ruakākā Estuary, by stratum, for 2021–22. 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	27	479	0.99	507	17.31
B	0.2	27	258	0.61	273	22.66
C	3.7	44	270	6.44	175	32.21

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2006–07	7.0	1.22	17	16.07	0.23	3	55.99
2010–11	11.0	3.27	30	20.30	0.04	<1	>100
2014–15	6.5	43.97	675	8.77	0.15	2	35.4
2016–17	5.6	13.08	233	18.38	0.00	0	
2018–19	3.9	3.46	88	12.25	0.03	<1	>100
2021–22	4.1	8.04	197	25.94	0.05	1	>100

Table 45: Summary statistics of the length-frequency (LF) distribution of cockles at Ruakākā 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 (%)
2016–17	15.34	20	4–29	52.17	0.00
2018–19	17.22	17	6–32	33.16	0.73
2021–22	17.06	23	5–32	39.42	0.62

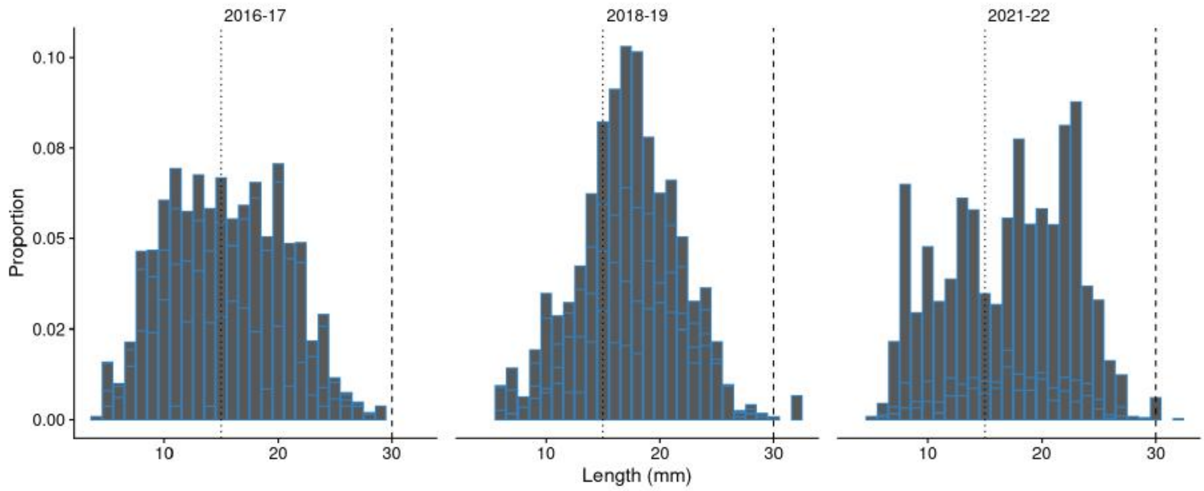


Figure 48: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ruakākā Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

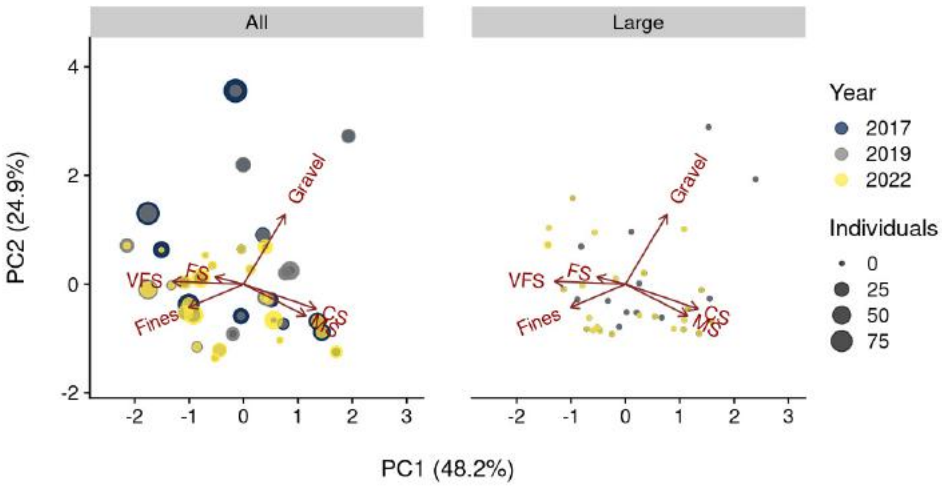


Figure 49: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Ruakākā Estuary. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.10.2 Pipi at Ruakākā Estuary

Figure 50: Map of sample strata and individual sample locations for pipi at Ruakākā 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 Ruakākā Estuary, by stratum, for 2021–22. 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	27	599	1.24	634	22.50
B	0.2	27	457	1.08	484	16.62
C	3.7	44	6 870	163.75	4 461	14.74

Table 47: Estimates of pipi abundance at Ruakākā 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	21	21.28
2010–11	11.0	25.93	235	19.84	0.05	<1	100
2014–15	6.5	81.23	1 247	16.51	0.08	1	83.35
2016–17	5.6	56.53	1 008	30.91	1.12	20	46.67
2018–19	3.9	91.64	2 333	17.84	0.19	5	51.87
2021–22	4.1	166.06	4 061	14.54	0.02	<1	>100

Table 48: Summary statistics of the length-frequency (LF) distribution of pipi at Ruakākā 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 (%)
2016–17	27.29	13	5–55	37.25	1.97
2018–19	21.01	15	7–52	51.11	0.16
2021–22	19.69	12	5–57	64.21	0.01

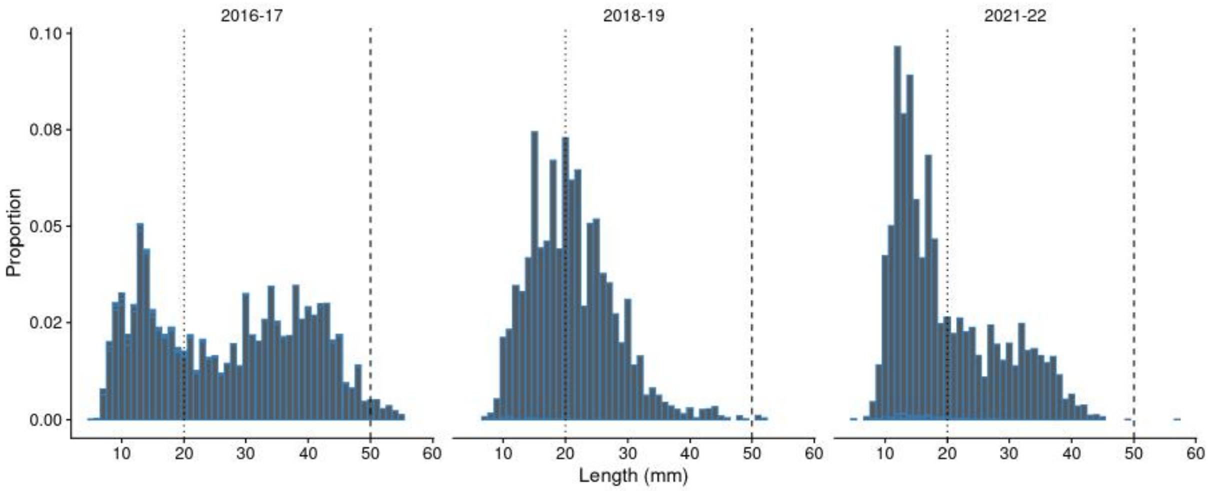


Figure 51: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ruakākā Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Tairua Harbour

Tairua Harbour is part of an extensive estuary system on the east coast of Coromandel Peninsula. There have been frequent bivalve surveys at this site since 1999–2000, with a total of twelve assessments since then (see Appendix A, Tables A-1, A-2). Throughout the survey series, the field sampling has been conducted in the lower part of the harbour, across separate strata north and south of the main channel. Variation in the sampling extent over time was related to changes in the location and size of pipi beds, particularly in the area close to the harbour entrance. In 2021–22, cockles and pipi were surveyed in a total of 101 sampling points across five strata.

The cockle strata were characterised by sediment that was low in organic content ($<5\%$), with varying proportions of sediment fines (grain size <63 µm); this grain size fraction made up over 30% of the sediment in one of the samples (Figure 52, and see details in Appendix B, Table B-1). The two prevalent grain size fractions were fine and medium sands (grain sizes >125 and >250 µm), with varying proportions of sediment at other grain sizes.

The cockle population was concentrated in strata A to C, on the intertidal mudflat north of the main channel (Figure 53, Table 49). Current estimates for the total population were 53.95 million (CV: 14.64%) cockles and 907 cockles per m^2 (Table 50). Although these estimates signified a marked decline from preceding estimates in 2019–20, they were similar to values in earlier surveys. Overall, the cockle population at this site has been characterised by marked fluctuations over time. Some of this fluctuation was also evident in the population of large cockles ($\geq$30 mm shell length), although their abundance was generally too small to influence population dynamics. In 2021–22, there were an estimated 1.32 million (CV: 32.21%) large cockles within the total population, and their density was 22 large cockles per m^2.

Based on the small number of large individuals, this size class was only a minor proportion (2.44%) of the population, which mostly consisted of medium-sized cockles and recruits ($\leq$15 mm shell length) (Table 51, Figure 54). The latter size class consistently contributed over 20% of individuals to recent populations (i.e., since 2017–18), with 30.98% of recruits in 2021–22. The recent increase in recruits and concomitant decrease of medium-sized cockles was also documented in the length-frequency distributions, even though the population size structure remained unimodal with a modal size of 23 mm shell length.

Patterns in total cockle abundance changed in relation to sediment grain sizes across surveys, as evident in the principal component analysis (Figure 55). In recent surveys, total abundance was higher when associated with sand fractions and fines, compared with gravel.

Pipi at Tairua Harbour were in localised areas within pipi strata D and E and also occurred close to channels in the cockle strata (Figure 56, Table 52). Their total abundance was estimated at 16.43 million (CV: 19.55%) pipi; their average density was 276 pipi per m^2 (Table 53). These estimates documented a decreasing trend from a comparatively large population size in 2013–14. Although some of this decline may be attributed to the diminishing sampling extent over the same period, reductions in the latter area were relatively small in recent surveys, e.g., between 2017–18 and 2021–22, when the pipi population decreased by about 50%. The population of large pipi ($\geq$50 mm shell length) underwent a similar overall decline between these two surveys but a short-term increase from the preceding assessment in 2019–20. The current abundance of large pipi was 1.48 million (CV: 39.66%) pipi, and their average density was 25 large pipi per m^2. This increase and the concomitant decrease in the overall population meant that large pipi made up 9.05% of the 2021–22 population (Table 54). At the same time, recruitment was consistent in recent surveys, and the current population included 21.99% of recruits ($\leq$20 mm shell length). This size class continued to form a second cohort in the bimodal population dominated by medium-sized pipi (Figure 57). The prevalence of the latter size class led to a stable population size structure over time, with continued growth of recruits across the 20 mm size threshold to contribute to the strong medium-size cohort. At the same time, medium-sized pipi grew towards the large-size threshold of 50 mm, evident in the increase in modal sizes from 40 mm shell length in 2019–20 to 47 mm in 2021–22.

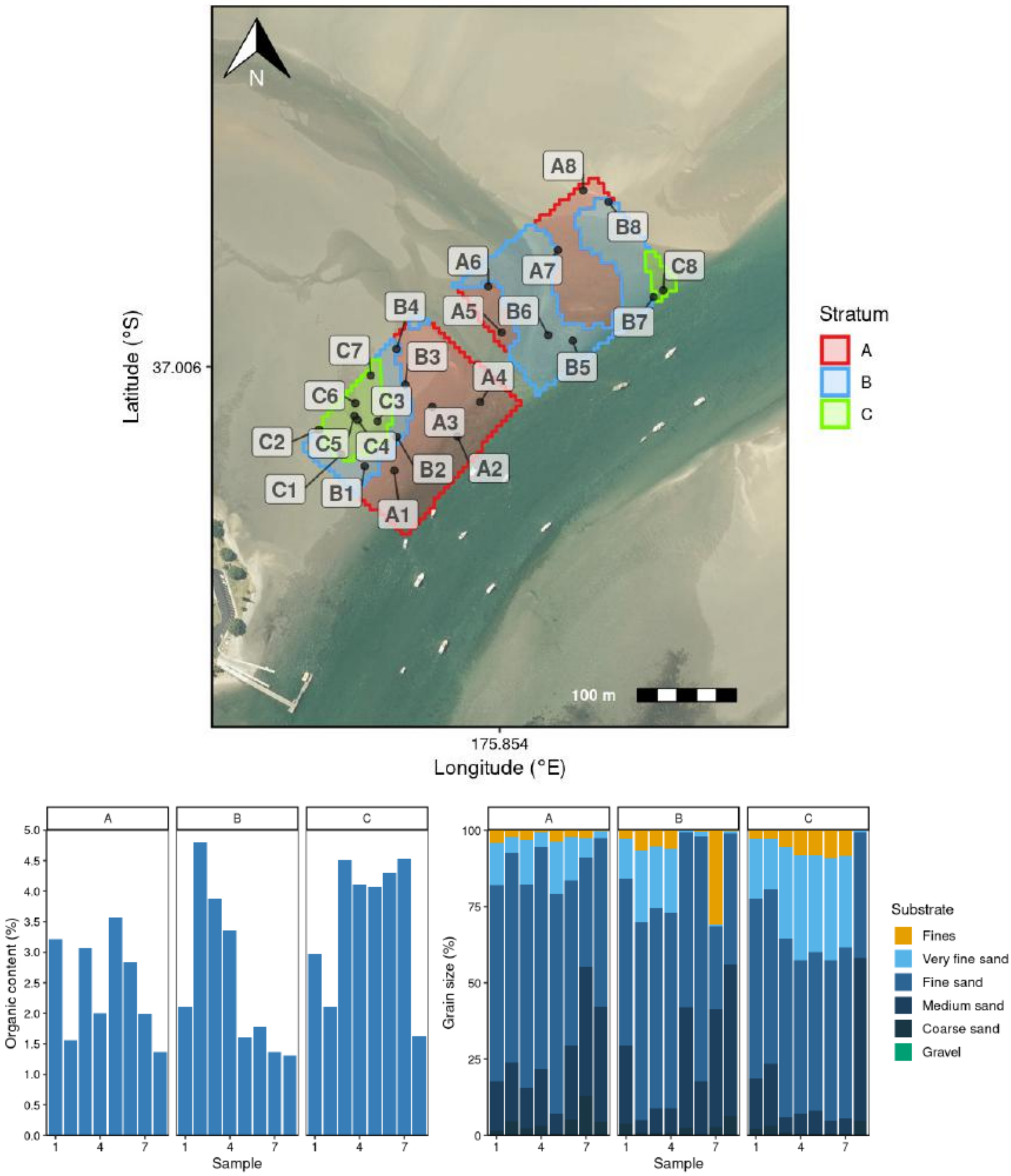


Figure 52: Sediment sample locations and characteristics at Tairua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.11.1 Cockles at Tairua Harbour

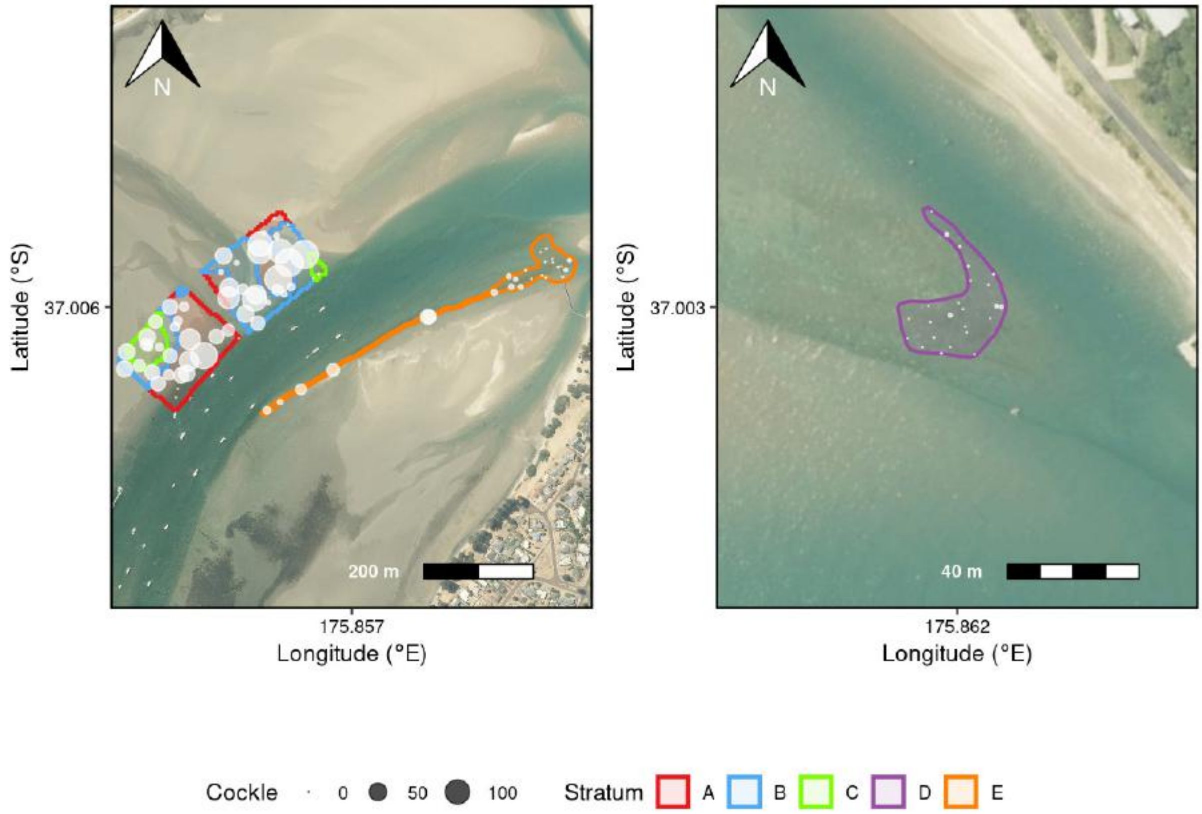


Figure 53: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	25	1 043	30.34	1 192	20.65
B	2.0	20	684	19.28	977	24.52
C	0.5	8	168	3.13	600	25.53
D	0.1	24	4	0.00	5	46.63
E	0.8	24	120	1.20	143	37.57

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	3.7	61.70	1 668	8.07	17.57	475	7.95
2000–01	3.9	56.07	1 438	4.93	10.65	273	6.26
2001–02	3.9	19.04	488	6.80	4.58	117	8.07
2002–03	3.9	32.76	840	5.14	5.56	143	6.53
2005–06	3.9	23.68	607	4.74	4.71	121	6.07
2006–07	4.8	53.82	1 121	6.47	4.28	89	11.80
2010–11	5.8	25.52	440	10.69	0.87	15	47.88
2013–14	9.4	69.66	742	8.93	0.81	9	14.22
2015–16	8.2	57.22	700	10.46	0.37	4	43.97
2017–18	6.5	59.74	922	9.62	0.86	13	22.90
2019–20	6.1	74.73	1 221	9.88	0.69	11	35.93
2021–22	5.9	53.95	907	14.64	1.32	22	32.21

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	19.61	22	5–35	21.50	1.44
2019–20	19.14	20	5–34	20.64	0.92
2021–22	19.09	23	5–37	30.98	2.44

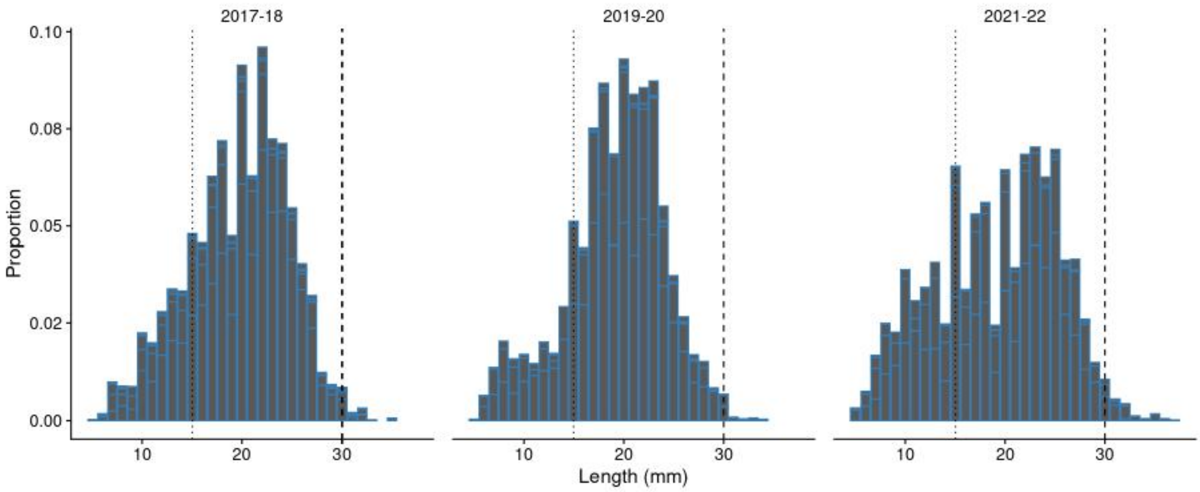


Figure 54: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

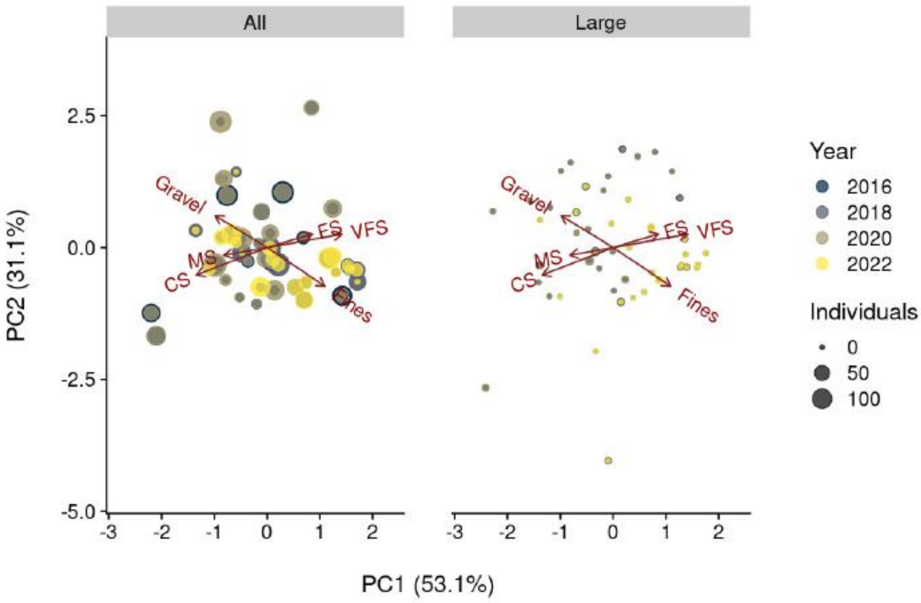


Figure 55: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Tairua Harbour. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.11.2 Pipi at Tairua Harbour

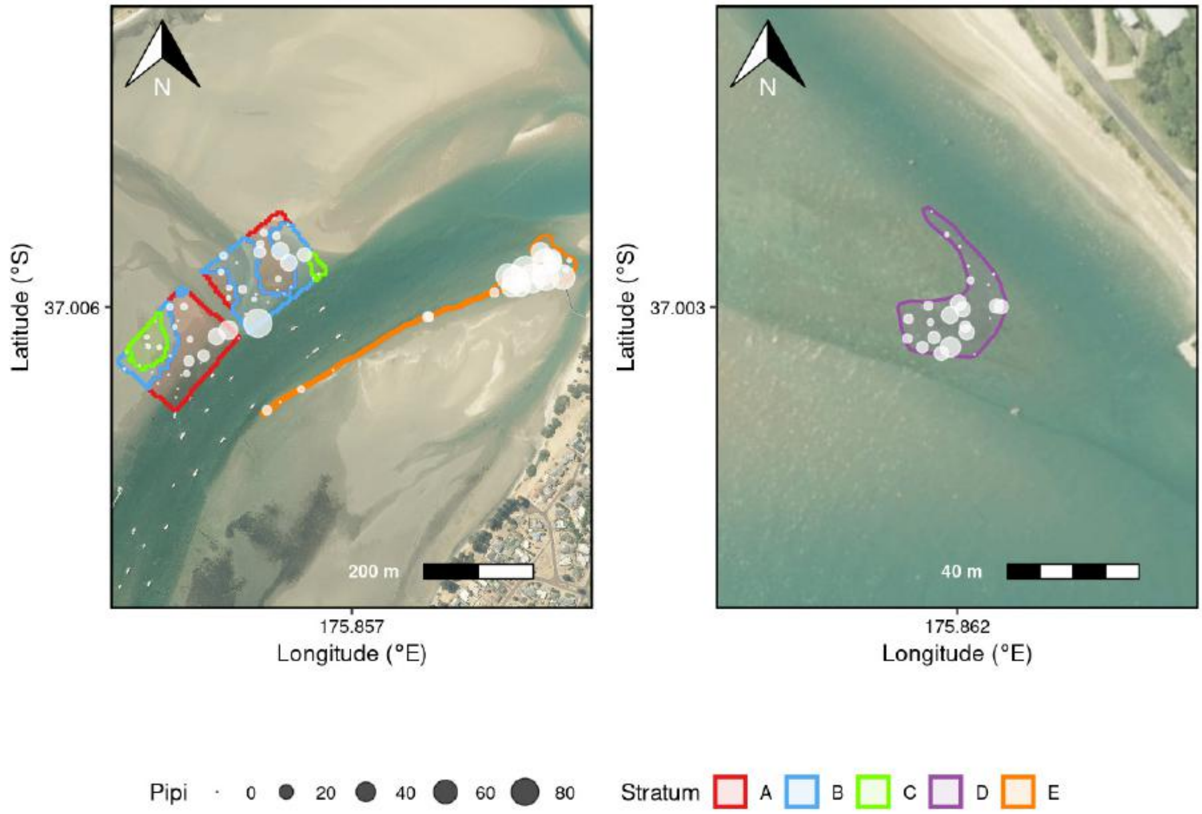


Figure 56: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	25	143	4.16	163	33.79
B	2.0	20	150	4.23	214	58.13
C	0.5	8	3	0.06	11	48.80
D	0.1	24	260	0.21	310	21.34
E	0.8	24	775	7.78	923	19.50

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	3.7	9.41	254	6.56	3.81	103	5.79
2000–01	3.9	8.35	214	6.25	2.11	54	7.78
2001–02	3.9	4.28	110	11.30	0.84	22	8.70
2002–03	3.9	4.98	128	6.73	0.43	11	11.51
2005–06	3.9	3.01	77	9.00	0.71	18	12.62
2006–07	4.8	6.33	132	6.72	2.10	44	8.36
2010–11	5.8	25.80	445	11.26	0.84	14	25.04
2013–14	9.4	49.99	533	13.05	0.44	5	28.85
2015–16	8.2	26.71	327	15.64	0.38	5	39.85
2017–18	6.5	31.67	489	9.29	3.52	54	21.56
2019–20	6.1	18.89	309	19.23	0.34	6	32.27
2021–22	5.9	16.43	276	19.55	1.48	25	39.66

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	33.95	42	7–65	23.20	11.13
2019–20	33.70	40	5–55	15.44	1.83
2021–22	35.56	47	7–59	21.99	9.05

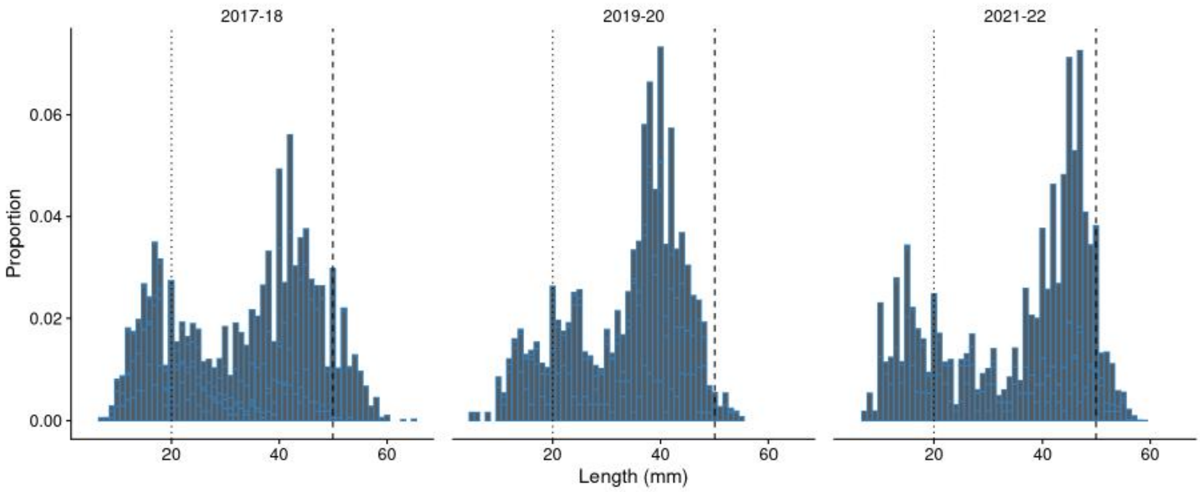


Figure 57: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Te Haumi

Te Haumi is a Northland site, on the east coast of this region. This site has been surveyed since 1999–2000, and the current assessment was the twelfth survey in the monitoring programme (see Appendix A, Tables A-1, A-2). Cockles and pipi at this site have been surveyed in an area across the main beach, north of the estuary channel, with another, separate pipi bed in the lower estuary. In 2021–22, the sampling extent was split into seven strata, with a survey effort of a total 132 sampling points.

Sediment at Te Haumi had a low organic content of 1.7 to 3.3% (Figure 58, and see details in Appendix B, Table B-1). The proportion of sediment grain sizes varied across samples, but were generally dominated by different sand fractions, most prominently fine sand (grain size $>$125 µm). Some of the samples also contained gravel (grain size $>$2000 µm), and this grain size fraction made up over 10% in three of the samples.

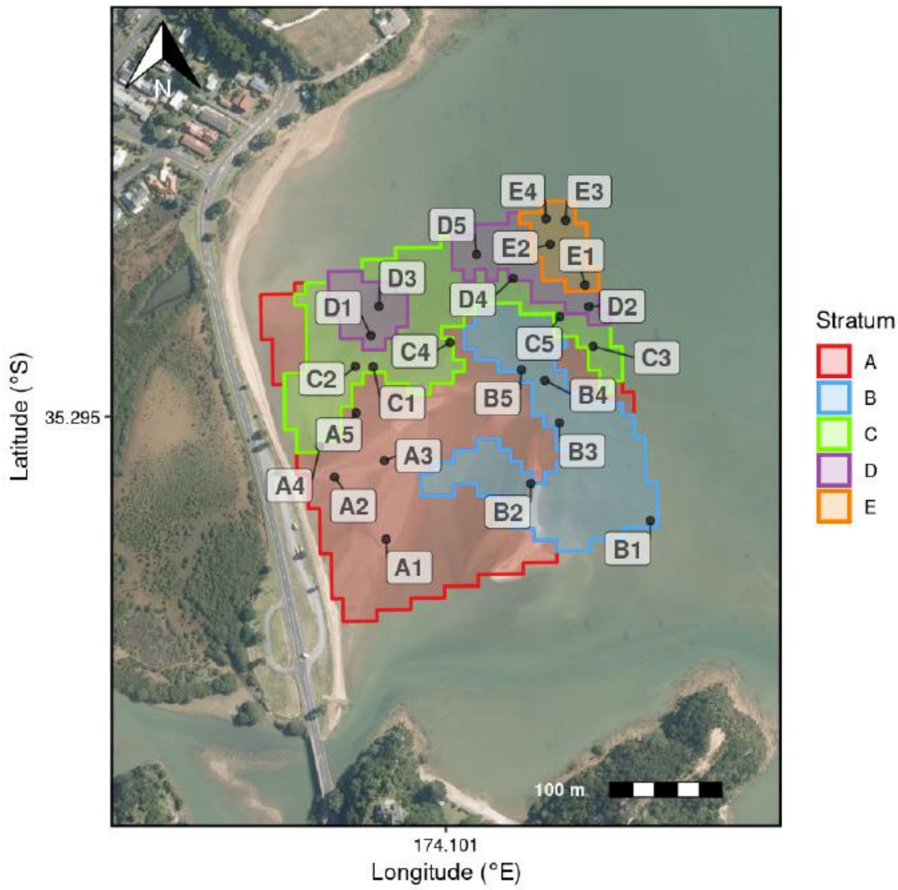
The cockle population at Te Haumi was distributed across the beach area of the sampling extent, mostly in strata A and B (Figure 59, Table 55). Both the abundance and density estimates were the highest values in the survey series, with an estimated population size of 97.01 million (CV: 10.44%) individuals and an average density of 912 individuals per m^2 in 2021–22 (Table 56). Nevertheless, there was only a small population of large cockles ($\geq$30 mm shell length), and there were 4.65 million (CV: 14.67%) large cockles in the 2021–22 survey. Their estimated density was 44 large individuals per m^2.

In the three most recent surveys, the contribution of large cockles was consistent over time, with large individuals comprising about 4% of the population (Table 57, Figure 60). At the same time, there was marked fluctuation in the proportion of recruits ($\leq$15 mm shell length), with strong recruitment in 2016–17 and 2021–22 leading to about 50% of recruits within the population, compared with 17.72% in the interim, in 2018–19. The fluctuations were also evident in the length-frequency distributions of the bimodal population, with an opposite pattern between the cohorts of recruits and of medium-sized cockles. The strong cohort of recruits in 2016–17 grew into the medium-size class by 2018–19, strengthening the latter size class. By 2021–22, there were fewer medium-sized cockles compared with another strong cohort of recruits. This shift in the size composition was reflected in the mean and modal sizes, which declined from about 20 mm in 2018–19 to 17.69 mm and 12 mm shell length, respectively, in 2021–22.

Principal component analysis of cockle abundance in relation to sediment granulometry did not distinguish a clear pattern for total abundance (Figure 61). For large cockles, comparatively high abundances were associated with fine grain size fractions in the most recent survey.

Pipi occurred throughout the entire sampling extent at Te Haumi, with particularly high densities in the low-tide pipi bed, stratum F (Figure 62, Table 58). Following a notable decline in 2018–19, the pipi population remained similar in 2021–22; its abundance and density were estimated at 41.89 million (CV: 14.45%) pipi and 394 pipi per m^2, and the population of large pipi ($\geq$50 mm shell length) was small, with 0.62 million (CV: 23.27%) individuals in this size class, at a density of 6 large pipi per m^2 (Table 59).

Similar to the cockle population, the size structure of the pipi population was bimodal and determined by medium-sized individuals and varying proportions of recruits ($\leq$20 mm shell length) (Table 60, Figure 63). In 2021–22, recruits made up 46.76% of the population, compared with 26.62% in 2018–19. Varying recruitment in recent surveys led to shifts in cohort strength between recruits and medium-sized pipi, with concomitant variation in mean and modal sizes over time. In 2021–22, the strong influx of recruits led to comparatively small mean and modal sizes at 24.97 mm and 17 mm shell length.



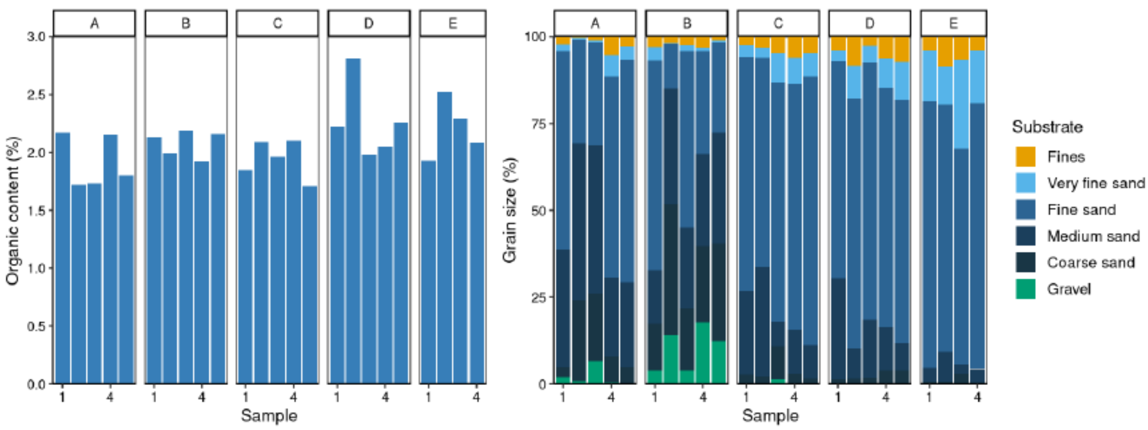


Figure 58: Sediment sample locations and characteristics at Te Haumi. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.12.1 Cockles at Te Haumi

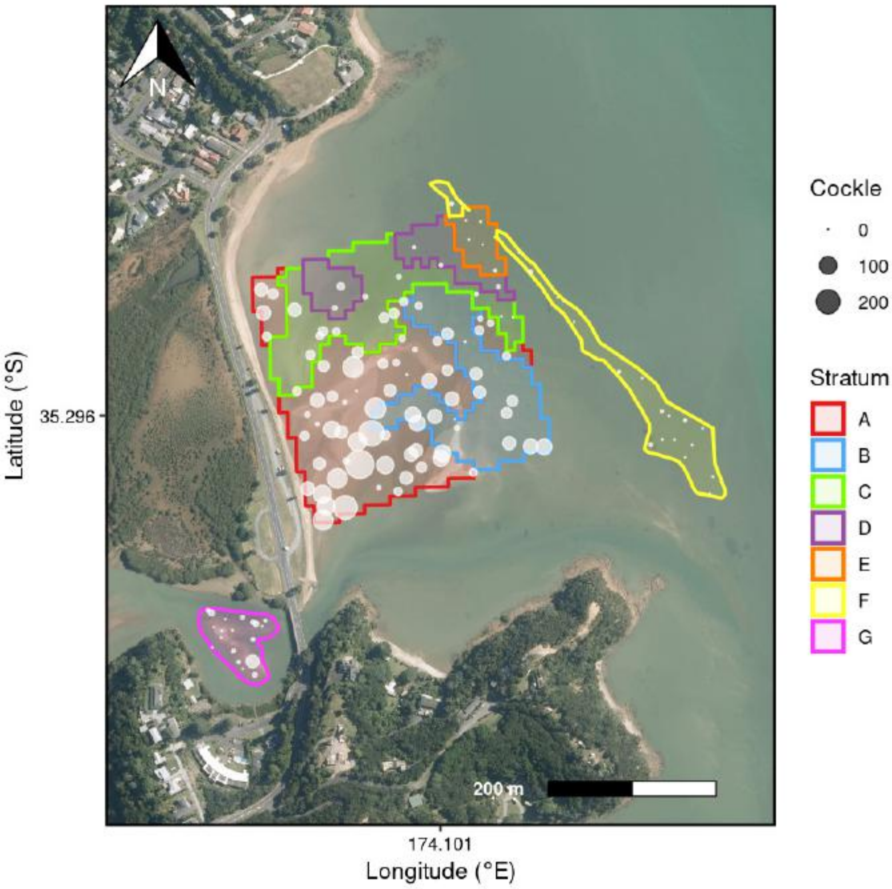


Figure 59: Map of sample strata and individual sample locations for cockles at Te Haumi, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of cockle abundance at Te Haumi, by stratum, for 2021–22. 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	3.9	55	3 068	61.69	1 594	14.32
B	2.1	15	634	24.90	1 208	17.11
C	1.8	12	194	8.49	462	28.53
D	0.8	5	23	1.11	131	52.17
E	0.4	5	1	0.02	6	>100
F	1.1	20	9	0.15	13	37.72
G	0.5	20	85	0.65	121	60.32

Table 56: Estimates of cockle abundance at Te Haumi for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.0	34.73	347	7.95	8.36	84	8.86
2000–01	9.9	17.06	172	11.00	4.11	41	10.27
2001–02	9.9	24.67	249	9.92	1.75	18	11.52
2002–03	9.9	41.77	422	7.97	2.16	22	13.99
2006–07	9.8	15.73	160	12.87	1.98	20	14.53
2009–10	12.1	34.99	290	9.66	2.13	18	26.58
2012–13	12.1	44.67	370	12.28	3.27	27	40.71
2014–15	12.8	35.36	277	11.35	3.42	27	19.75
2016–17	12.8	69.91	548	12.39	2.96	23	24.82
2018–19	11.9	79.69	669	11.69	3.71	31	19.30
2021–22	10.6	97.01	912	10.44	4.65	44	14.67

Table 57: 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 $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2016–17	17.01	10	5–39	49.33	4.24
2018–19	20.71	20	5–39	17.72	4.65
2021–22	17.69	12	4–39	46.00	4.79

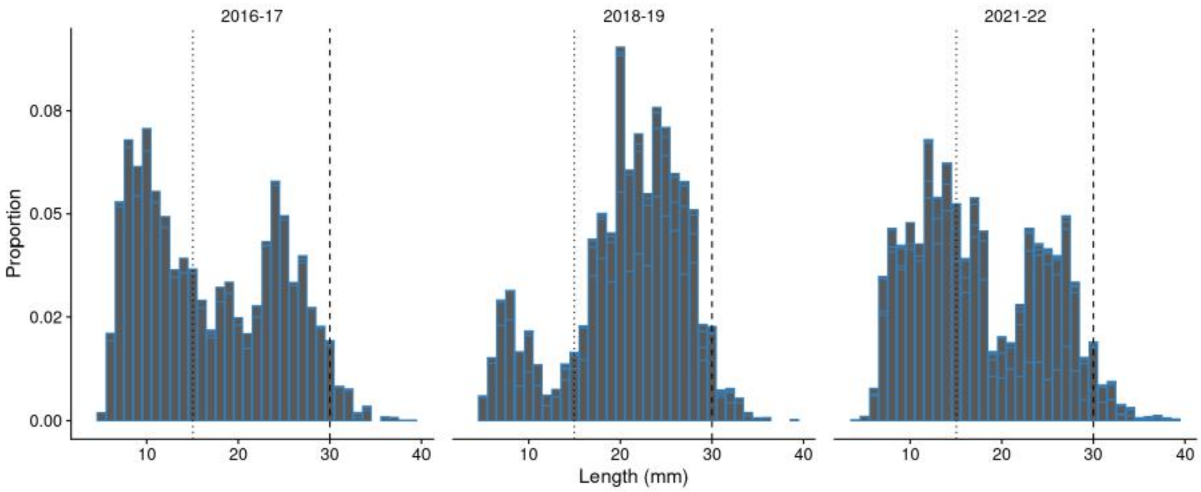


Figure 60: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Te Haumi. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

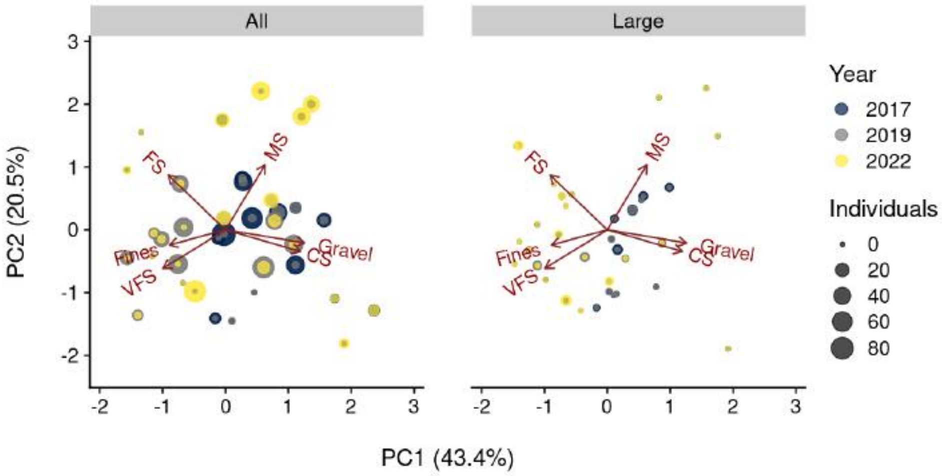


Figure 61: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Te Haumi. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.12.2 Pipi at Te Haumi

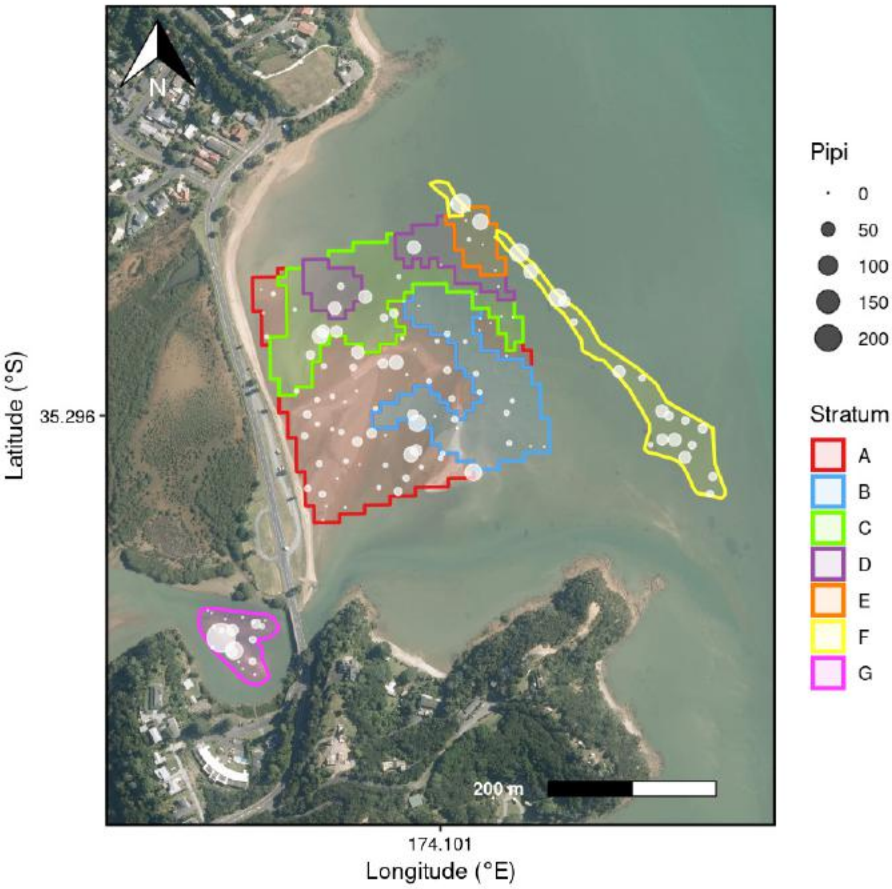


Figure 62: Map of sample strata and individual sample locations for pipi at Te Haumi, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 58: Estimates of pipi abundance at Te Haumi, by stratum, for 2021–22. 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	3.9	55	436	8.77	226	24.89
B	2.1	15	127	4.99	242	56.63
C	1.8	12	213	9.33	507	33.04
D	0.8	5	88	4.24	503	52.65
E	0.4	5	63	1.28	360	98.03
F	1.1	20	628	10.17	897	20.95
G	0.5	20	409	3.12	584	58.17

Table 59: 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	73	17.30
2000–01	9.9	62.33	630	9.35	12.17	123	11.94
2001–02	9.9	16.73	169	13.44	1.85	19	16.64
2002–03	9.9	34.04	344	11.17	2.39	24	24.56
2006–07	9.8	31.84	325	13.07	1.14	12	18.85
2009–10	12.1	43.93	364	12.64	0.20	2	33.60
2012–13	12.1	76.45	634	20.73	0.71	6	74.98
2014–15	12.8	55.91	438	18.38	1.16	9	47.92
2016–17	12.8	101.49	795	24.80	0.55	4	37.83
2018–19	11.9	48.56	408	20.19	0.45	4	24.34
2021–22	10.6	41.89	394	14.45	0.62	6	23.27

Table 60: 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 (%)
2016–17	23.03	18	3–58	52.71	0.54
2018–19	30.42	42	6–58	26.62	0.92
2021–22	24.97	17	5–57	46.76	1.49

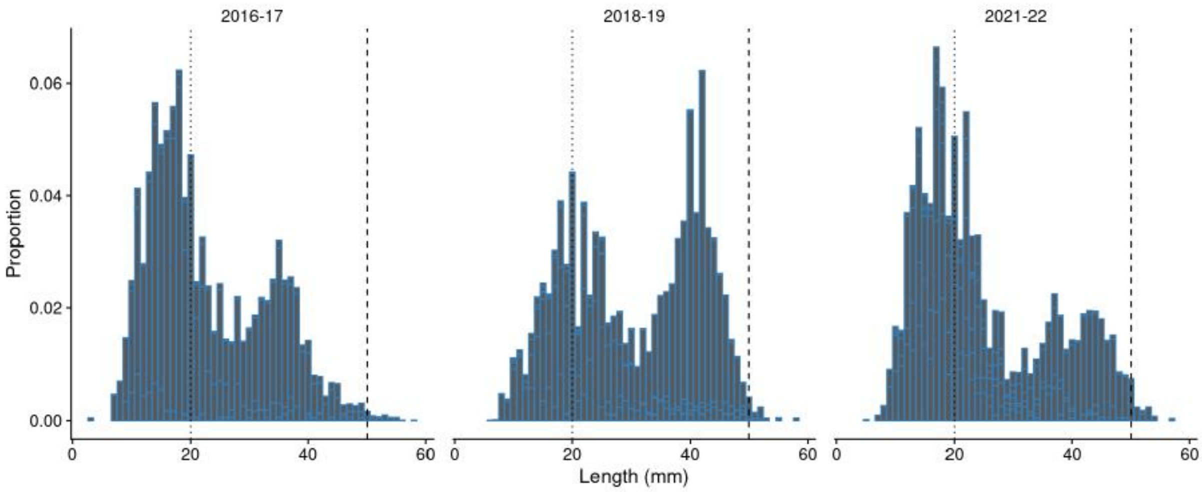


Figure 63: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Haumi. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.13 Te Mata Bay

Te Mata and Waipatukahu (hereafter "Te Mata Bay") are in the Waikato region, on the west coast of Coromandel Peninsula. The bay is part of a temporary fishing closure, that includes cockles, pipi, several species of mussels and oysters (Department of Internal Affairs 2020b). The first monitoring survey at this site was in 2020–21, so the current assessment was the first follow-up survey (see Appendix A, Tables A-1, A-2). Because there are no notable cockle populations at Te Mata Bay, the assessments have focused on pipi only. This species was surveyed in two separate beds associated with the rocky headlands that include the entrances of Te Mata River and Tapu River, respectively. The current sampling extent was slightly smaller than previously, owing to a higher low-tide boundary necessitated by challenging sampling conditions at this site (i.e., strong onshore swell, rocky sediment with boulders). In 2021–22, there were 80 sampling points, which were equally split between the two strata (Figure 64, Table 61).

The current pipi population estimates were a total of 6.35 million (CV: 9.14%) pipi, corresponding to a density of 933 individuals per m^2 (Table 62). These estimates were markedly lower than values in the preceding survey, when the total population consisted of 12.46 million (CV: 7.31%) pipi, and the density estimate was 1284 pipi per m^2. Although the current sampling extent was smaller than in 2020–21, the magnitude of the documented population decrease, such as the 50% reduction in total pipi abundance, notably exceeded the reduction in sampling area. Similarly, the population of large pipi ($\geq$50 mm shell length) declined from an estimated 1.16 million (CV: 14.38%) large individuals in 2020–21 to a current abundance of 0.57 million (CV: 14.65%) large pipi. Their average density decreased from 119 to 83 large pipi per m^2.

In view of the overall decrease in the population, the smaller number of large pipi still contributed a similar proportion (8.94%) to the total population in 2021–22 (Table 63). Length-frequency distributions from 2020–21 and 2021–22 indicated a similar population size structure, characterised by a strong size class of medium-sized pipi (Figure 65); however, the recent increase in the proportion of recruits ($\leq$20 mm shell length) from 4.48% to 11.27% resulted in the formation of a second cohort around the cut-off length of this size class. Current mean and modals sizes were 36.33 mm and 43 mm shell length, respectively. Similar to the survey in 2020–21, the current pipi population also contained the largest documented pipi size across all sites in the 2021–22 survey, with a recorded shell length of 61 mm.

3.13.1 Pipi at Te Mata Bay

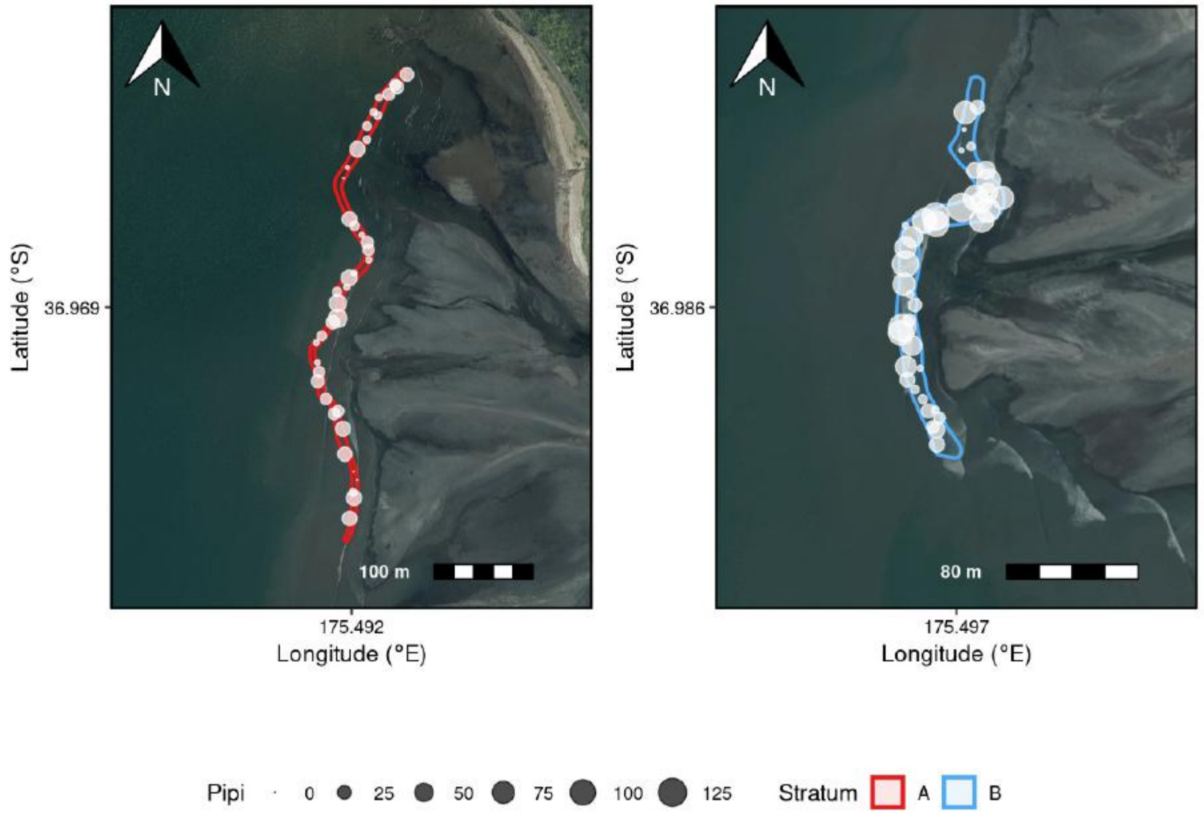


Figure 64: Map of sample strata and individual sample locations for pipi at Te Mata Bay, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 61: Estimates of pipi abundance at Te Mata Bay, by stratum, for 2021–22. 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	40	631	1.63	451	12.67
B	0.3	40	2 074	4.72	1 481	11.50

Table 62: Estimates of pipi abundance at Te Mata Bay for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2020–21	1.0	12.46	1 284	7.31	1.16	119	14.38
2021–22	0.7	6.35	933	9.14	0.57	83	14.65

Table 63: Summary statistics of the length-frequency (LF) distribution of pipi at Te Mata Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$20 mm and large individuals by a shell length of $\geq$50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2020–21	39.39	42	9–61	4.48	9.29
2021–22	36.33	43	7–61	11.27	8.94

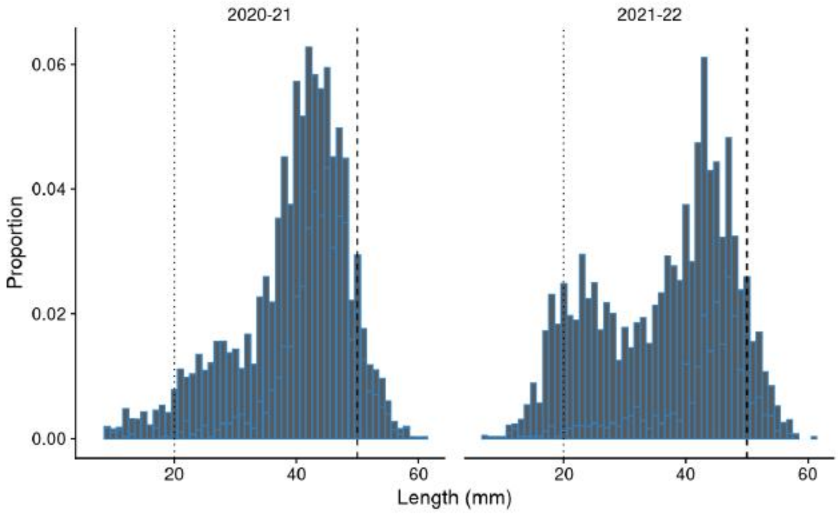


Figure 65: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Mata Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.14 Umupuia Beach

Umupuia Beach is a sheltered beach in Hauraki Gulf, close to the Auckland metropolitan area. The beach was closed to the collection of cockles in 2008, and this closure is still in place. Umupuia Beach is one of the most frequently sampled sites in the bivalve monitoring series, with fifteen surveys preceding the current assessment (see Appendix A, Tables A-1, A-2). The population assessments only include cockles, because there are no pipi at this beach. The sampling extent has remained largely unchanged throughout the survey series, covering most of the bay between the two headlands. In 2021–22, it was divided into two strata, and cockles were sampled in a total of 82 points.

There was considerable variation in sediment properties across samples at Umupuia Beach (Figure 66, and see details in Appendix B, Table B-1). Sediment organic content was generally low, but was about 8% in a couple of samples. Similarly, the proportion of sediment fines (grain size <63 µm) was generally high (i.e., $>20\%$), with percentages exceeding 40% in most samples; it was close to or exceeded 60% in seven of the 24 samples. Other prevalent grain size fractions were very fine and fine sands (grain sizes >65 and >125 µm).

The cockle population at Umupuia Beach was concentrated in the mid-intertidal zone of stratum A, with only two individuals in stratum B (Figure 67, Table 64). Their current total population size was estimated at 52.05 million (CV: 17.18%) individuals, with a corresponding average density of 159 cockles per m^2 (Table 65). These population estimates signified a marked reduction in the cockle population from the three preceding surveys (i.e., 2015–16 to 2019–20) and were the lowest values since 2006–07. The marked decrease in the total population was also evident in the current estimates for large cockles (≥ 30 mm shell length), highlighting their continuing decline in recent surveys (since 2012–13; e.g., their current estimates were 23.41 million (CV: 17.12%) large cockles, and their average density was 72 individuals per m^2, compared with 2019–20 estimates of 32.61 million (CV: 21.90%) large cockles at an average density of 98 large cockles per m^2.

In spite of the decreasing population trend, large cockles continued to constitute a significant proportion of the population: in 2021–22, 44.98% of all cockles were in this size class (Table 66, Figure 68). The influence of large cockles on the unimodal population size structure was also evident in mean and modal shell lengths, which were around the 30 mm cut-off for this size class at 29.02 mm and 27 mm, respectively. At the same time, the population included only a minor proportion (0.76%) of recruits (≤ 15 mm shell length). This finding was consistent with the population size structure in 2019–20 and highlighted the lack of recruitment in this previous and the current population.

Principal component analysis of total cockle and large cockle abundances documented a clear relationship of low abundances with sediment fines (Figure 69).

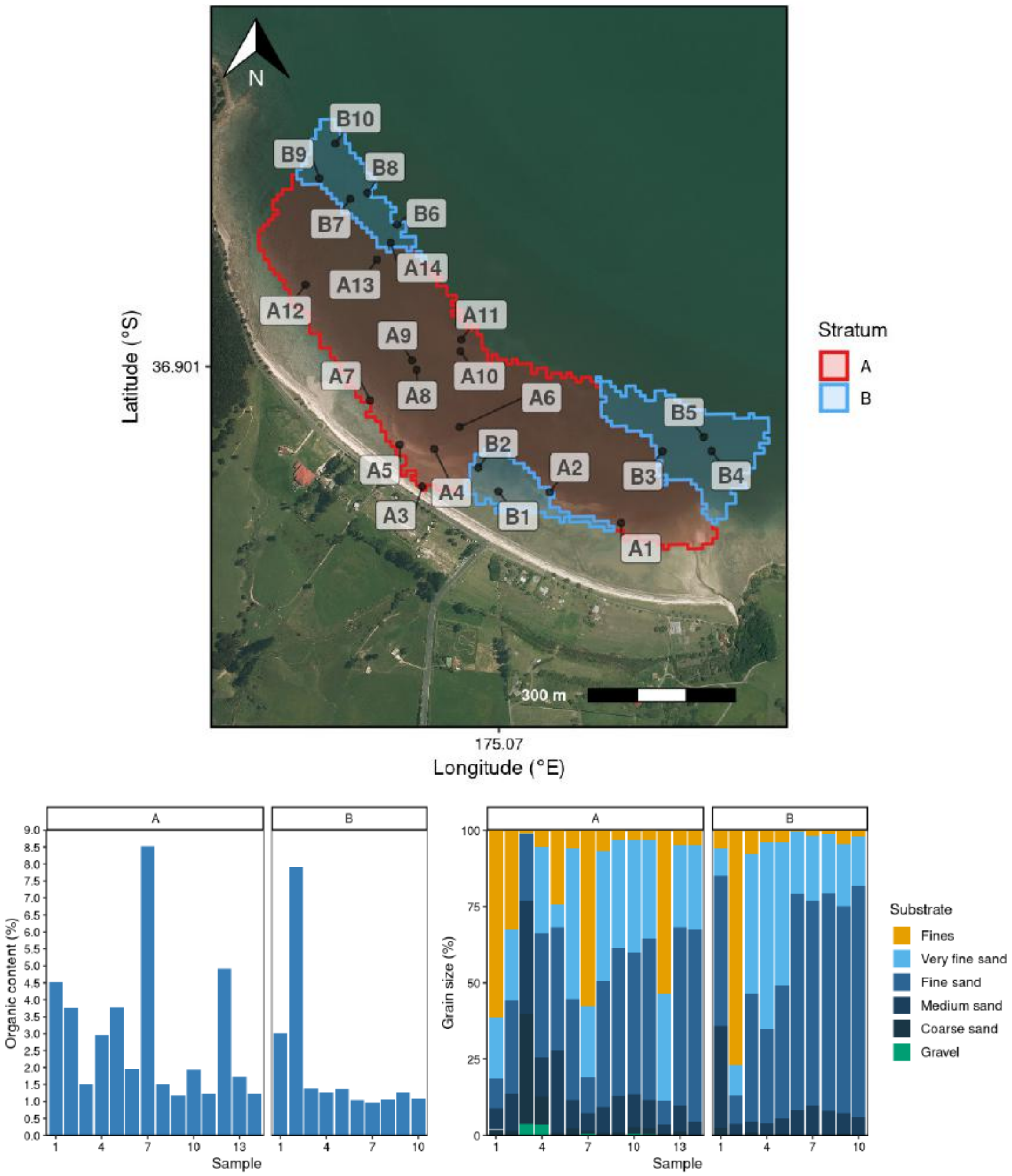


Figure 66: Sediment sample locations and characteristics at Umupuia Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.14.1 Cockles at Umupuia Beach

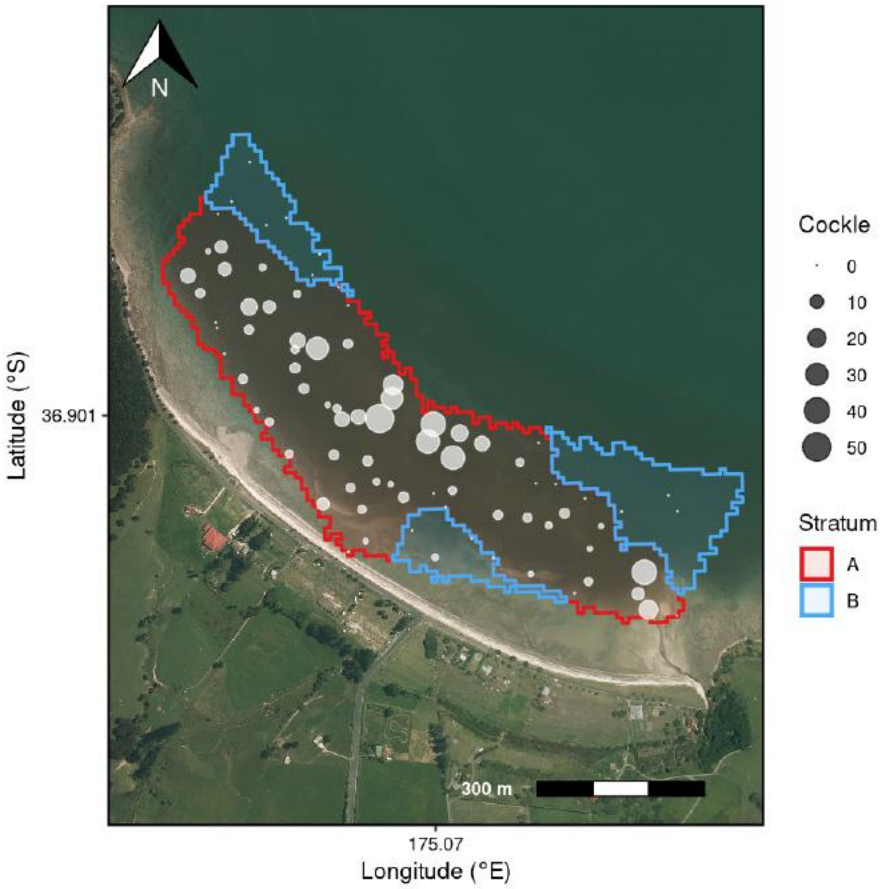


Figure 67: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 64: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2021–22. 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	24.2	70	522	51.65	213	17.3
B	8.5	12	2	0.40	5	>100

Table 65: Estimates of cockle abundance at Umupuia Beach for all sizes and large size ($\geq$30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	25.0	84.41	338	5.51	18.59	74	7.99
2000–01	36.0	177.48	493	5.50	66.98	186	8.32
2001–02	36.0	66.22	184	7.00	29.49	82	9.42
2002–03	36.0	64.43	179	5.26	24.96	69	7.87
2003–04	36.0	29.94	83	9.53	21.62	60	11.44
2004–05	36.0	41.49	115	6.95	30.72	85	7.97
2005–06	36.0	26.86	75	9.99	14.53	40	15.93
2006–07	36.0	11.59	32	13.84	5.07	14	23.91
2009–10	36.0	61.58	171	11.30	1.89	5	20.84
2010–11	36.0	103.08	286	9.96	9.32	26	17.10
2012–13	36.0	125.18	348	14.17	47.99	133	14.64
2013–14	33.9	170.35	503	16.79	44.29	131	17.80
2015–16	33.9	98.88	292	15.93	39.12	115	10.61
2017–18	33.4	92.15	276	19.27	41.70	125	22.25
2019–20	33.4	90.05	269	18.45	32.61	98	21.90
2021–22	32.7	52.05	159	17.18	23.41	72	17.12

Table 66: Summary statistics of the length-frequency (LF) distribution of cockles at Umupuia Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$15 mm and large individuals by a shell length of $\geq$30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	27.77	30	10–49	4.85	45.25
2019–20	27.74	27	12–46	0.48	36.21
2021–22	29.02	27	13–46	0.76	44.98

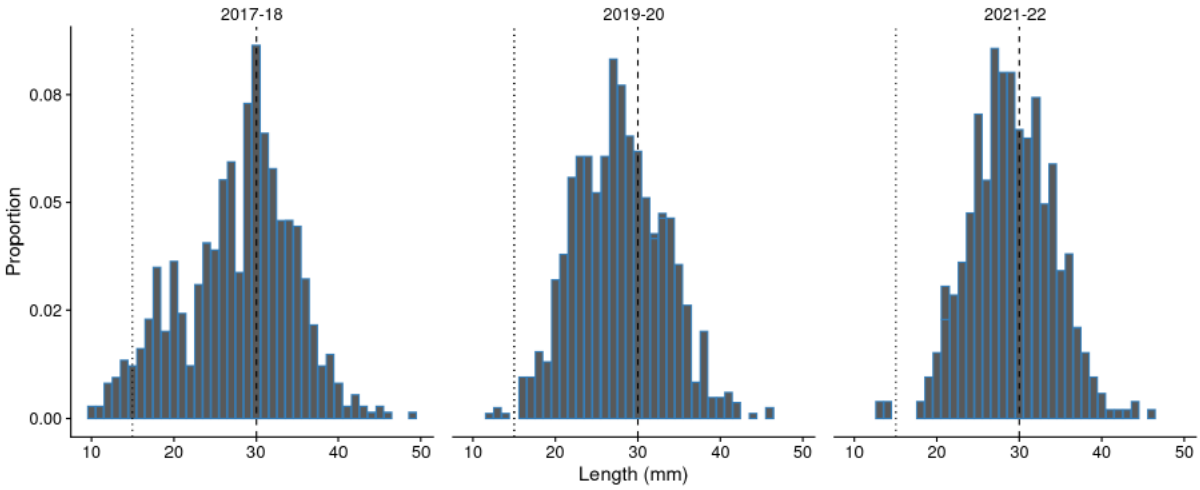


Figure 68: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

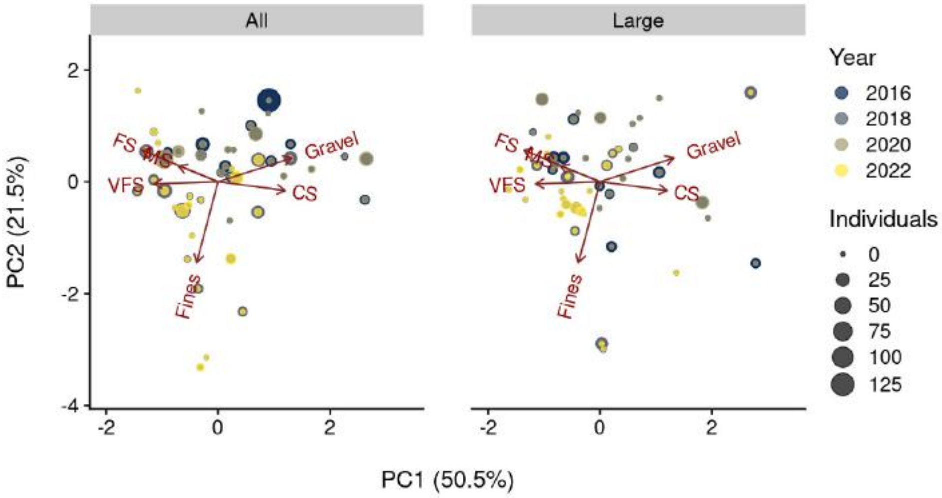


Figure 69: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Umupuia Beach. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, 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.

3.15 Whangateau Harbour

Whangateau Harbour is northeast of Auckland and part of the Hauraki Gulf Marine Park. The harbour supports cockle and pipi population and has been closed to the collection of both species since 2010 (Department of Internal Affairs 2015b).

The first survey of cockle and pipi populations as part of this monitoring series was conducted in 2001–02, and there have been eleven surveys since then, including this assessment in 2021–22 (see Appendix A, Tables A-1, A-2). The sampling area was considerably extended in 2013–14 and has remained consistent since then. There were five strata in 2021–22, including a separate pipi stratum in the main channel close to the harbour entrance. Bivalves were sampled across 101 points spread throughout the entire sampling extent.

Whangateau Harbour sediment had a low organic content ($< 2.5\%$) and contained a small proportion of sediment fines (grain size <63 μm), with less than 3.0% of sediment in this grain size fraction (Figure 70, and see details in Appendix B, Table B-1). Most of the sediment consisted of varying proportions of fine and medium sands (grain sizes >125 and >250 μm, respectively).

The Whangateau Harbour cockle population was distributed throughout stratum A (in the southern part of the harbour) and in stratum D, which was in the high- to mid-intertidal area in the northern part (Figure 71, Table 67). Total cockle abundance was an estimated 983.06 million (CV: 9.91%) individuals, and the average density was 884 cockles per m^2 (Table 68). The current estimates for large cockles ($\geq$30 mm shell length) were 34.49 million (CV: 37.90%) individuals, and their mean density was 31 large cockles per m^2. These estimates indicated a stable cockle population with a general increasing population trend in recent years, particularly since 2013–14, when the sampling extent was increased.

Length-frequency distributions from the three most recent surveys revealed regular recruitment events, with about 30% of the population consisting of recruits ($\leq$15 mm shell length) in each of these assessments (Table 69, Figure 72). The consistent recruitment at about 30% indicated that observed population increases were not caused by a strong influx of recruits, but by the strengthening of the single cohort of small- to medium-sized cockles. Nevertheless, this latter size class showed no growth to larger sizes, and both mean and modal shell lengths have remained at about 18 to 20 mm since 2017–18. This aspect also highlighted the general scarcity of large cockles over the same period, with only about 3% of the population within this size class.

Principal component analysis illustrated a general pattern of high total cockle abundance associated with fine sediment grain size fractions compared with gravel, particularly in recent surveys (Figure 73).

Pipi at Whangateau Harbour were almost exclusively in the pipi bed, stratum E, with no or few individuals in other parts of the sampling extent (Figure 74, Table 70). Their total abundance estimate in 2021–22 was 20.03 million (CV: 12.34%) pipi, and their estimated density was 18 pipi per m^2 (Table 71). Although both total pipi abundance and density were lower than in the preceding survey, they were similar to estimates in 2017–18, and there have been similar fluctuations in earlier surveys. Furthermore, estimates for large pipi ($\geq$50 mm shell length) indicated an increase in this size class although it generally contained few individuals; in 2021–22, there were an estimated 0.50 million (CV: 22.32%) large pipi at Whangateau Harbour, and this low abundance corresponded with an average density of <1 large individuals per m^2.

There was a concomitant increase in the proportion of large pipi within the total population, but their overall contribution remained minor at 2.51% (Table 72, Figure 75). Length-frequency distributions from 2017–18 onwards were dominated by medium-sized pipi, with a relatively strong contribution from recruits ($\leq$20 mm shell length) of about 30% in 2017–18 and 2019–20. In the current assessment, there were fewer recruits (20.32%), even though this size class formed a small second cohort. The smaller proportion of recruits combined with some growth within the medium pipi size class, led to a 10 mm increase in modal shell length to 34 mm in 2021–22.

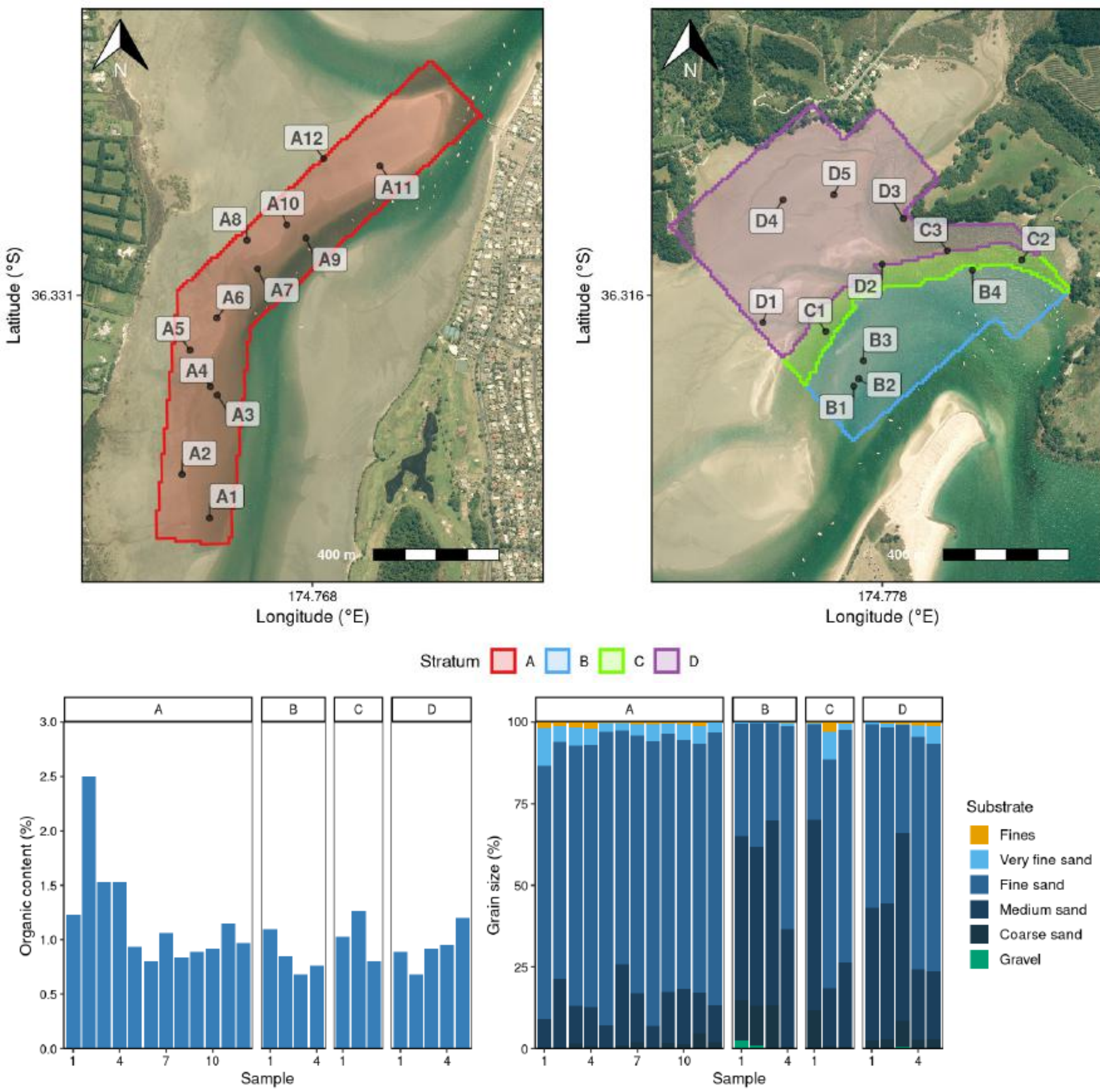


Figure 70: Sediment sample locations and characteristics at Whangateau Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.15.1 Cockles at Whangateau Harbour

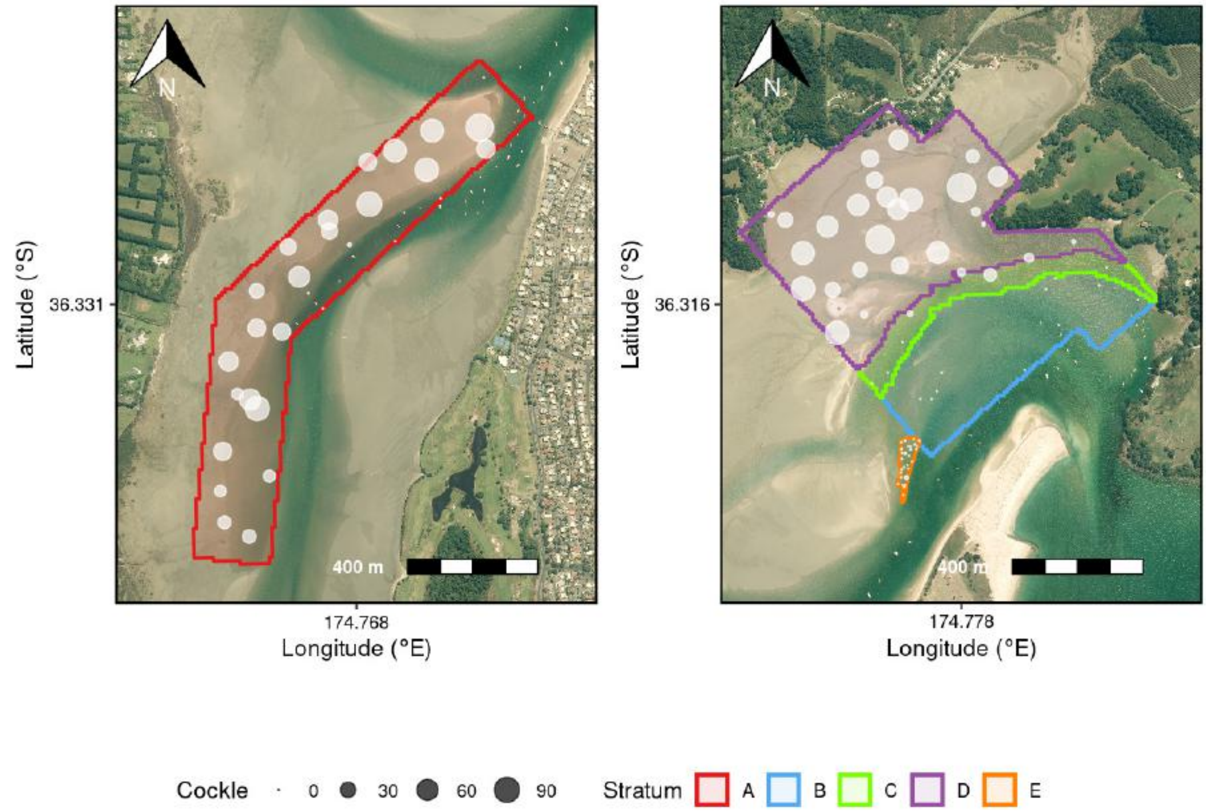


Figure 71: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 67: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	43.0	30	1 102	451.21	1050	14.68
B	20.9	8	0	0.00	0	
C	7.1	8	38	9.70	136	50.29
D	39.5	25	1 157	522.14	1322	13.66
E	0.6	30	1	0.01	<1	>100

Table 68: Estimates of cockle abundance at Whangateau Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	253.26	395	6.51	62.36	97	16.17
2003–04	64.2	376.68	587	5.80	56.85	89	12.66
2004–05	64.2	349.04	544	8.52	59.52	93	13.12
2006–07	64.2	266.04	415	8.24	35.20	55	21.91
2009–10	64.5	230.55	357	7.16	16.16	25	25.71
2010–11	64.2	239.27	373	5.06	19.77	31	16.19
2012–13	64.2	363.72	567	5.87	30.84	48	14.67
2013–14	110.9	730.89	659	5.70	44.50	40	13.45
2015–16	110.7	742.44	671	7.02	45.43	41	18.77
2017–18	110.9	852.27	768	9.28	33.69	30	28.12
2019–20	110.9	887.67	801	10.72	32.10	29	37.02
2021–22	111.2	983.06	884	9.91	34.49	31	37.90

Table 69: Summary statistics of the length-frequency (LF) distribution of cockles at Whangateau Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	18.64	20	4–41	30.94	3.95
2019–20	18.49	18	4–37	30.18	3.62
2021–22	18.87	17	6–40	29.04	3.51

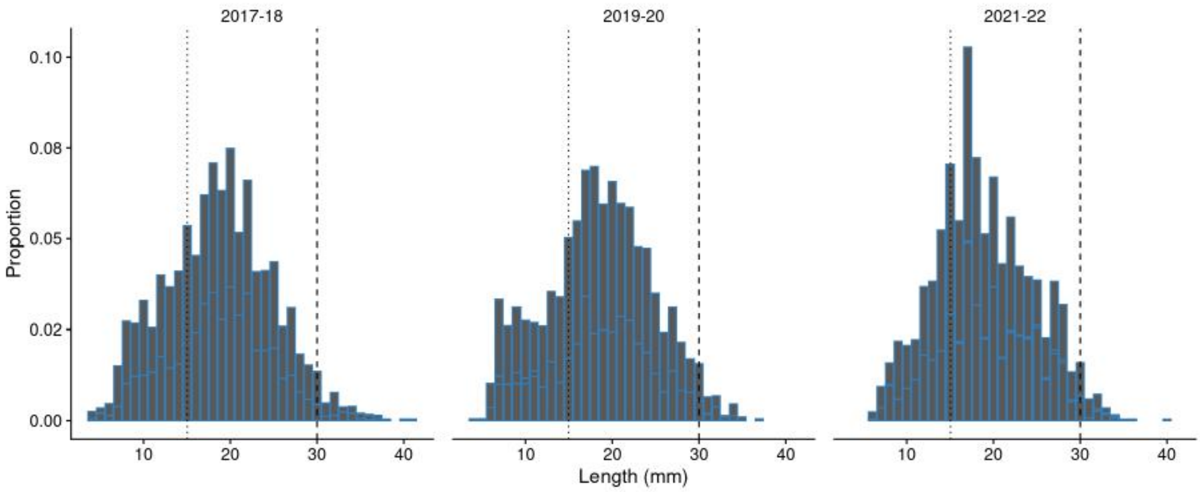


Figure 72: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

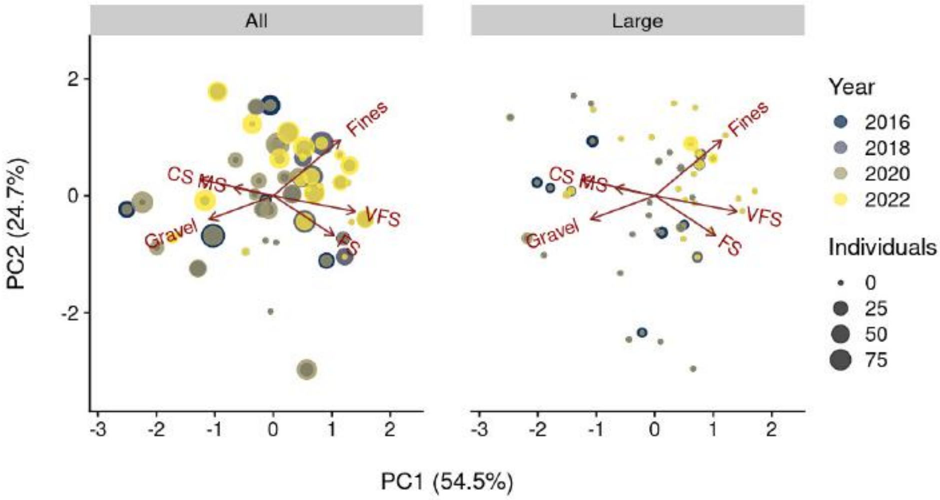


Figure 73: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Whangateau Harbour. Sediment grain size fractions are defined as fines (silt and clay) <63 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.

3.15.2 Pipi at Whangateau Harbour

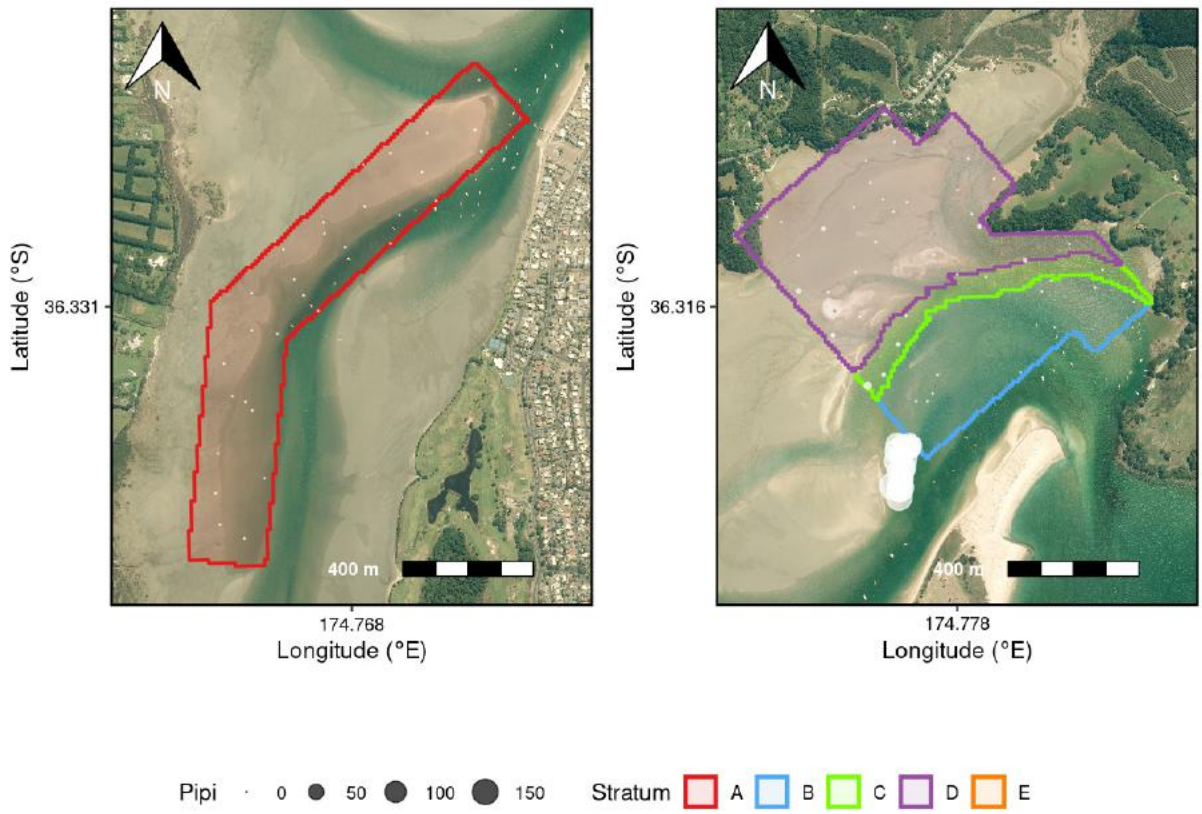


Figure 74: Map of sample strata and individual sample locations for pipi at Whangateau Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 70: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	43.0	30	0	0.00	0	
B	20.9	8	0	0.00	0	
C	7.1	8	10	2.55	36	67.19
D	39.5	25	4	1.81	5	46.77
E	0.6	30	2 621	15.67	2 496	9.99

Table 71: Estimates of pipi abundance at Whangateau Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	1.83	3	31.83	0.31	<1	>100
2003–04	64.2	0.48	<1	10.18	0.42	<1	9.85
2004–05	64.2	6.85	11	22.46	0.58	<1	9.72
2006–07	64.2	10.56	16	33.78	0.05	<1	>100
2009–10	64.5	17.58	27	33.35	0.11	<1	>100
2010–11	64.2	9.31	15	17.74	1.57	2	22.52
2012–13	64.2	19.58	30	16.89	0.60	<1	42.05
2013–14	110.9	55.39	50	26.92	0.68	<1	24.04
2015–16	110.7	15.00	14	23.20	0.40	<1	9.04
2017–18	110.9	20.13	18	42.77	0.09	<1	28.79
2019–20	110.9	29.96	27	72.05	0.26	<1	22.41
2021–22	111.2	20.03	18	12.34	0.50	<1	22.32

Table 72: Summary statistics of the length-frequency (LF) distribution of pipi at Whangateau Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	26.06	25	10–58	31.77	0.47
2019–20	24.42	24	9–57	33.15	0.87
2021–22	29.37	34	8–58	20.32	2.51

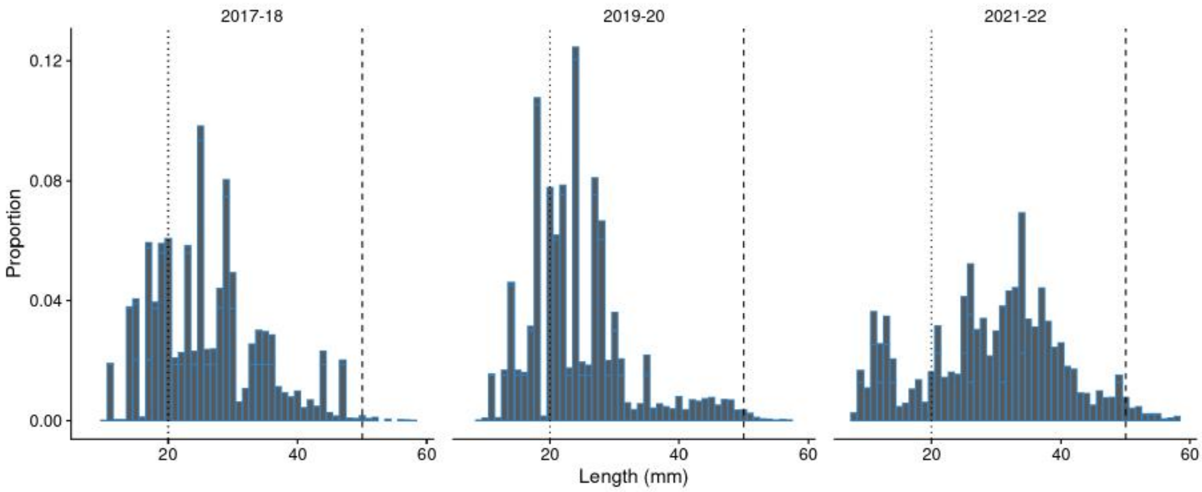


Figure 75: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.16 Whitianga Harbour

Whitianga Harbour is in the Waikato region, on the east coast of Coromandel Peninsula. The initial survey in 2012–13 assessed the pipi bed at the harbour entrance, with subsequent surveys also assessing cockles within the harbour, across an intertidal mudflat. The same area has been part of cockle surveys in the Hauraki Gulf Forum community monitoring programme (Auckland Council 2013). In the current monitoring series, there were four and five surveys of cockles and pipi, respectively, including the present assessment (see Appendix A, Tables A-1, A-2). Throughout the survey series, there has been little change in the sampling extent, with some variation in the shape and extent of the pipi bed.

Sediment in the cockle stratum was relatively uniform and characterised by an organic content of 3 to 4% (Figure 76, and see details in Appendix B, Table B-1). The sediment grain size distribution was largely determined by fine sand (grain size >250 µm), followed by medium sand (grain size >500 µm). The proportion of sediment fines (grain size <63 µm) ranged from 4 to 11% across samples.

The distribution of cockles at Whitianga Harbour was relatively even throughout stratum A, but there were no cockles in stratum B (Figure 77, Table 73). Current population estimates were similar to previous estimates, with 57.22 million (CV: 11.53%) cockles, and 1055 cockles per m^2 (Table 74). There were no large cockles ($\geq$30 mm shell length) within the population, and this size class was consistently absent in previous surveys also.

The cockle population was largely determined by recruits ($\leq$15 mm shell length) with this size class consistently comprising about 70 to 80% of the population; their proportion in 2021–22 was 68.46% (Table 75, Figure 78). These results highlight the importance of recruitment for determining the cockle population at Whitianga Harbour. Although strong recruitment events appeared to occur regularly at this site, there was no little subsequent growth of recruits into the larger size classes. The single cohort of small individuals was mostly characterised by mean and modal sizes below the 15 mm threshold, although the modal shell length in 2021–22 was just above this cut-off at 17 mm shell length.

In relation to sediment grain size fractions, total cockle abundance associated with sand fractions was distinctly higher compared with gravel in recent surveys (Figure 79).

Similar to cockles, pipi at Whitianga Harbour were confined to a single stratum, stratum B (Figure 80, Table 76). This population showed a marked recent increase in abundance, tripling from 8.86 million (CV: 13.38%) pipi in 2019–20 to 28.36 million (CV: 9.48%) pipi in 2021–22 (Table 77). The same increase was also evident in the population density with an estimated 163 pipi per m^2 in 2019–20 compared with 523 pipi per m^2 in 2021–22. Current estimates for large pipi ($\geq$50 mm shell length) were similar to the preceding estimates in 2019–20, and there were 0.80 million (CV: 16.22%) pipi in this size class in 2021–22. The corresponding density was 15 large pipi per m^2.

The small number of large pipi was evident in the population size structure, with only 2.84% of the current population consisting of large individuals (Table 78, Figure 81). At the same time, recruits ($\leq$20 mm shell length) made up 22.45% of the population, reflecting a notable recruitment event prior to the field survey. In view of the lack of recruits in 2019–20, their recent influx explained some of the observed population increase in 2021–22. This aspect was also evident in the length-frequency distributions, which highlighted the growth of recruits over time, shifting the population size structure towards the dominant size class of medium-sized pipi, albeit with a smaller modal size of 30 mm shell length than the 42 mm mode in 2019–20.

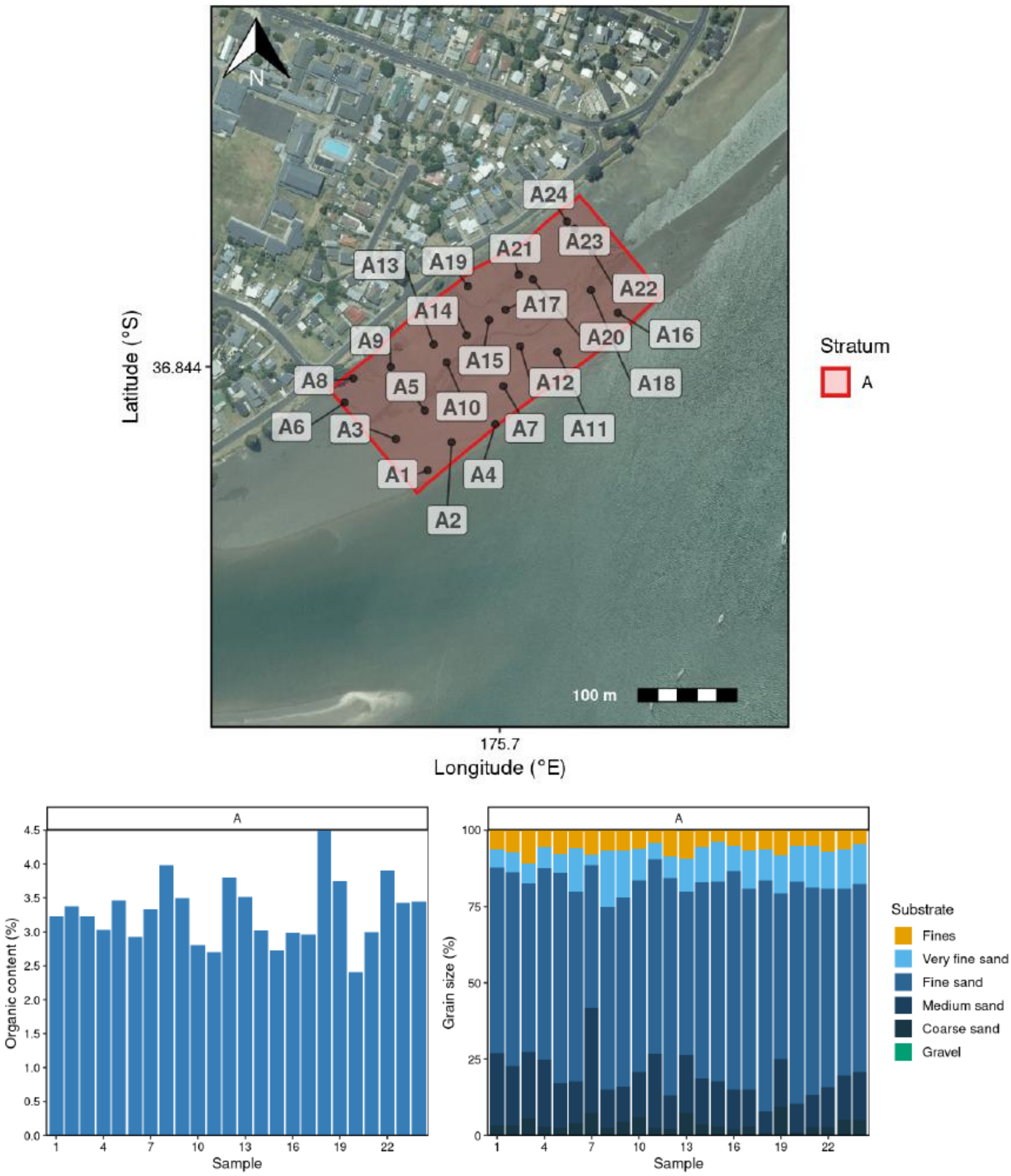


Figure 76: Sediment sample locations and characteristics at Whitianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.16.1 Cockles at Whitianga Harbour

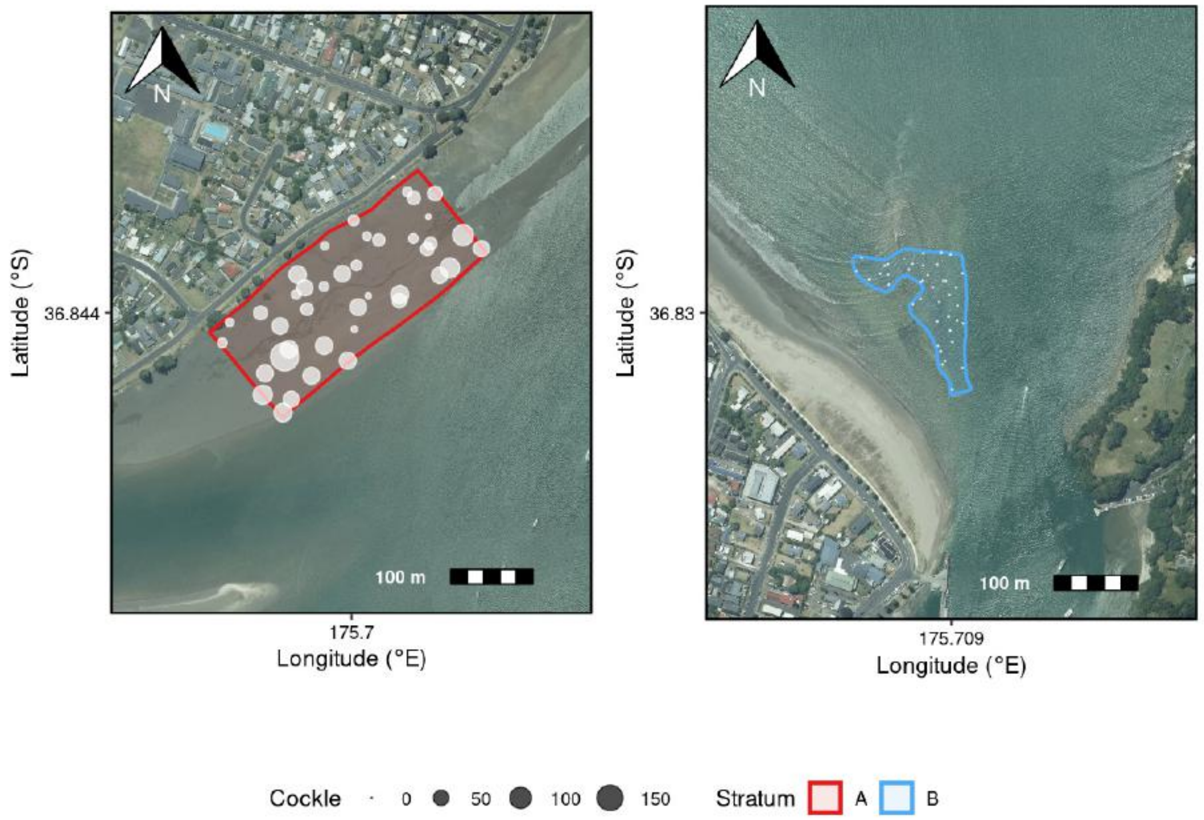


Figure 77: Map of sample strata and individual sample locations for cockles at Whitianga Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 73: Estimates of cockle abundance at Whitianga Harbour, by stratum, for 2021–22. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.4	40	1 818	57.22	1 299	11.53
B	1.0	40	0	0.00	0	

Table 74: Estimates of cockle abundance at Whitianga Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2015–16	6.1	51.98	852	9.16	0.00	0	
2017–18	5.8	51.43	885	11.21	0.00	0	
2019–20	5.4	59.00	1 084	12.50	0.00	0	
2021–22	5.4	57.22	1 055	11.53	0.00	0	

Table 75: Summary statistics of the length-frequency (LF) distribution of cockles at Whitianga Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	12.46	12	5–26	81.25	0.00
2019–20	14.14	15	5–24	68.63	0.00
2021–22	13.23	17	3–25	68.46	0.00

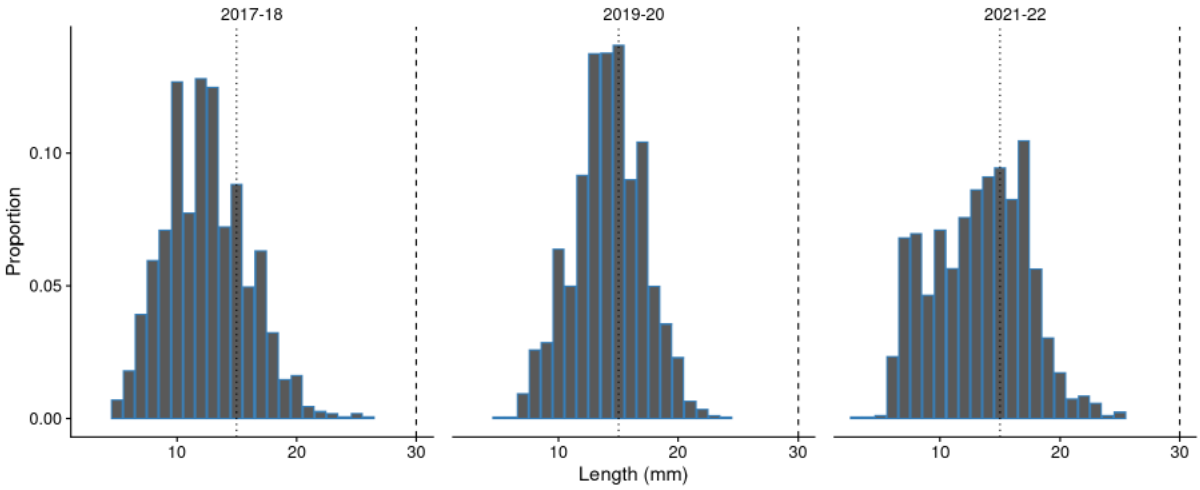


Figure 78: Weighted length-frequency (LF) distribution of cockles for the present survey at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

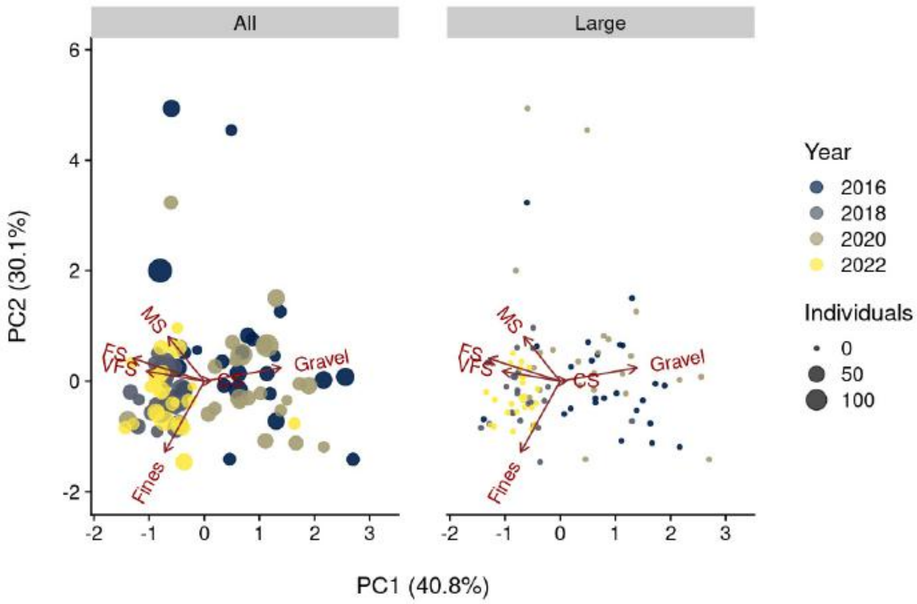


Figure 79: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Whitianga Harbour. Sediment grain size fractions are defined as fines (silt and clay) <63 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.

3.16.2 Pipi at Whitianga Harbour

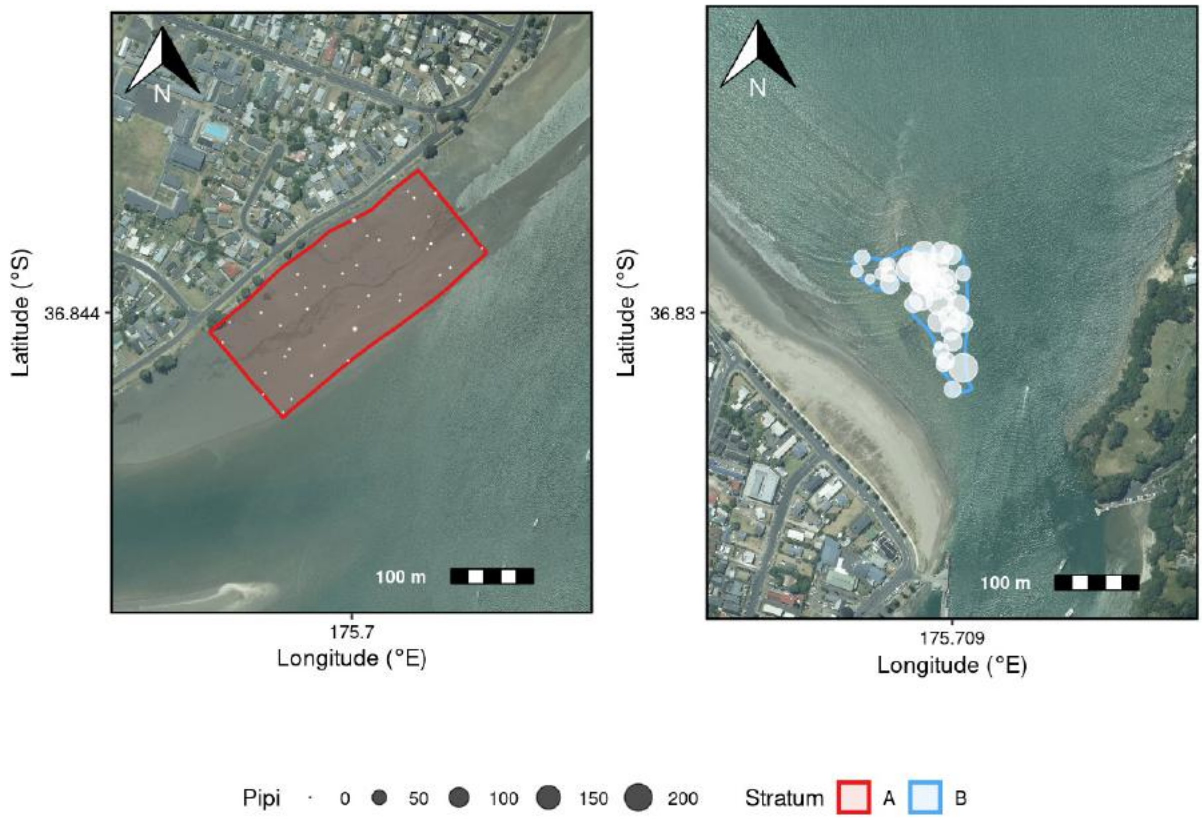


Figure 80: Map of sample strata and individual sample locations for pipi at Whitianga Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 76: Estimates of pipi abundance at Whitianga Harbour, by stratum, for 2021–22. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.4	40	2	0.06	1	69.80
B	1.0	40	3 885	28.29	2 775	9.50

Table 77: Estimates of pipi abundance at Whitianga Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2012–13	7.1	18.65	263	18.39	1.99	28	22.27
2015–16	6.1	6.36	104	18.17	1.91	31	22.66
2017–18	5.8	95.12	1 637	12.93	2.37	41	14.68
2019–20	5.4	8.86	163	13.38	0.86	16	19.02
2021–22	5.4	28.36	523	9.48	0.80	15	16.22

Table 78: Summary statistics of the length-frequency (LF) distribution of pipi at Whitianga Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of $\leq$20 mm and large individuals by a shell length of $\geq$50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2017–18	21.16	22	6–65	54.82	2.49
2019–20	40.01	42	10–64	0.18	9.68
2021–22	27.67	30	7–60	22.45	2.84

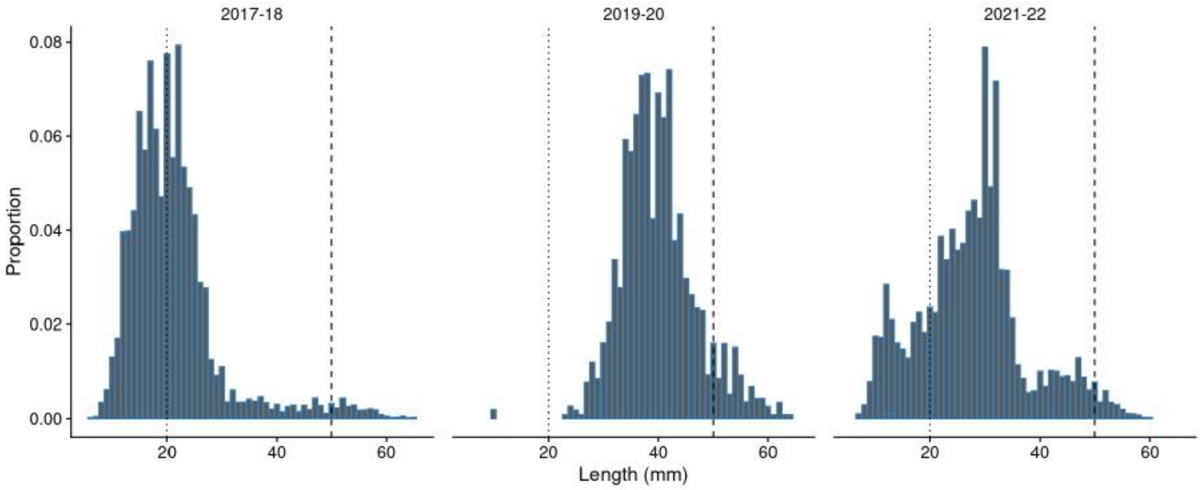


Figure 81: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whitianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

Cockle populations were surveyed at 14 of the 16 sites in 2021–22, occurring in diverse habitats from sheltered beaches (e.g., Umupuia Beach and Te Haumi) to extensive estuarine systems and harbours (e.g., Tairua and Whangateau harbours) in the different regions. Across these sites, population sizes varied considerably from the lowest abundance estimate of 8.04 million cockles at Ruakākā Estuary (that also had a high CV of 25.94%) to the highest estimate of 983.06 million (CV: 9.91%) cockles at Whangateau Harbour (Table 79). All of the total population estimates had an associated CV of less than 20%, except for Ruakākā Estuary, where increased sampling did not achieve a lowering of the CV below this percentage.

Population densities were generally high, with most sites supporting average densities of several hundred individuals per square metre. The highest density estimate was 1774 cockles per m^2 at Ngunguru Estuary, followed by 1579 cockles per m^2 at Raglan Harbour, and 1278 cockles per m^2 at Pataua Estuary. Densities estimates were comparatively low at three sites: at Little Waihi Estuary, Umupuia Beach, and Cockle Bay, densities ranged from 141 to 222 cockles per m^2.

Although the density estimates were low at Cockle Bay and Umupuia Beach, these two sites supported a comparatively large population of large cockles ($\geq$30 mm shell length). At the remaining sites, large individuals were scarce or absent, and their current estimates frequently had high uncertainty, evident in CV values exceeding 20%. Based on this finding, the current cockle populations consisted predominantly of medium-sized individuals and recruits ($\leq$15 mm shell length), whereas large individuals had little influence on the overall population.

At most sites that had high density estimates in 2021–22, temporal trends showed that cockle densities remained high or increased in recent surveys (Figure 82). These sites were in the wider Auckland region (Mill Bay, Whangateau Harbour), Northland (Mangawhai Harbour, Ngunguru Estuary, Pataua Estuary, Te Haumi), and Waikato (Raglan Harbour, Tairua Harbour, Whitianga Harbour). There were marked recent decreases in cockle density at Bowentown Beach, with smaller declines at Little Waihi Estuary and Umupuia Beach. Population trends at Little Waihi Estuary showed regular fluctuation throughout the time series, but densities at Umupuia Beach illustrated a continuing decline at this site since 2013–14.

In addition to temporal trends in population estimates, combined length-frequency distributions provided information about cockle population size structures over time (Figure 83). These time-series data highlighted a distinct shift towards smaller sized individuals between 2000–01 and 2021–22. This aspect is evident in the change in modal sizes from early surveys to more recent assessments. Over the assessment period, modal shell lengths decreased from sizes around the cut-off length of the large class at 30 mm to the smaller cut-off length for the medium-size class. Depending on the survey year, the size class of recruits varied in strength, whereas the large cockle size class underwent an overall decrease. Since 2016–17, the latter size class has been consistently scarce at most sites.

The scarcity of large individuals was also evident in the inter-site comparisons of large cockle densities over time (Figure 84). Several of the 2021–22 sites had a similar temporal trend, with high densities of large cockles early in the survey series, followed by notable declines in more recent assessments. These sites were spread across the different regions, including Auckland (Cockle Bay), Northland (Mangawhai Harbour, Pataua Estuary, Te Haumi, Whangateau Harbour), Bay of Plenty (Bowentown Beach), and Waikato (Raglan Harbour). The remaining sites also experienced declines in the large size class, but these declines were from relatively low density estimates at the start of the survey series. Populations at these remaining sites, at Little Waihi Estuary, Mill Bay, and Ruakākā Estuary only contained few large individuals, and this size class was generally lacking in recent assessments.

Table 79: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2021–22 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all cockles (total) and for large cockles (≥30 mm shell length).

Survey site	Population estimate			Population ≥30 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Bowentown Beach	16.00	1 068	7.35	0.09	6	22.32
Cockle Bay	34.58	222	14.93	4.99	32	15.57
Little Waihi Estuary	23.45	141	17.48	0.44	3	45.75
Mangawhai Harbour	65.64	915	8.84	5.68	79	17.56
Mill Bay	46.68	964	12.00	0.29	6	37.8
Ngunguru Estuary	112.60	1 774	12.24	0.72	11	46.61
Pataua Estuary	356.31	1 278	12.83	2.25	8	50.01
Raglan Harbour	115.66	1 579	8.25	1.65	23	26.29
Ruakākā Estuary	8.04	197	25.94	0.05	1	>100
Tairua Harbour	53.95	907	14.64	1.32	22	32.21
Te Haumi	97.01	912	10.44	4.65	44	14.67
Umupuia Beach	52.05	159	17.18	23.41	72	17.12
Whangateau Harbour	983.06	884	9.91	34.49	31	37.9
Whitianga Harbour	57.22	1 055	11.53	0.00	0	

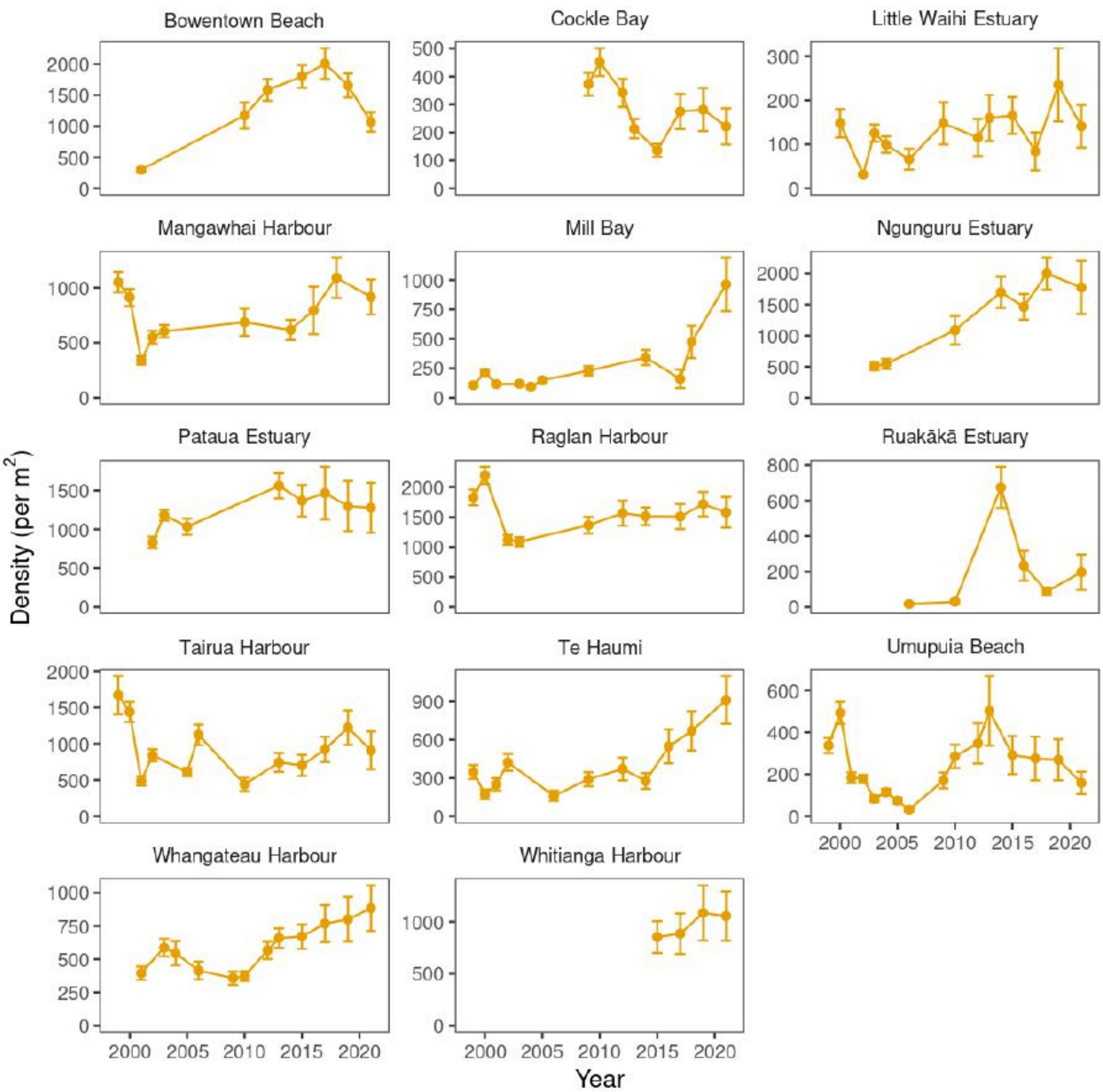


Figure 82: Estimated density of cockles for all sites included in the 2021–22 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

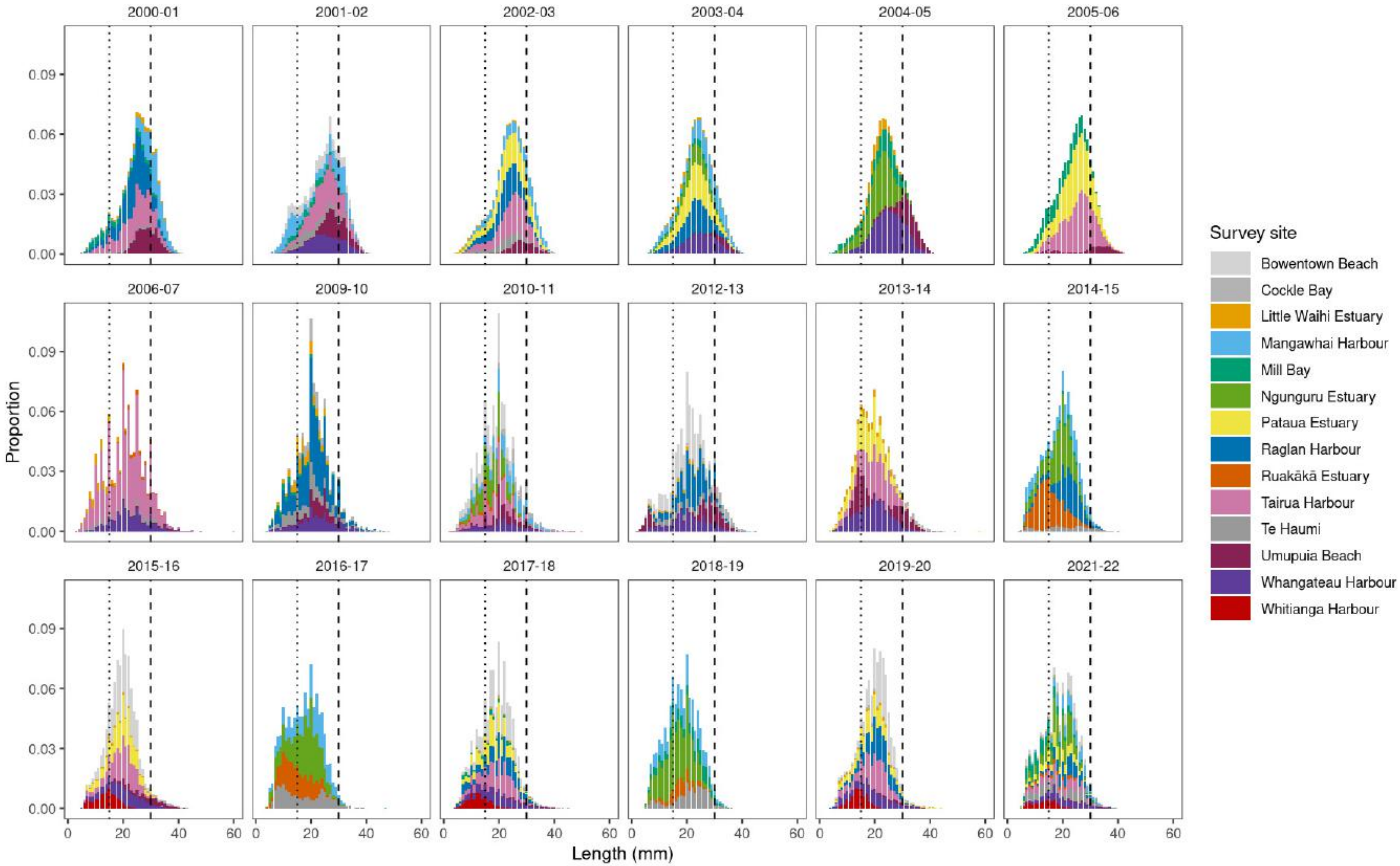


Figure 83: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2021–22 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

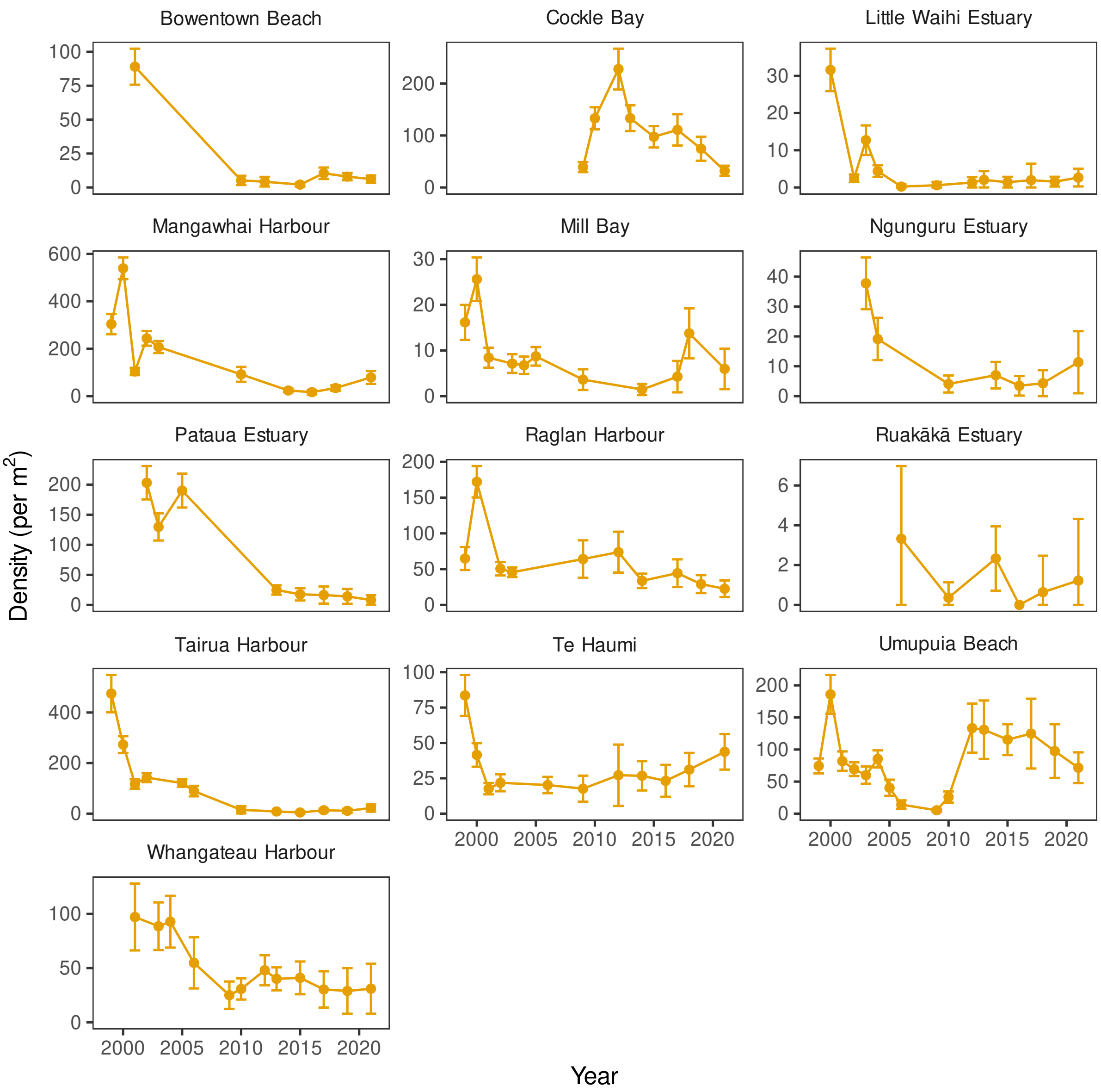


Figure 84: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

For pipi, the current survey assessed populations at eleven of the northern sites (Table 80). In addition to these sites, the 2021–22 field survey also included Marsden Bank, but there were no pipi at this site. Across the sites that supported pipi populations, abundance and density estimates varied considerably, reflecting notable differences in the pipi beds surveyed, particularly in population densities. The largest pipi population in 2021–22 was at Ruakākā Estuary, and this site also had the highest population density; the current estimates were 166.06 million (CV: 14.54%) pipi at a density of 4061 pipi per m^2. The second-highest pipi density was at Te Mata Bay with an estimated 933 pipi per m^2, even though the total abundance was comparatively small (6.35 million pipi; CV: 9.14%). The smallest pipi population was at Bowentown Beach, and the total population estimate of 0.46 million pipi at this site had a high uncertainty with a CV of 23.00%. Other sites with CV values exceeding 20% were Little Waihi Estuary and Pataua Estuary, in spite of increased sampling effort through phase-2 sampling. All three sites were characterised by low population densities (i.e., $\leq$30 individuals per m^2), and this population characteristic was also evident at Raglan Harbour. Densities at all other sites were several hundred individuals per square metre.

Regardless of the total population size, large individuals ($\geq$50 mm shell length) were universally scarce at all sites. In addition, most of the current estimates for this size class had considerable uncertainty. In view of the small number of large pipi, populations were determined by medium-sized individuals and recruits ($\leq$20 mm shell length).

Time-series data highlighted distinct differences between northern pipi populations over time, and notable fluctuations at some of the sites (Figure 85). Pipi populations at Bowentown Beach, Raglan Harbour, and Whangateau Harbour were characterised by low densities overall (i.e., $\leq$100 individuals per m^2), with some variation throughout the survey series. At Ngunguru Estuary and Ruakākā Estuary, pipi densities markedly increased in recent surveys, leading to high estimates in 2021–22. In comparison, Tairua Harbour and Te Haumi supported relatively stable pipi population, with some fluctuations but similar density estimates in recent surveys. Recent density estimates were also similar at Little Waihi Estuary, but this population showed marked fluctuations over the course of the survey series. There were also notable fluctuations at Marsden Bank and Whitianga Harbour, where changes occurred over short time frames (i.e., between any two surveys), indicating the impact of recruitment events on some of the density estimates.

The influence of recruits on pipi populations was also illustrated in the combined length-frequency distributions of the 2021–22 survey sites (Figure 86). In most survey years, recruits either formed a second cohort or contributed to the consistently strong cohort of medium-sized pipi. At the same time, the impact of large pipi on the population size structure lessened over time, as individuals in this size class became fewer.

Low densities and declines of this size class were also documented in the time-series data, although there were some differences across sites (Figure 87). At Pataua Estuary, Raglan Harbour, and Whangateau Harbour, large pipi were only present at low average densities (less than five large pipi per m^2) throughout the survey series. At the other sites, their densities were relatively high at the start of the surveys but experienced an overall decline, except at Ngunguru Estuary. At this latter site, densities of large pipi decreased early in the survey series, leading to their absence in 2014–15, but slowly returned subsequently, reaching similarly high density estimates as at the start of the time series. When comparing the current density estimates at the different sites, the density of large pipi was highest at Te Mata Bay; however, the current estimate signified a decrease from the preceding estimate in the previous survey year.

Table 80: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2020–21 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all pipi (total) and for large pipi (≥50 mm shell length).

Survey site	Population estimate			Population ≥50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Bowentown Beach	0.46	30	23.00	0.01	<1	63.45
Little Waihi Estuary	65.19	392	20.37	1.45	9	45.27
Ngunguru Estuary	34.54	544	9.81	2.74	43	21.58
Pataua Estuary	3.53	13	23.14	0.23	<1	35.33
Raglan Harbour	1.52	21	15.39	0.14	2	18.83
Ruakākā Estuary	166.06	4 061	14.54	0.02	<1	>100
Tairua Harbour	16.43	276	19.55	1.48	25	39.66
Te Haumi	41.89	394	14.45	0.62	6	23.27
Te Mata Bay	6.35	933	9.14	0.57	83	14.65
Whangateau Harbour	20.03	18	12.34	0.50	<1	22.32
Whitianga Harbour	28.36	523	9.48	0.80	15	16.22

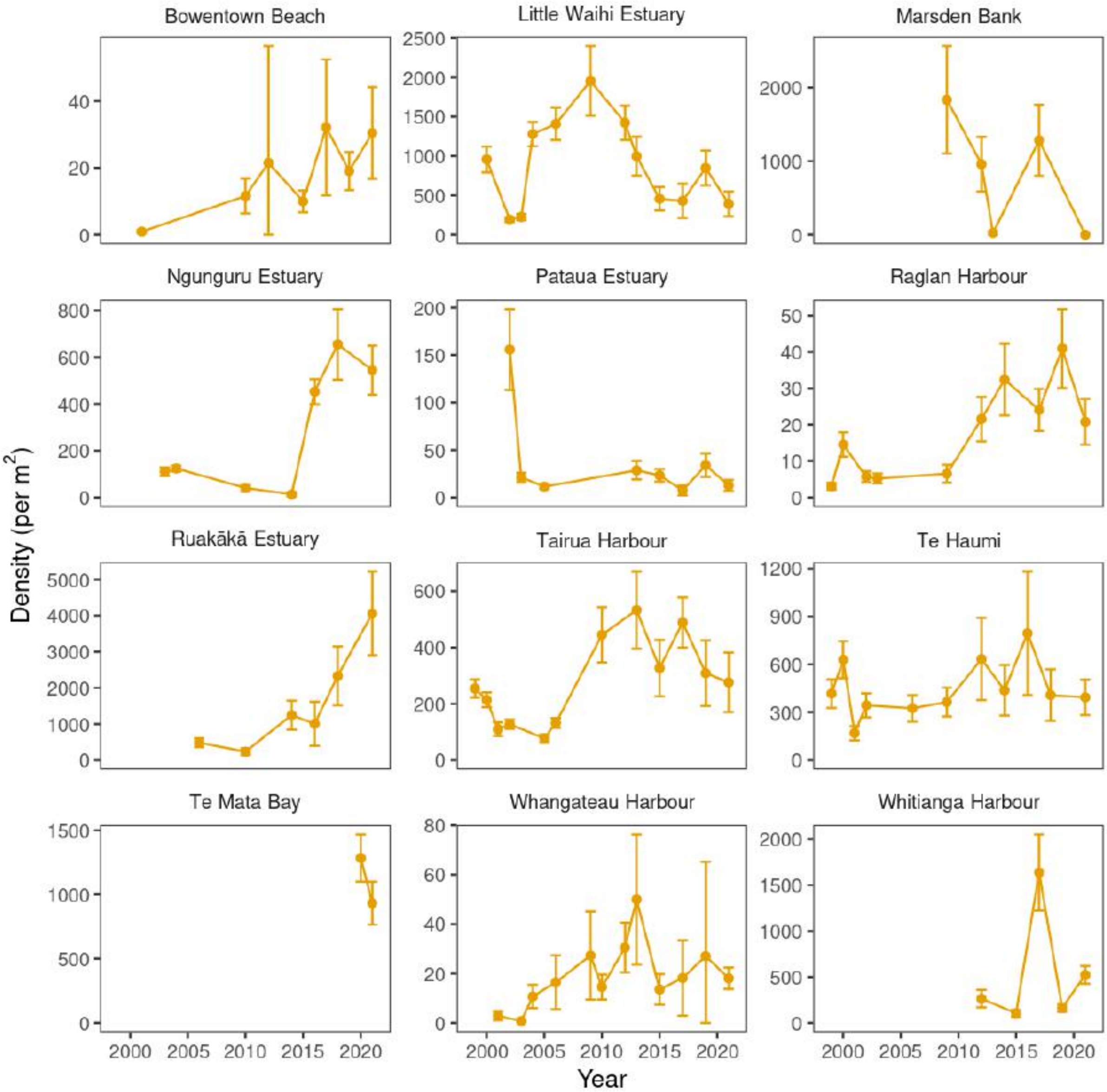


Figure 85: Estimated density of pipi for all sites included in the 2020–21 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

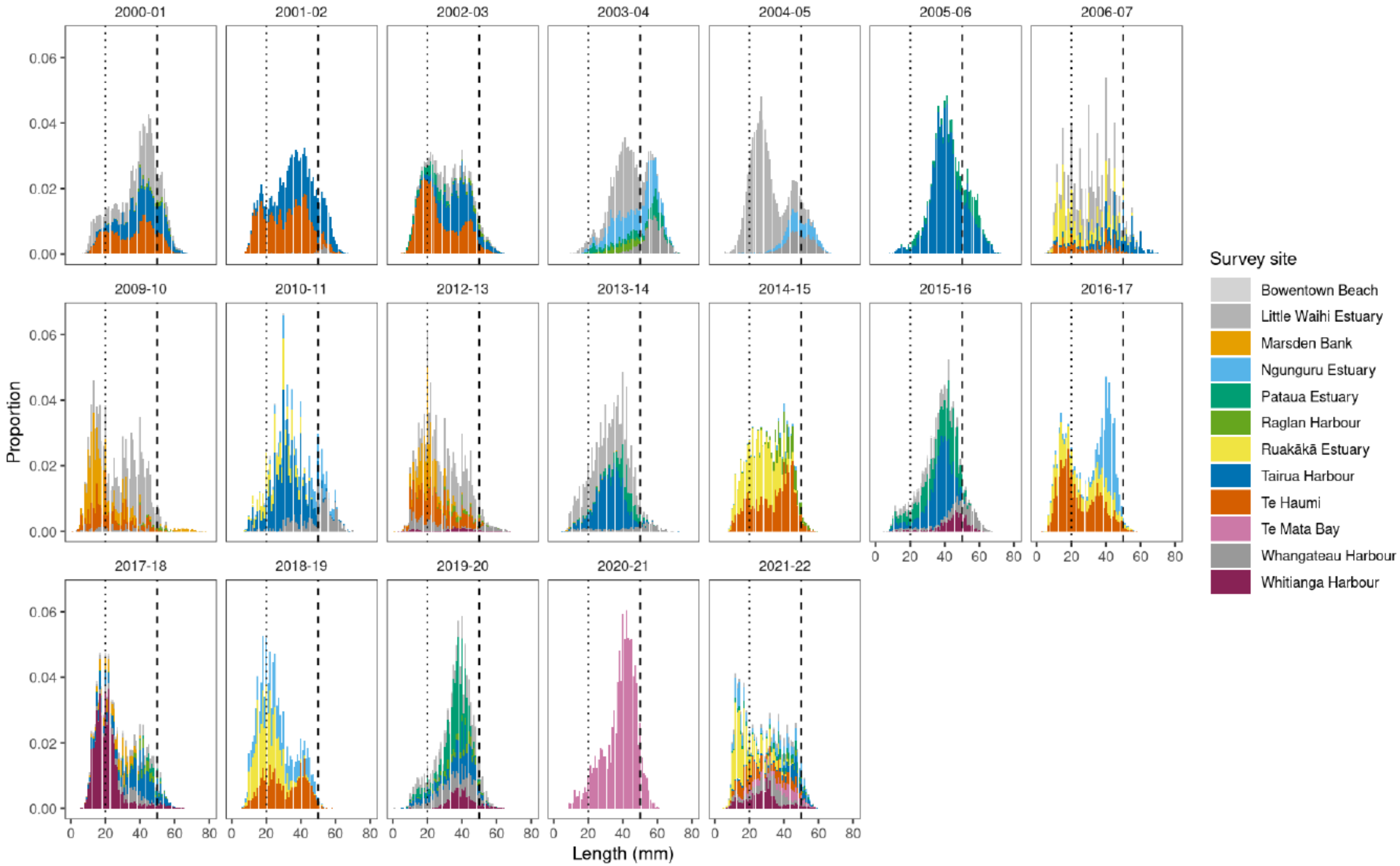


Figure 86: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2020–21 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

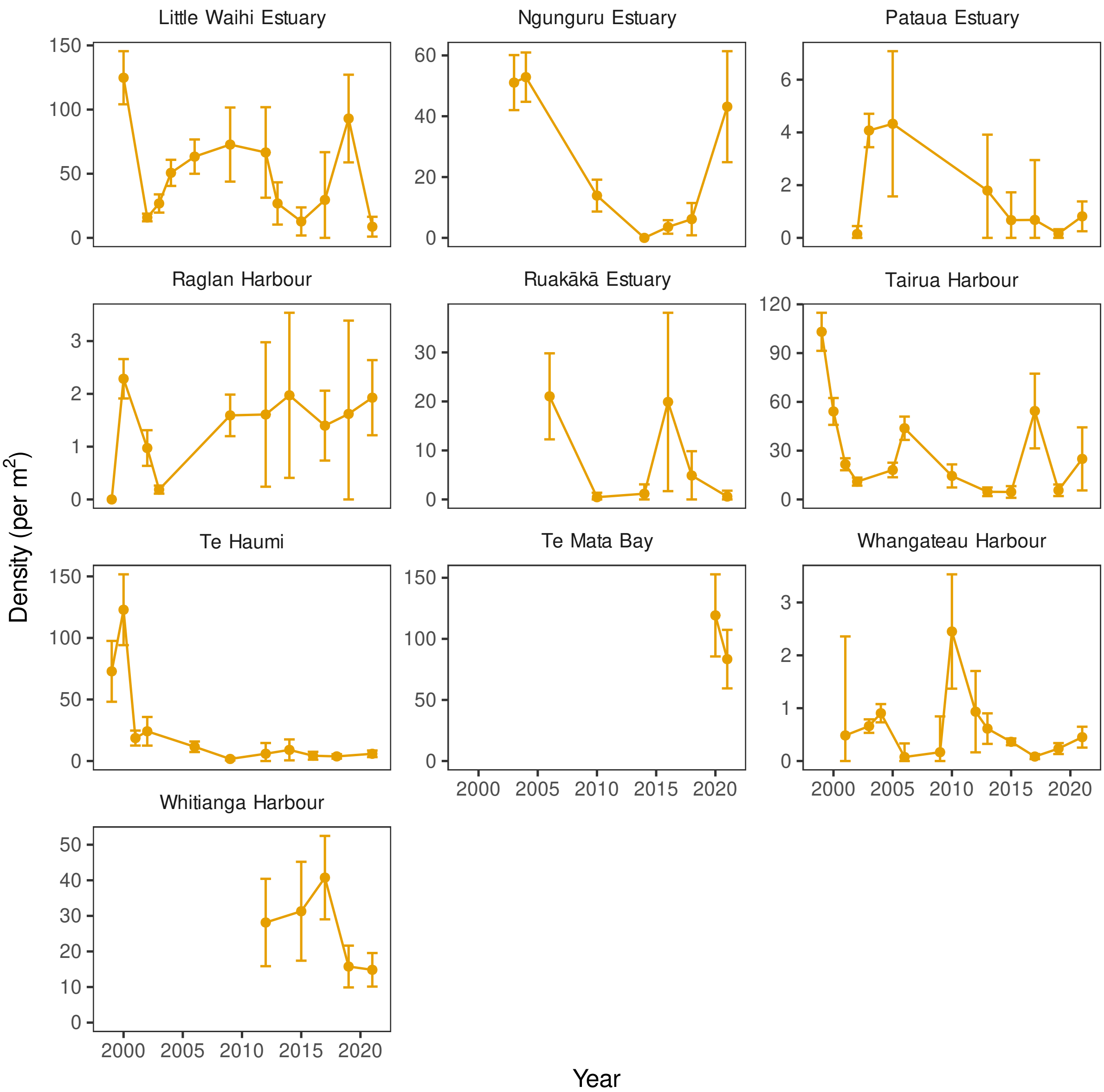


Figure 87: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.3 Sediment data

At all of the 2021–22 sites, the sediment contained only a small amount of organic matter, with organic content averaging between 0.7 and 3.3% (Figure 88). Similarly, the sediment composition was largely determined by fine and medium sands (grain sizes >125 and >250 µm), although there was some variation in the proportion of other grain size fractions depending on the site. This variation included several sites with comparatively high proportions of sediment fines (grain size <63 µm), such as Umupuia Beach, Mill Bay, Raglan Harbour, Whitianga Harbour, and Cockle Bay. Although the average percentage of this grain size fraction only exceeded 10% at Umupuia Beach (where it was 15%), a number of samples contained a substantially larger proportion (up to 77%) of sediment in this grain size fraction. For example, at both Cockle Bay and Tairua Harbour, the average proportion of fines was below 10%, but individual samples contained 37% and 31% of this grain size fraction, respectively.

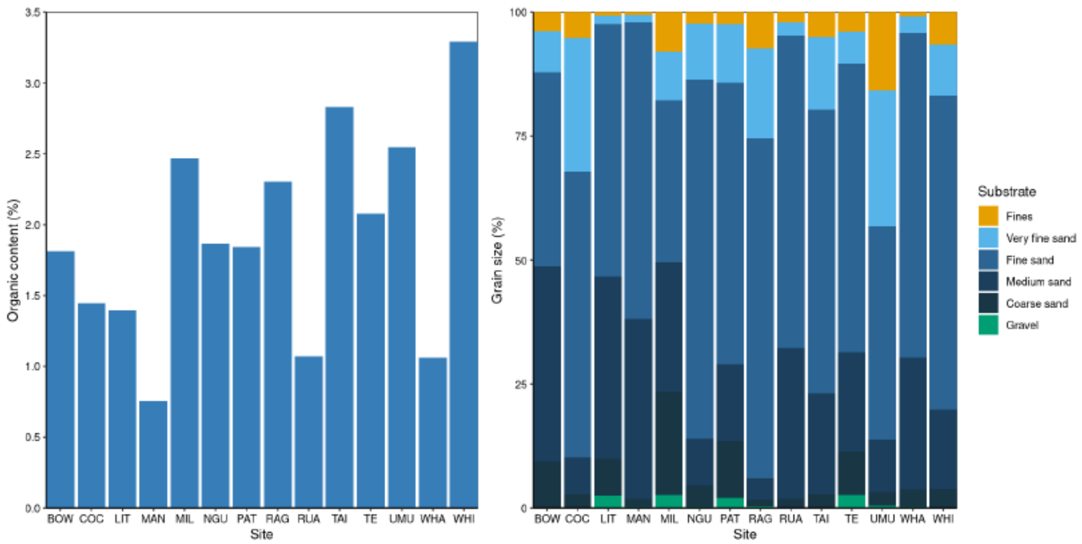


Figure 88: Sediment organic content and grain size composition (averages per site) at the 2020–21 northern survey sites with cockle strata. Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand >63 µm, fine sand >125 µm, medium sand >250 µm, coarse sand >500 µm, and gravel >2000 µm. The sites were Bowentown Beach, Cockle Bay, Little Waihi Estuary, Mangawhai Harbour, Mill Bay, Ngunguru Estuary, Pataua Estuary, Raglan Harbour, Ruakākā Estuary, Tairua Harbour, Te Haumi, Umupuia Beach, Whangateau Harbour, and Whitianga Harbour.

4.4 Geostatistical model predictions of cockle density

The current study also used the survey data to update geostatistical models of cockle densities. These models were not used to provide estimates, but to document spatio-temporal patterns in predicted cockle densities at the 2021–22 survey sites (see maps in Appendix C).

At Bowentown Beach, Pataua Estuary, and Raglan Harbour, high-density areas were similar for all cockles and for large individuals throughout the survey series; these areas were relatively consistent in their spatial extent and cockle densities over time. Similar patterns were evident at Cockle Bay and Umupuia Beach, but with some differences: at Cockle Bay, the spatial distribution of high-density areas shifted over time, whereas at Umupuia Beach there was an overall reduction in cockle densities in the high-density patches, even though their spatial extent remained the same.

At other sites, there were pronounced differences in the spatial patterns between predicted densities of all and large cockles. These sites were Mill Bay, Tairua Harbour, Te Haumi, and Whitianga Harbour. At the former three sites, localised high-density areas of total cockles shifted in their spatial distribution and also changed in predicted densities over time. At Whitianga Harbour, spatial and temporal patterns of predicted total cockle densities were consistent throughout the survey series. In comparison, at Mangawhai Harbour, the spatial distribution of cockle densities was similar for both density measures and over time, but there was a reduction in the spatial extent and density of high-density areas of total cockles.

At Little Waihi Estuary, Ngunguru Estuary, and Whangateau Harbour, there were no distinct localised areas of predicted high cockle densities. Nevertheless, there were some spatial differences in predicted cockle densities at these sites.

5. DISCUSSION

The sixteen survey sites in 2021–22 were spread across northern North Island, within Fisheries Management Areas 1 and 9. The sites were in Auckland (Cockle Bay, Mill Bay, Umupuia Beach), Northland (Mangawhai Harbour, Marsden Bank, Ngunguru Estuary, Pataua Estuary, Ruakākā Estuary, Te Haumi, Whangateau Harbour), Waikato (Raglan Harbour, Tairua Harbour, Te Mata Bay, Whitianga Harbour), and Bay of Plenty (Bowentown Beach, Little Waihi Estuary). These northern sites represented a diversity of intertidal, sedimentary habitats, from small, sheltered bays to beaches and extensive sandflats within large estuarine systems. Six of the 2021–22 survey sites had fishery restrictions in place that prohibited the collection of cockles and pipi; these sites were Cockle Bay and Umupuia Beach within the Auckland metropolitan area, Whangateau Harbour, Marsden Bank, and Ngunguru Estuary in Northland, and Te Mata Bay on Coromandel Peninsula.

Apart from recently-added Te Mata Bay (first surveyed in 2020–21), bivalves at the current sites have been frequently monitored since 1999–2000, with at least five assessments at each site. The most-frequently surveyed site was Umupuia Beach (16 assessments), followed by Little Waihi Estuary, Tairua Harbour, Te Haumi, and Whangateau Harbour (12 surveys each). The high sampling frequency meant that a number of sites were surveyed every two years, or every three years. Based on the regular sampling and consistency of survey methods, time-series data allowed comparisons between sites and the identification of temporal trends.

For cockles, most of the current sites supported high total population numbers and densities. The high estimates were often related to strong recruitment events, ensuring the continuation of cockle populations at these sites. Nevertheless, small-sized recruits did not necessarily grow to larger sizes between surveys, and recent length-frequency distributions highlighted a general lack of growth by individuals into medium and large size classes. The prevalence of recruits was evident in a number of cockle populations: at Little Waihi Estuary, Mill Bay, Pataua Estuary, Ruakākā Estuary, Tairua Harbour, Te Haumi, Whangateau Harbour, and Whitianga Harbour.

A similar population size composition was also evident in the pipi beds at Little Waihi Estuary, Ngunguru Estuary, Pataua Estuary, Ruakākā Estuary, Te Haumi, Whangateau Harbour, Raglan Harbour, Tairua Harbour, and Whitianga Harbour. Nevertheless, several of the populations contained a small proportion of large pipi; there were 8 to 10% of individuals in this size class at Ngunguru Estuary, Raglan Harbour, Tairua Harbour, and Te Mata Bay.

The reasons for the general scarcity of large individuals within northern cockle and pipi populations remain unknown. Large individuals are considered to be preferentially taken in shellfish collections, but the lack of fishing data prevents an assessment of this notion. Furthermore, large individuals also continue to be absent at sites where fishing restrictions have been in place for several years. For example, Whangateau Harbour has been closed to the take of shellfish since 2010, but cockle and pipi populations continue to contain only minor proportions of large individuals at this site. The current mean and modal sizes of either species were around the cut-off lengths for the medium size class (i.e., 15 and 20 mm shell length for cockles and pipi, respectively). A recent analysis of annual survey data collected between 1997 and 2018 in Whangateau Harbour documented similar findings for the cockle population (Tricklebank et al. 2021). Although the population recovered from a mass-mortality event in 2009, there has been no concomitant return of large individuals, and mean sizes have remained at about 18 mm shell length. Potential reasons for the persistent change in the population size structure suggested by the authors were extremely slow growth rates, high mortality of cockles at 25 to 30 mm shell length, and changes in environmental conditions.

In addition to the general dearth of large individuals at most sites, previously-surveyed pipi beds at Mangawhai Harbour and Marsden Bank were no longer present in 2021–22. There was no obvious cause for their disappearance, although changes to the dynamic channel habitat may explain the loss of pipi beds at Mangawhai Harbour. At Marsden Bank, the pipi bed surveyed in 2017–18 was also in a physically-dynamic area, but this habitat still supported a relatively large pipi population given its low abundance and density and prevalence of recruits (about 70%) in 2013–14. In addition, about 22% of the 2017–18 population consisted of recruits, confirming ongoing recruitment to the resident population. Subsequent surveys by Te Patuharakeke Te Iwi Trust Board documented a more restricted spatial distribution of pipi, and predominantly small sizes, including recruits, at this site. By the time of the current survey in 2021–22, there were no pipi at Marsden Bank and no signs of recruitment.

Marsden Bank has been closed to pipi collections since February 2011, so that fishing pressure does not explain the recent depletion of pipi at this site. The 2017–18 Marsden Bank survey reported recently-dead and dying pipi (and other bivalves) at the sediment surface (Berkenbusch & Neubauer 2018). It is possible that this initially small-scale mortality led to the loss of the pipi bed; however, it does not explain the lack of recruits in 2021–22, unless the population is largely self-recruiting. The latter aspect would significantly hamper any population recovery following the unexplained pipi mortalities at this site.

Small-scale bivalve mortalities were also encountered at other sites during the current field sampling: small patches of recently-dead and moribund bivalves were noted at the sediment surface at Cockle Bay (cockles), Mill Bay (cockles), and Ruakākā Estuary (pipi) (K. Berkenbusch, pers. obs.). These mortalities were restricted to localised areas within the sampling extent, but not evident in other areas.

Bivalve mortalities have also been previously reported at other northern sites: large-scale cockle mortalities were recorded during the field sampling at Mill Bay in 2017–18 (Berkenbusch & Neubauer 2018), and there was an extensive pipi die-off at Te Haumi during the reconnaissance of the field survey in 2014–15 (Berkenbusch & Neubauer 2015). Pipi mass mortalities were also reported from Ngunguru Estuary in 2015, which was subsequently closed to cockle and pipi collections in January 2016 (Department of Internal Affairs 2015a). Since the closure, both cockle and pipi populations have maintained high population densities in this estuary; it was the only site where densities of large pipi exhibited a significant increase in 2021–22.

Considering other sites with fishery restrictions, Te Mata Bay had one of the highest total pipi densities and the highest density of large pipi in 2021–22; however, the current estimates signified recent decreases in the population compared with values from 2020–21. At Whangateau Harbour, both species showed some fluctuations but overall stable population trends since the closure was implemented. At Cockle Bay, the total cockle population has been relatively stable in recent surveys, but large cockles continuously declined from initial increases and high densities in 2013–14, following the introduction of the seasonal (summer) closure in 2008. Similarly, large cockles at Umupuia Beach decreased over a similar period, but to a lesser extent, and their current densities were still relatively high. At Cockle Bay, the extension from a seasonal to a year-round closure may alleviate potential impacts from fishing on this size class, but this type of closure is already in place at Umupuia Beach.

Cockle populations at both sites may be impacted by low habitat quality, which may particularly affect large individuals. For example, some of the sediment samples at Cockle Bay and Umupuia Beach had high proportions of sediment fines, indicating potentially unsuitable habitat for filter-feeding cockles. In addition, at both sites, there has been an increasing number of bivalve sampling points that cannot be sampled to the full extent of the 15-cm sampling depth, because solid clay below the sediment surface prevents the penetration of the sampling cores. Although cockles typically reside in the top 3 cm of the sediment (Hewitt & Cummings 2013), the significant compaction below the immediate sediment surface is likely to affect their burrowing and movement, in addition to benthic processes, such as sediment oxygenation and microbial decomposition.

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

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

Table A-1: Sampling years (coloured blue) for sites included in the northern North Island bivalve surveys since 1999–2000. Fishing years are referred to by the latter year (e.g., 1999–2000 is shown as 2000).

Survey site	Year																			
	2000	2001	2002	2003	2004	2005	2006	2007	2010	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Aotea Harbour							■		■				■		■		■		■	
Bowentown Beach			■							■	■			■		■		■		■
Cheltenham Beach														■						
Clarks Beach						■														
Cockle Bay									■	■	■	■		■		■		■		■
Cornwallis Wharf			■																	
Eastern Beach			■										■		■			■		
Grahams Beach								■		■	■	■			■			■		
Hokianga Harbour																	■			
Howick Harbour							■													
Kawakawa Bay (West)						■		■					■		■		■		■	
Little Waihi Estuary		■		■	■	■		■	■		■	■		■		■		■		■
Mangawhai Harbour	■	■	■	■	■					■			■		■		■			■
Marokopa Estuary							■			■				■						
Marsden Bank									■		■	■				■				■
Mill Bay	■	■	■		■	■	■		■				■			■	■			■
Ngunguru Estuary					■	■				■			■		■		■			■
Ōhiwa Harbour			■				■	■	■		■			■			■		■	
Okoromai Bay	■		■	■	■	■		■	■		■	■		■		■			■	
Otūmoetai (Tauranga Harbour)		■		■			■	■	■				■		■		■		■	
Papamoa Beach	■																			
Pataua Estuary				■	■		■					■		■		■		■		■
Raglan Harbour	■	■		■	■				■		■		■			■		■		■
Ruakākā Estuary								■		■			■		■		■			■
Tairua Harbour	■	■	■	■			■	■		■		■		■		■		■		■
Te Haumi Bay	■	■	■	■				■	■		■		■		■		■			■
Te Mata Bay																			■	■
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■		■		■		■		■
Waikawau Beach	■	■				■	■					■								
Waiotahe Estuary				■	■	■	■		■			■			■			■		
Whangamatā Harbour	■	■	■	■	■	■		■		■			■		■		■		■	
Whangapoua Estuary				■	■	■	■			■			■		■		■		■	
Whangateau Harbour			■		■	■		■	■	■	■	■		■		■		■		■
Whitianga Harbour											■			■		■		■		■

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–00, including the present survey in 2021–22. Surveys are ordered by site and year.

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
Aotea Harbour	2005–06	17 Jan–18 Jan	9.60	AKI2005-01
	2009–10	26 Mar–13 Jul	28.10	AKI2009-01
	2014–15	19 Feb	19.46	AKI2014-01
	2016–17	9 Feb	19.46	AKI2016-01
	2018–19	3 Feb	19.46	AKI2018-01
	2020–21	26 Feb	19.40	AKI2018-01
Bowentown Beach	2001–02	26 Apr–25 May	1.58	AKI2001-01
	2010–11	18 Mar	1.58	AKI2010-01
	2012–13	8 Feb	1.58	AKI2012-01
	2015–16	20 Jan	1.50	AKI2015-01
	2017–18	22 Feb	1.50	AKI2017-01
	2019–20	25 Feb	1.50	AKI2018-01
	2021–22	21 Feb–22 Feb	1.50	AKI2021-01
Cheltenham Beach	2015–16	14 Jan	31.92	AKI2015-01
Clarks Beach	2004–05	3 Feb–24 Feb	144.71	AKI2004-01
Cockle Bay	2009–10	16 Feb	16.00	AKI2009-01
	2010–11	5 May	16.00	AKI2010-01
	2012–13	31 Jan	16.00	AKI2012-01
	2013–14	29 Mar	15.77	AKI2013-01
	2015–16	18 Jan	15.77	AKI2015-01
	2017–18	27 Jan–28 Jan	15.77	AKI2017-01
	2019–20	15 Feb	15.77	AKI2018-01
	2021–22	17 Feb	15.59	AKI2021-01
Cornwallis Wharf	2001–02	26 Mar–20 Apr	2.65	AKI2001-01
Eastern Beach	2001–02	14 Mar–16 Apr	43.38	AKI2001-01
	2014–15	27 Jan–18 Feb	41.42	AKI2014-01
	2016–17	16 Feb	22.58	AKI2016-01
	2019–20	10 Feb	22.58	AKI2018-01
Grahams Beach	2006–07	20 Apr	24.75	AKI2006-01
	2010–11	17 May	25.15	AKI2010-01
	2012–13	11 Mar	20.06	AKI2012-01
	2013–14	28 Mar	26.76	AKI2013-01
	2016–17	10 Feb–28 Feb	26.78	AKI2016-01
	2019–20	9 Feb	26.78	AKI2018-01
Hokianga Harbour	2018–19	20 Feb	10.07	AKI2018-01
Howick Harbour	2005–06	23 Dec–24 Jan	6.90	AKI2005-01
Kawakawa Bay (West)	2004–05	5 Feb–8 Apr	60.37	AKI2004-01
	2006–07	19 Apr	62.94	AKI2006-01
	2014–15	17 Feb–25 Feb	60.90	AKI2014-01
	2016–17	27 Feb	60.89	AKI2016-01
	2018–19	4 Feb–25 Feb	60.89	AKI2018-01
	2020–21	10 Feb	60.89	AKI2018-01
Little Waihi Estuary	2000–01	21 Mar–31 Mar	3.00	AKI2000-01
	2002–03	30 Jan–1 Feb	3.00	AKI2002-01
	2003–04	7 Jan–19 Jan	3.12	AKI2003-01
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01
	2006–07	15 Jun–28 Jun	3.16	AKI2006-01
	2009–10	2 Mar	13.92	AKI2009-01
	2012–13	10 Feb	15.42	AKI2012-01
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
	2015–16	8 Feb–11 Feb	18.38	AKI2015-01
	2017–18	23 Feb–24 Feb	18.38	AKI2017-01
	2019–20	28 Feb–29 Feb	16.76	AKI2018-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2021–22	19 Feb–20 Feb	16.63	AKI2021-01
Mangawhai Harbour	1999–00	23 Mar–30 Jun	9.40	AKI1999-01
	2000–01	29 Jan–31 Jan	8.40	AKI2000-01
	2001–02	15 Mar–14 Apr	8.40	AKI2001-01
	2002–03	1 Jan–31 Jan	8.40	AKI2002-01
	2003–04	1 Jan–31 Jan	8.40	AKI2003-01
	2010–11	24 Mar–15 Apr	9.00	AKI2010-01
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
	2018–19	18 Jan–19 Jan	7.23	AKI2018-01
	2021–22	1 Feb–2 Feb	7.17	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
	2021–22	5 Feb	0.87	AKI2021-01
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
	2021–22	16 Feb	4.84	AKI2021-01
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
	2021–22	3 Feb	6.35	AKI2018-01
Ōhiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
	2015–16	9 Feb–10 Feb	4.58	AKI2015-01
	2018–19	1 Feb–2 Feb	2.54	AKI2018-01
	2020–21	16 Feb–19 Feb	2.65	AKI2018-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2015–16	11 Jan	19.84	AKI2015-01
	2017–18	6 Feb	19.83	AKI2017-01
	2020–21	27 Feb	19.83	AKI2018-01
Otūmoetai (Tauranga Harbour)	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
	2016–17	20 Feb–21 Feb	8.09	AKI2016-01
	2018–19	30 Jan–31 Jan	8.06	AKI2018-01
	2020–21	17 Feb	6.52	AKI2018-01
Papamoa Beach	1999–00	1 May–3 May	2.00	AKI1999-01
Pataua Estuary	2002–03	4 Mar–28 Mar	10.65	AKI2002-01
	2003–04	14 Feb–16 Feb	10.45	AKI2003-01
	2005–06	14 Feb–16 Feb	10.45	AKI2005-01
	2013–14	3 Feb–6 Feb	26.30	AKI2013-01
	2015–16	12 Jan–13 Jan	27.78	AKI2015-01
	2017–18	3 Feb–4 Feb	27.71	AKI2017-01
	2019–20	13 Feb	27.92	AKI2018-01
	2021–22	6 Feb–7 Feb	27.88	AKI2021-01
Raglan Harbour	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
	2017–18	29 Jan	7.24	AKI2017-01
	2019–20	8 Feb	7.38	AKI2018-01
	2021–22	30 Jan	7.32	AKI2021-01
Ruakākā 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
	2021–22	5 Feb–6 Feb	4.09	AKI2018-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
	2015–16	6 Feb–7 Feb	8.17	AKI2015-01
	2017–18	20 Feb–22 Feb	6.48	AKI2017-01
	2019–20	23 Feb	6.12	AKI2018-01
	2021–22	23 Feb	5.95	AKI2021-01
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
	2016–17	12 Feb	12.77	AKI2016-01
	2018–19	21 Feb–24 Feb	11.91	AKI2018-01
	2021–22	4 Feb	10.64	AKI2018-01
Te Mata Bay	2020–21	14 Feb–20 Feb	0.97	AKI2018-01
	2021–22	24 Feb–26 Feb	0.68	AKI2021-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
	2017–18	28 Jan	33.43	AKI2017-01
	2019–20	14 Feb	33.43	AKI2018-01
	2021–22	18 Feb	32.72	AKI2021-01
Waikawau Beach	1999–00	20 May–30 Jun	2.90	AKI1999-01
	2000–01	24 Feb–15 May	2.70	AKI2000-01
	2004–05	18 Jan–10 Mar	3.10	AKI2004-01
	2005–06	15 Feb–27 Feb	3.10	AKI2005-01
	2013–14	21 Mar		AKI2013-01
Waiotahe Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
	2019–20	26 Feb–27 Feb	11.98	AKI2018-01
Whangamatā Harbour	1999–00	20 May–29 May	5.48	AKI1999-01
	2000–01	15 Feb–16 Feb	5.48	AKI2000-01
	2001–02	9 May–26 May	5.48	AKI2001-01
	2002–03	9 Mar–28 Mar	5.48	AKI2002-01
	2003–04	1 Jan–31 Jan	5.48	AKI2003-01
	2004–05	6 Feb–8 Feb	5.48	AKI2004-01
	2006–07	2 May–2 Aug	24.61	AKI2006-01
	2010–11	19 Apr	5.89	AKI2010-01
	2014–15	28 Jan–30 Jan	7.62	AKI2014-01
	2016–17	24 Feb–26 Feb	7.71	AKI2016-01
	2018–19	29 Jan–30 Jan	7.55	AKI2018-01
	2020–21	11 Feb	8.18	AKI2018-01
Whangapoua Estuary	2002–03	30 Mar–6 Apr	1.66	AKI2002-01
	2003–04	1 Feb–3 Feb	5.20	AKI2003-01
	2004–05	8 Mar–10 Mar	5.20	AKI2004-01
	2005–06	8 Mar–10 Mar	5.20	AKI2005-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2010–11	21 Apr	5.20	AKI2010-01
	2014–15	24 Feb–25 Feb	6.32	AKI2014-01
	2016–17	25 Feb–26 Feb	6.32	AKI2016-01
	2018–19	27 Jan–28 Jan	5.28	AKI2018-01
	2020–21	12 Feb–13 Feb	5.27	AKI2018-01
Whangateau Harbour	2001–02	7 Apr–22 May	64.19	AKI2001-01
	2003–04	17 Dec–2 Mar	64.15	AKI2003-01
	2004–05	2 Feb–26 Mar	64.15	AKI2004-01
	2006–07	19 Mar–2 May	64.15	AKI2006-01
	2009–10	18 Mar–14 Jul	64.51	AKI2009-01
	2010–11	19 May–20 May	64.15	AKI2010-01
	2012–13	14 Dec–17 Dec	64.20	AKI2012-01
	2013–14	29 Jan–6 Feb	110.91	AKI2013-01
	2015–16	15 Jan–17 Jan	110.71	AKI2015-01
	2017–18	1 Feb–2 Feb	110.91	AKI2017-01
	2019–20	11 Feb	110.88	AKI2018-01
	2021–22	31 Jan–1 Feb	111.20	AKI2021-01
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01
	2015–16	5 Feb	6.10	AKI2015-01
	2017–18	19 Feb–21 Feb	5.81	AKI2017-01
	2019–20	24 Feb	5.44	AKI2018-01
	2021–22	22 Feb–24 Feb	5.43	AKI2021-01

APPENDIX B: Sediment properties

Table B-1: Sediment organic content and sediment grain size distributions at sites surveyed in 2021–22 as part of the northern North Island bivalve surveys. Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediment grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Bowentown Beach	A	1	-37.45750	175.97408	2.0	11.1	6.8	20.1	43.8	18.2	0.0
	A	2	-37.45739	175.97390	2.4	3.8	3.3	22.4	51.2	19.4	0.0
	A	3	-37.45731	175.97369	1.0	1.9	5.2	35.1	43.9	13.6	0.3
	A	4	-37.45720	175.97373	1.6	4.2	2.5	22.4	52.8	18.1	0.0
	A	5	-37.45707	175.97351	0.9	1.1	2.5	26.0	50.6	19.2	0.5
	A	6	-37.45695	175.97336	2.4	2.6	4.1	33.8	46.1	13.2	0.2
	A	7	-37.45689	175.97341	2.2	3.6	10.6	53.2	27.3	5.3	0.0
	A	8	-37.45652	175.97317	1.6	4.1	6.8	40.6	41.4	7.1	0.0
	B	1	-37.45673	175.97210	1.8	4.0	12.4	42.6	35.2	5.7	0.0
	B	2	-37.45665	175.97208	1.6	2.1	13.0	47.5	33.3	4.2	0.0
	B	3	-37.45651	175.97166	4.2	11.0	16.1	42.5	25.6	4.8	0.0
	B	4	-37.45640	175.97136	1.8	5.5	12.3	37.8	35.8	8.5	0.1
	B	5	-37.45639	175.97151	1.4	3.0	9.7	42.2	39.2	5.8	0.0
	B	6	-37.45628	175.97113	1.2	1.9	4.3	30.1	52.3	11.5	0.0
	B	7	-37.45624	175.97117	1.5	4.0	13.4	46.8	31.2	4.5	0.0
	B	8	-37.45624	175.97110	2.1	4.1	9.7	35.0	43.5	7.7	0.0
	C	1	-37.45593	175.97099	1.6	3.2	8.7	46.2	36.6	5.2	0.0
	C	2	-37.45579	175.97222	1.0	1.3	3.1	40.1	48.2	7.4	0.0
	C	3	-37.45570	175.97239	1.0	1.9	2.8	28.8	50.5	15.9	0.0
	C	4	-37.45568	175.97118	2.0	3.7	14.6	44.3	31.4	5.9	0.0
	C	5	-37.45562	175.97149	3.4	5.5	13.7	50.1	26.6	4.0	0.2
	C	6	-37.45550	175.97192	1.1	1.1	6.5	48.9	37.2	6.1	0.0
	C	7	-37.45541	175.97247	1.7	2.6	9.3	54.0	28.7	5.3	0.0
	C	8	-37.45527	175.97255	1.9	3.6	8.1	49.5	34.0	4.9	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Cockle Bay	A	1	-36.90057	174.95355	1.7	8.1	46.2	40.2	3.9	1.5	0.0
	A	2	-36.90009	174.95485	1.2	2.4	20.7	64.8	10.2	1.8	0.2
	A	3	-36.90005	174.95372	1.4	4.1	36.6	48.5	6.7	3.9	0.2
	A	4	-36.89986	174.95327	1.7	4.1	38.1	50.9	4.7	2.2	0.0
	A	5	-36.89860	174.95750	1.1	2.9	24.0	71.2	1.4	0.5	0.0
	A	6	-36.89791	174.95410	1.8	12.7	31.4	43.9	8.0	4.0	0.0
	A	7	-36.89772	174.95365	1.4	3.6	23.8	65.8	5.9	0.9	0.0
	A	8	-36.89720	174.95349	1.1	2.9	19.6	74.8	2.7	0.0	0.0
	B	1	-36.90036	174.95548	0.9	2.8	21.8	64.3	9.0	2.1	0.0
	B	2	-36.90023	174.95546	1.5	4.4	24.3	56.3	11.5	3.4	0.2
	B	3	-36.89998	174.95525	1.3	5.2	29.2	55.6	6.1	3.8	0.0
	B	4	-36.89988	174.95171	1.7	3.5	32.6	46.2	12.6	5.1	0.0
	B	5	-36.89986	174.95526	1.4	3.8	25.4	58.7	6.7	5.5	0.0
	B	6	-36.89965	174.95548	1.4	3.8	24.0	64.0	7.0	1.2	0.0
	B	7	-36.89942	174.95147	1.8	2.7	14.8	41.2	27.7	11.2	2.5
	B	8	-36.89924	174.95429	1.1	2.5	24.6	62.8	8.3	1.9	0.0
	B	9	-36.89910	174.95364	1.3	2.9	28.6	58.9	7.8	1.9	0.0
	B	10	-36.89909	174.95352	1.3	2.5	29.4	59.3	6.7	2.0	0.0
	B	11	-36.89856	174.95303	3.5	37.5	29.5	25.7	3.8	3.5	0.0
	B	12	-36.89842	174.95339	1.2	2.9	28.7	61.5	5.5	1.4	0.0
	B	13	-36.89803	174.95292	1.4	4.9	34.9	50.2	5.1	4.9	0.0
	B	14	-36.89798	174.95605	1.1	1.9	18.5	73.1	5.9	0.6	0.0
	B	15	-36.89797	174.95621	1.1	2.1	22.5	72.1	2.9	0.4	0.0
	B	16	-36.89787	174.95559	1.2	1.2	16.8	75.5	5.9	0.6	0.0
Little Waihi Estuary	A	1	-37.76331	176.48023	2.0	0.2	0.3	29.2	47.5	22.4	0.3
	A	2	-37.76299	176.48139	2.3	1.2	3.4	56.1	31.6	7.3	0.4
	A	3	-37.76211	176.48128	1.2	0.7	2.6	77.7	17.9	1.0	0.1
	A	4	-37.76201	176.48199	1.6	3.2	3.4	60.5	28.8	4.3	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	5	-37.76200	176.48236	1.6	1.0	2.8	67.2	26.3	2.7	0.0
	A	6	-37.76086	176.48044	1.4	0.0	1.5	62.8	34.4	1.2	0.1
	A	7	-37.76068	176.48067	1.3	0.2	1.2	47.6	42.9	7.8	0.2
	A	8	-37.76059	176.48088	1.0	0.0	1.5	68.2	29.9	0.4	0.0
	A	9	-37.76027	176.48051	1.0	0.2	0.8	40.0	47.6	9.2	2.1
	A	10	-37.76007	176.47990	1.4	0.0	0.5	43.7	43.6	6.5	5.7
	B	1	-37.76094	176.48230	2.1	2.5	5.2	66.0	23.4	2.8	0.0
	B	2	-37.76005	176.48140	1.8	1.2	5.2	63.3	25.4	4.8	0.1
	B	3	-37.75991	176.48119	2.3	1.8	4.3	70.3	20.9	2.2	0.5
	B	4	-37.75963	176.48052	1.2	0.0	0.2	23.2	64.1	11.7	0.8
	B	5	-37.75961	176.48118	1.6	1.3	3.1	67.2	27.7	0.7	0.0
	B	6	-37.75940	176.47935	0.9	0.2	1.0	29.2	34.6	14.2	20.8
	B	7	-37.75925	176.48079	1.0	0.0	0.4	31.3	50.5	17.8	0.0
	B	8	-37.75893	176.48028	0.9	0.1	0.6	63.2	35.5	0.6	0.0
	B	9	-37.75805	176.47851	1.6	1.0	2.1	53.1	24.0	15.3	4.4
	C	1	-37.75879	176.47994	1.6	0.2	0.4	42.6	51.7	5.0	0.1
	C	2	-37.75878	176.48014	1.0	0.0	0.8	55.8	42.2	1.3	0.0
	C	3	-37.75849	176.47983	0.9	0.0	0.3	45.4	50.1	3.0	1.2
	C	4	-37.75768	176.47941	0.8	0.2	0.2	37.9	56.2	5.6	0.0
	C	5	-37.75711	176.47910	1.0	0.2	0.1	22.8	26.9	25.3	24.7
Mangawhai Harbour	A	1	-36.08549	174.59034	1.1	1.4	1.5	57.1	38.7	1.3	0.0
	A	2	-36.08461	174.59021	0.5	0.1	0.5	33.2	60.0	6.2	0.0
	A	3	-36.08457	174.59107	0.8	0.2	1.5	78.5	18.5	1.3	0.0
	A	4	-36.08435	174.59111	0.9	0.2	1.5	78.7	19.0	0.6	0.0
	A	5	-36.08431	174.59051	0.8	0.5	0.8	40.3	54.2	4.3	0.0
	A	6	-36.08365	174.59097	0.7	0.5	1.0	47.0	47.5	4.0	0.0
	B	1	-36.08699	174.59031	0.8	0.3	1.5	63.8	33.5	0.8	0.0
	B	2	-36.08684	174.59018	0.7	0.4	1.1	64.5	33.0	1.0	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	3	-36.08640	174.59055	1.0	0.3	2.0	71.5	23.8	2.3	0.0
	B	4	-36.08624	174.59038	0.6	0.4	1.2	65.3	32.6	0.5	0.0
	B	5	-36.08605	174.59081	1.1	0.6	1.9	72.3	23.1	2.1	0.0
	B	6	-36.08577	174.59091	0.7	0.3	1.4	63.3	31.4	2.5	1.2
	C	1	-36.08904	174.59020	0.6	0.4	1.1	49.8	47.8	0.7	0.2
	C	2	-36.08886	174.59037	0.6	0.0	0.2	43.1	55.6	1.1	0.0
	C	3	-36.08857	174.59016	0.7	1.1	1.2	60.9	36.2	0.6	0.0
	C	4	-36.08798	174.59007	0.5	0.1	1.4	48.4	48.2	1.0	0.8
	C	5	-36.08787	174.59040	0.6	0.2	2.4	57.5	35.7	2.5	1.7
	C	6	-36.08746	174.59022	0.6	0.1	0.7	48.8	49.8	0.6	0.0
	D	1	-36.09892	174.59252	0.7	0.7	2.3	61.4	34.0	1.6	0.0
	D	2	-36.09832	174.59210	0.6	0.1	1.7	57.7	38.8	1.7	0.0
	D	3	-36.09784	174.59184	1.3	3.1	2.8	65.7	27.9	0.4	0.0
	D	4	-36.09718	174.59221	0.6	0.3	1.8	70.0	27.7	0.1	0.0
	D	5	-36.09687	174.59148	1.1	1.1	3.6	77.8	17.3	0.2	0.0
	D	6	-36.09656	174.59173	0.7	0.2	1.0	61.1	36.5	1.2	0.0
Mill Bay	A	1	-36.99545	174.60734	1.5	8.4	7.3	33.4	32.0	17.6	1.2
	A	2	-36.99518	174.60718	2.2	7.4	8.0	22.7	33.0	27.5	1.4
	A	3	-36.99496	174.60743	2.4	5.1	6.7	39.0	30.8	17.5	0.8
	A	4	-36.99472	174.60743	2.3	9.7	6.3	27.5	33.3	22.4	0.7
	A	5	-36.99469	174.60792	2.6	8.1	7.8	29.5	31.6	21.5	1.5
	A	6	-36.99455	174.60773	5.5	6.2	4.8	36.4	33.5	18.4	0.8
	B	1	-36.99399	174.60517	2.9	10.0	31.1	28.1	13.2	15.7	1.9
	B	2	-36.99387	174.60589	2.6	11.5	12.0	30.5	20.8	20.8	4.4
	B	3	-36.99362	174.60669	2.0	10.3	12.1	41.5	17.7	16.7	1.7
	B	4	-36.99342	174.60491	2.6	4.0	9.1	19.2	22.1	31.8	13.7
	B	5	-36.99333	174.60668	2.0	8.0	12.4	48.1	17.3	12.8	1.3
	B	6	-36.99304	174.60545	2.5	5.0	8.2	21.1	21.4	30.9	13.5

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	C	1	-36.99525	174.60762	1.4	5.4	5.1	36.1	32.9	18.8	1.8
	C	2	-36.99505	174.60754	2.3	10.3	6.0	15.0	36.8	28.6	3.3
	C	3	-36.99498	174.60799	1.2	4.9	5.7	47.7	24.4	16.4	0.9
	C	4	-36.99494	174.60803	1.8	6.2	5.1	37.9	29.5	20.0	1.3
	C	5	-36.99488	174.60820	2.2	9.0	7.5	31.9	28.3	22.5	0.8
	C	6	-36.99474	174.60822	1.8	3.1	2.3	21.4	38.6	33.9	0.6
	D	1	-36.99522	174.60678	3.3	8.2	17.5	34.2	19.3	17.8	3.0
	D	2	-36.99443	174.60634	2.2	9.0	9.1	31.1	23.6	21.1	6.0
	D	3	-36.99439	174.60668	3.6	8.6	13.7	42.2	22.0	13.0	0.5
	D	4	-36.99438	174.60640	2.1	10.5	11.7	35.3	20.5	20.3	1.7
	D	5	-36.99403	174.60700	2.9	10.2	12.8	39.1	22.6	15.3	0.1
	D	6	-36.99380	174.60727	3.2	13.2	12.1	34.2	20.8	18.6	1.2
Ngunguru Estuary	A	1	-35.63521	174.50083	2.2	3.4	15.2	64.9	11.6	4.9	0.0
	A	2	-35.63455	174.50113	1.7	1.5	11.0	72.2	12.4	2.9	0.0
	A	3	-35.63447	174.50123	1.9	2.2	10.2	76.3	8.8	2.5	0.0
	A	4	-35.63413	174.50127	1.9	1.6	11.4	72.1	10.8	4.0	0.0
	A	5	-35.63408	174.50150	2.3	2.4	7.4	61.6	19.2	9.4	0.0
	A	6	-35.63396	174.50152	1.5	2.5	7.7	69.3	15.2	5.2	0.0
	A	7	-35.63336	174.50194	1.8	2.3	8.3	60.9	17.3	10.8	0.3
	A	8	-35.63274	174.50258	2.1	1.1	14.7	56.3	11.1	14.7	2.1
	B	1	-35.63726	174.50438	1.2	1.2	7.0	77.4	13.6	0.7	0.0
	B	2	-35.63680	174.50445	1.0	0.6	7.4	77.7	13.2	1.2	0.0
	B	3	-35.63647	174.50460	1.5	1.8	8.5	82.3	6.6	0.8	0.0
	B	4	-35.63631	174.50460	1.2	1.1	13.9	77.2	5.7	2.1	0.0
	B	5	-35.63614	174.50468	1.2	1.8	11.3	72.5	10.8	3.6	0.0
	B	6	-35.63596	174.50469	1.4	0.6	5.5	63.7	17.2	11.3	1.7
	B	7	-35.63589	174.50469	2.4	0.5	4.3	45.7	27.7	21.7	0.0
	B	8	-35.63546	174.50498	1.5	2.1	8.8	78.4	9.7	1.0	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	C	1	-35.63744	174.50272	1.9	2.9	14.3	79.5	2.8	0.6	0.0
	C	2	-35.63723	174.50264	2.0	2.9	15.5	79.1	1.8	0.8	0.0
	C	3	-35.63696	174.50283	1.7	1.8	14.0	81.5	1.9	0.8	0.0
	C	4	-35.63681	174.50269	2.4	3.5	13.2	81.4	1.5	0.4	0.0
	C	5	-35.63667	174.50160	1.5	1.2	12.8	81.9	3.7	0.4	0.0
	C	6	-35.63614	174.50242	2.9	5.8	17.3	74.1	1.9	1.0	0.0
	C	7	-35.63576	174.50263	2.7	5.4	17.5	74.9	1.8	0.4	0.0
	C	8	-35.63569	174.50267	2.7	4.8	15.4	77.0	2.0	0.7	0.0
Pataua Estuary	A	1	-35.71896	174.51573	1.8	1.0	8.8	50.4	18.2	19.6	2.0
	A	2	-35.71798	174.51704	1.6	2.7	7.4	48.5	26.0	11.0	4.4
	A	3	-35.71795	174.51642	1.6	1.7	12.4	78.2	5.7	2.0	0.0
	A	4	-35.71779	174.51520	1.3	1.3	6.1	67.4	21.0	4.2	0.0
	A	5	-35.71762	174.51586	1.4	2.3	10.7	58.7	19.4	8.0	1.0
	A	6	-35.71742	174.51691	2.3	3.0	16.9	53.1	9.8	14.1	3.1
	A	7	-35.71732	174.51838	1.4	0.3	3.9	24.6	19.4	28.2	23.5
	A	8	-35.71715	174.51915	1.3	0.0	0.8	53.1	35.0	10.3	0.8
	A	9	-35.71696	174.51773	2.2	3.2	14.4	77.3	3.1	2.0	0.0
	A	10	-35.71683	174.51589	1.9	3.8	10.9	56.1	16.0	10.2	3.1
	A	11	-35.71649	174.51805	1.7	2.4	7.4	66.6	17.4	6.2	0.0
	A	12	-35.71647	174.51810	1.7	1.6	10.6	69.6	15.2	3.1	0.0
	B	1	-35.72126	174.51205	1.9	8.3	5.4	27.6	28.6	25.1	5.0
	B	2	-35.72103	174.51360	3.0	3.2	21.3	40.2	14.2	17.4	3.7
	B	3	-35.72026	174.51091	1.0	1.8	5.3	35.7	28.7	27.0	1.5
	B	4	-35.71949	174.51288	1.9	2.1	16.8	69.0	6.9	5.2	0.0
	B	5	-35.71937	174.51147	2.3	3.4	21.1	68.5	4.3	2.7	0.0
	B	6	-35.71935	174.51331	1.4	0.7	7.1	49.5	27.6	15.0	0.2
	B	7	-35.71905	174.51185	2.1	2.5	17.1	63.3	7.4	9.8	0.0
	B	8	-35.71889	174.51098	2.3	4.6	12.4	51.0	14.6	17.3	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	9	-35.71880	174.51299	1.2	0.0	4.1	31.2	29.9	34.8	0.0
	B	10	-35.71827	174.51344	2.0	2.1	21.8	74.6	1.1	0.4	0.0
	B	11	-35.71775	174.51251	2.1	2.6	18.0	77.3	1.7	0.4	0.0
	B	12	-35.71729	174.51217	2.8	3.2	21.5	73.0	1.9	0.4	0.0
Raglan Harbour	A	1	-37.80524	174.86619	2.2	8.0	20.1	69.1	1.6	1.2	0.0
	A	2	-37.80506	174.86560	3.4	9.5	19.0	65.7	2.8	3.1	0.0
	A	3	-37.80488	174.86637	2.2	7.5	19.1	72.2	0.8	0.4	0.0
	A	4	-37.80452	174.86646	1.9	5.6	17.2	74.7	1.6	0.8	0.0
	A	5	-37.80384	174.86702	2.0	6.6	18.4	73.3	1.0	0.7	0.0
	A	6	-37.80369	174.86715	2.6	11.2	20.6	66.9	0.7	0.5	0.0
	A	7	-37.80366	174.86651	2.1	2.8	8.6	68.0	17.0	3.6	0.0
	A	8	-37.80298	174.86725	2.5	10.1	16.8	70.3	1.8	1.0	0.0
	A	9	-37.80293	174.86761	3.2	10.2	22.8	54.1	3.1	4.0	5.7
	A	10	-37.80270	174.86694	2.7	1.9	5.2	61.9	25.1	5.3	0.6
	A	11	-37.80249	174.86778	3.8	16.8	26.5	52.3	2.3	2.1	0.0
	A	12	-37.80222	174.86739	2.7	11.7	18.8	68.3	1.0	0.2	0.0
	D	1	-37.79663	174.86938	2.0	5.8	19.7	67.0	6.5	0.9	0.0
	D	2	-37.79629	174.86913	1.5	2.2	10.3	87.1	0.3	0.0	0.0
	D	3	-37.79625	174.87044	1.1	3.5	21.7	67.3	6.6	0.9	0.0
	D	4	-37.79615	174.87093	1.4	5.9	18.9	68.3	6.2	0.8	0.0
	D	5	-37.79609	174.87093	2.6	8.7	17.2	67.1	6.2	0.8	0.0
	D	6	-37.79607	174.87087	2.4	8.4	13.3	68.2	8.8	1.3	0.0
	D	7	-37.79598	174.87132	1.9	5.9	23.1	66.6	3.6	0.9	0.0
	D	8	-37.79597	174.87198	2.4	8.6	27.4	62.3	1.4	0.3	0.0
	D	9	-37.79589	174.87025	1.9	3.4	16.0	79.8	0.5	0.4	0.0
	D	10	-37.79580	174.87034	1.7	3.6	19.8	75.0	0.5	1.1	0.0
	D	11	-37.79573	174.87113	2.1	7.6	17.0	73.4	1.6	0.4	0.0
	D	12	-37.79567	174.87147	2.9	9.9	16.1	71.1	1.3	1.5	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Ruakākā Estuary	A	1	-35.89835	174.46164	1.7	6.0	4.1	45.0	42.1	2.7	0.0
	A	2	-35.89826	174.46144	1.5	4.5	3.2	46.3	44.1	2.0	0.0
	A	3	-35.89822	174.46056	0.8	0.7	2.2	83.2	13.8	0.1	0.0
	A	4	-35.89821	174.46128	2.8	8.7	4.0	52.1	33.3	1.9	0.0
	A	5	-35.89820	174.46045	1.2	1.0	3.6	82.0	13.2	0.2	0.0
	A	6	-35.89820	174.46074	2.1	6.2	7.6	73.5	11.9	0.9	0.0
	A	7	-35.89819	174.46141	1.4	3.8	2.2	53.5	39.5	0.9	0.0
	A	8	-35.89818	174.46093	1.3	2.1	4.2	65.5	26.3	1.9	0.0
	A	9	-35.89817	174.46064	2.1	3.9	5.8	82.7	7.3	0.3	0.0
	A	10	-35.89816	174.46110	1.1	3.1	2.3	63.7	29.0	1.8	0.0
	A	11	-35.89814	174.46058	1.0	1.1	3.0	73.1	22.2	0.7	0.0
	A	12	-35.89814	174.46043	1.4	3.0	3.9	76.3	16.1	0.6	0.0
	B	1	-35.90250	174.45676	0.5	0.2	1.4	73.2	25.1	0.1	0.0
	B	2	-35.90246	174.45647	0.7	0.5	1.7	55.5	40.5	1.9	0.0
	B	3	-35.90244	174.45667	0.6	0.5	1.6	75.9	21.8	0.2	0.0
	B	4	-35.90236	174.45654	0.7	0.5	1.9	72.5	24.8	0.3	0.0
	B	5	-35.90232	174.45645	0.6	0.3	1.5	68.7	28.8	0.6	0.0
	B	6	-35.90221	174.45596	0.7	0.2	1.7	58.1	38.3	1.8	0.0
	B	7	-35.90217	174.45598	0.6	0.2	0.7	45.0	51.4	2.7	0.0
	B	8	-35.90213	174.45584	0.7	0.3	0.8	45.1	51.1	2.6	0.0
	B	9	-35.90206	174.45551	0.5	0.5	1.7	46.1	46.6	5.1	0.0
	B	10	-35.90204	174.45570	0.6	0.5	1.5	63.1	33.7	1.1	0.1
	B	11	-35.90200	174.45566	0.7	0.3	2.4	51.0	35.3	10.7	0.3
	B	12	-35.90193	174.45530	0.7	0.2	1.8	61.3	34.8	1.9	0.0
Tairua Harbour	A	1	-37.00733	175.85290	3.2	4.2	13.9	64.2	16.3	1.4	0.0
	A	2	-37.00702	175.85362	1.6	2.2	5.3	68.5	19.4	4.5	0.0
	A	3	-37.00675	175.85333	3.1	3.4	14.6	66.4	13.3	2.4	0.0
	A	4	-37.00670	175.85388	2.0	0.7	5.0	72.5	18.7	3.1	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	A	5	-37.00607	175.85412	3.6	3.7	17.2	72.0	6.6	0.5	0.0
	A	6	-37.00565	175.85397	2.8	2.2	14.2	54.1	24.1	5.0	0.3
	A	7	-37.00532	175.85476	2.0	2.6	6.3	35.8	42.4	12.9	0.0
	A	8	-37.00477	175.85505	1.4	0.2	2.4	55.2	37.7	4.4	0.0
	B	1	-37.00729	175.85256	2.1	2.8	13.2	54.5	25.6	3.9	0.0
	B	2	-37.00702	175.85292	4.8	6.7	23.5	64.8	4.2	0.8	0.0
	B	3	-37.00654	175.85302	3.9	5.4	20.2	65.5	8.1	0.8	0.0
	B	4	-37.00622	175.85292	3.4	6.1	20.8	64.2	8.0	0.9	0.0
	B	5	-37.00614	175.85493	1.6	0.2	0.7	57.4	39.2	2.6	0.0
	B	6	-37.00609	175.85465	1.8	0.5	1.5	80.2	17.4	0.4	0.0
	B	7	-37.00575	175.85586	1.4	31.1	0.4	27.1	38.9	2.7	0.0
	B	8	-37.00488	175.85534	1.3	0.2	1.0	42.8	49.6	6.4	0.0
	C	1	-37.00718	175.85229	3.0	2.9	19.6	58.9	16.4	2.1	0.0
	C	2	-37.00696	175.85203	2.1	2.8	16.4	57.2	20.3	3.2	0.0
	C	3	-37.00688	175.85270	4.5	5.6	29.9	58.6	4.8	1.1	0.0
	C	4	-37.00687	175.85248	4.1	8.2	34.4	50.2	6.6	0.6	0.0
	C	5	-37.00683	175.85244	4.1	8.1	31.7	52.3	7.3	0.6	0.0
	C	6	-37.00671	175.85245	4.3	9.2	33.4	52.6	4.2	0.6	0.0
	C	7	-37.00646	175.85263	4.5	8.2	30.2	56.1	4.8	0.7	0.0
	C	8	-37.00568	175.85597	1.6	0.0	0.7	41.2	53.4	4.7	0.0
Te Haumi	A	1	-35.29649	174.09996	2.2	2.2	1.9	57.2	33.8	3.1	1.9
	A	2	-35.29599	174.09945	1.7	0.2	0.8	29.8	45.2	23.1	0.9
	A	3	-35.29586	174.09994	1.7	1.2	0.4	29.7	42.7	19.5	6.6
	A	4	-35.29574	174.09931	2.1	5.3	6.1	58.0	22.9	7.3	0.4
	A	5	-35.29547	174.09967	1.8	2.9	3.7	64.2	24.4	4.8	0.0
	B	1	-35.29634	174.10256	2.1	3.0	3.8	60.5	15.5	13.4	3.8
	B	2	-35.29604	174.10139	2.0	1.8	0.2	13.0	33.2	37.9	13.8
	B	3	-35.29555	174.10167	2.2	2.4	1.8	50.8	23.3	18.0	3.8

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	B	4	-35.29521	174.10152	1.9	3.2	1.0	29.6	26.8	21.7	17.7
	B	5	-35.29513	174.10129	2.2	1.1	0.5	26.0	31.9	28.1	12.3
	C	1	-35.29510	174.09983	1.9	2.4	3.5	67.4	24.0	2.7	0.0
	C	2	-35.29510	174.09966	2.1	3.2	2.8	60.3	31.6	2.0	0.0
	C	3	-35.29494	174.10200	2.0	4.7	8.5	68.9	7.0	9.7	1.2
	C	4	-35.29491	174.10059	2.1	6.0	7.6	70.8	12.7	3.0	0.0
	C	5	-35.29470	174.10167	1.7	4.7	6.7	77.4	9.8	1.4	0.0
	D	1	-35.29485	174.09981	2.2	4.0	3.1	62.3	29.2	1.3	0.0
	D	2	-35.29462	174.10196	2.8	8.3	9.6	71.9	8.7	1.5	0.0
	D	3	-35.29462	174.09989	2.0	2.7	4.9	74.0	16.8	1.6	0.1
	D	4	-35.29439	174.10121	2.0	6.2	8.6	68.9	12.5	3.7	0.1
	D	5	-35.29420	174.10085	2.3	7.2	11.1	69.7	8.1	3.8	0.0
	E	1	-35.29444	174.10192	1.9	4.0	14.6	76.9	4.0	0.6	0.0
	E	2	-35.29411	174.10157	2.5	8.6	11.1	71.0	8.7	0.6	0.0
	E	3	-35.29392	174.10173	2.3	6.8	25.5	62.1	2.6	3.0	0.0
	E	4	-35.29391	174.10153	2.1	3.9	15.2	76.6	4.0	0.3	0.0
Umupuia Beach	A	1	-36.90395	175.07239	4.5	61.4	20.0	9.8	7.0	1.8	0.0
	A	2	-36.90339	175.07076	3.8	32.4	23.4	30.4	12.3	1.4	0.0
	A	3	-36.90329	175.06784	1.5	1.1	0.3	21.8	37.0	35.9	3.9
	A	4	-36.90261	175.06812	3.0	5.6	28.1	40.6	13.0	9.0	3.6
	A	5	-36.90252	175.06733	3.8	24.5	7.4	40.2	27.2	0.7	0.0
	A	6	-36.90221	175.06870	2.0	5.8	49.6	32.9	9.5	2.2	0.0
	A	7	-36.90172	175.06665	8.5	57.7	23.3	11.5	6.0	0.8	0.6
	A	8	-36.90116	175.06772	1.5	6.9	42.6	41.1	8.4	0.8	0.1
	A	9	-36.90099	175.06761	1.2	3.2	35.5	48.4	11.8	1.1	0.0
	A	10	-36.90082	175.06872	1.9	3.4	36.7	46.3	10.9	2.0	0.6
	A	11	-36.90061	175.06874	1.2	3.3	32.1	52.9	9.3	1.9	0.4
	A	12	-36.89960	175.06518	4.9	53.8	34.7	8.0	2.8	0.7	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	A	13	-36.89915	175.06682	1.7	4.9	27.0	58.4	8.6	1.2	0.0
	A	14	-36.89884	175.06713	1.2	5.1	27.4	63.2	4.2	0.1	0.0
	B	1	-36.90338	175.06959	3.0	5.9	9.1	49.3	33.2	2.5	0.0
	B	2	-36.90295	175.06912	7.9	76.8	9.9	9.5	3.4	0.3	0.0
	B	3	-36.90265	175.07333	1.4	7.8	46.0	41.8	3.4	1.0	0.0
	B	4	-36.90264	175.07445	1.2	4.0	61.0	30.9	3.7	0.4	0.0
	B	5	-36.90238	175.07427	1.4	4.0	47.0	43.5	4.8	0.7	0.0
	B	6	-36.89851	175.06727	1.0	0.6	20.3	70.8	8.2	0.1	0.0
	B	7	-36.89804	175.06620	1.0	1.8	21.5	67.1	9.4	0.2	0.0
	B	8	-36.89793	175.06659	1.1	1.5	19.2	71.3	7.7	0.3	0.0
	B	9	-36.89766	175.06550	1.3	4.5	20.4	67.7	6.8	0.6	0.0
	B	10	-36.89703	175.06586	1.1	2.0	16.2	75.9	5.6	0.2	0.0
Whangateau Harbour	A	1	-36.33709	174.76433	1.2	1.9	11.7	77.4	8.8	0.2	0.0
	A	2	-36.33585	174.76335	2.5	1.3	4.8	72.6	21.1	0.2	0.0
	A	3	-36.33357	174.76461	1.5	1.6	5.6	79.6	11.8	1.4	0.0
	A	4	-36.33332	174.76437	1.5	2.1	5.0	80.3	11.7	0.9	0.0
	A	5	-36.33227	174.76363	0.9	0.3	2.8	89.6	7.0	0.2	0.0
	A	6	-36.33135	174.76459	0.8	0.4	2.1	71.7	24.8	0.9	0.0
	A	7	-36.32994	174.76604	1.1	0.8	3.3	79.0	15.1	1.8	0.0
	A	8	-36.32912	174.76567	0.8	0.7	5.1	87.3	6.6	0.4	0.0
	A	9	-36.32906	174.76777	0.9	0.6	3.0	79.0	15.7	1.7	0.0
	A	10	-36.32868	174.76708	0.9	0.7	4.9	76.2	16.8	1.2	0.0
	A	11	-36.32699	174.77041	1.1	1.5	5.2	76.3	12.4	4.7	0.0
	A	12	-36.32678	174.76839	1.0	0.2	3.1	83.5	11.4	1.8	0.0
	B	1	-36.31811	174.77698	1.1	0.0	0.5	34.5	50.3	12.3	2.4
	B	2	-36.31789	174.77716	0.8	0.0	0.4	37.7	48.7	12.1	1.1
	B	3	-36.31738	174.77733	0.7	0.0	0.3	29.8	56.6	13.2	0.1
	B	4	-36.31478	174.78121	0.8	0.4	1.0	62.0	36.0	0.6	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	C	1	-36.31654	174.77599	1.0	0.4	0.3	29.2	58.3	11.8	0.0
	C	2	-36.31449	174.78297	1.3	3.1	8.6	70.0	17.6	0.8	0.0
	C	3	-36.31421	174.78032	0.8	0.6	1.9	71.1	26.0	0.5	0.0
	D	1	-36.31628	174.77375	0.9	0.0	0.7	56.1	40.7	2.5	0.0
	D	2	-36.31461	174.77800	0.7	0.6	0.9	54.0	41.4	3.0	0.0
	D	3	-36.31329	174.77876	0.9	0.7	0.4	32.9	57.5	8.0	0.5
	D	4	-36.31276	174.77447	0.9	1.1	3.4	71.2	21.6	2.6	0.0
	D	5	-36.31262	174.77628	1.2	1.3	5.3	69.7	20.8	2.8	0.0
Whitianga Harbour	A	1	-36.84495	175.69918	3.2	6.2	5.9	61.1	23.5	3.3	0.0
	A	2	-36.84469	175.69945	3.4	7.3	6.6	63.4	19.5	3.3	0.0
	A	3	-36.84466	175.69882	3.2	10.9	6.6	55.2	21.9	5.5	0.0
	A	4	-36.84453	175.69995	3.0	5.6	6.9	62.8	21.8	3.0	0.0
	A	5	-36.84440	175.69915	3.5	7.6	6.6	68.7	14.5	2.5	0.0
	A	6	-36.84433	175.69823	2.9	5.8	14.4	62.1	13.8	3.8	0.2
	A	7	-36.84418	175.70004	3.3	7.9	3.7	46.8	34.2	7.4	0.0
	A	8	-36.84411	175.69833	4.0	6.7	18.4	60.0	12.4	2.5	0.0
	A	9	-36.84400	175.69876	3.5	6.6	15.5	61.9	11.5	4.5	0.0
	A	10	-36.84396	175.69939	2.8	6.0	10.3	63.0	14.9	5.8	0.0
	A	11	-36.84387	175.70066	2.7	4.2	5.4	63.9	24.0	2.5	0.0
	A	12	-36.84381	175.70023	3.8	8.5	7.4	71.1	11.0	2.1	0.0
	A	13	-36.84380	175.69925	3.5	9.4	10.9	53.3	19.0	7.5	0.0
	A	14	-36.84371	175.69962	3.0	5.6	11.4	64.3	15.0	3.6	0.0
	A	15	-36.84357	175.69988	2.7	3.7	13.1	65.4	14.9	2.9	0.0
	A	16	-36.84351	175.70135	3.0	5.1	8.3	71.7	13.1	1.8	0.0
	A	17	-36.84348	175.70007	3.0	6.7	12.5	65.9	12.1	2.8	0.0
	A	18	-36.84330	175.70104	4.5	6.3	10.2	75.8	6.9	0.8	0.0
	A	19	-36.84327	175.69964	3.8	8.2	12.4	54.5	15.7	9.3	0.0
	A	20	-36.84320	175.70038	2.4	5.1	11.7	72.7	9.4	1.1	0.0

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Table B-1 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	A	21	-36.84316	175.70021	3.0	5.2	13.7	67.9	10.4	2.8	0.0
	A	22	-36.84295	175.70105	3.9	7.1	12.0	65.0	13.2	2.7	0.0
	A	23	-36.84274	175.70085	3.4	6.3	12.8	61.2	14.4	5.3	0.0
	A	24	-36.84268	175.70077	3.5	4.6	13.1	61.6	15.6	5.1	0.0

APPENDIX C: Geostatistical model predictions

This section provides the outcomes of the geostatististal modelling for 13 of the 14 northern North Island sites that were surveyed in 2021–22 and contained cockle populations. Because these models require little to no change in the location and size of cockle strata over time, Ruakākā Estuary was excluded from the modelling. In this estuary, cockle strata have undergone considerable changes between surveys, owing to significant physical shifts of the main estuary channel over time.

C.1 Bowentown Beach

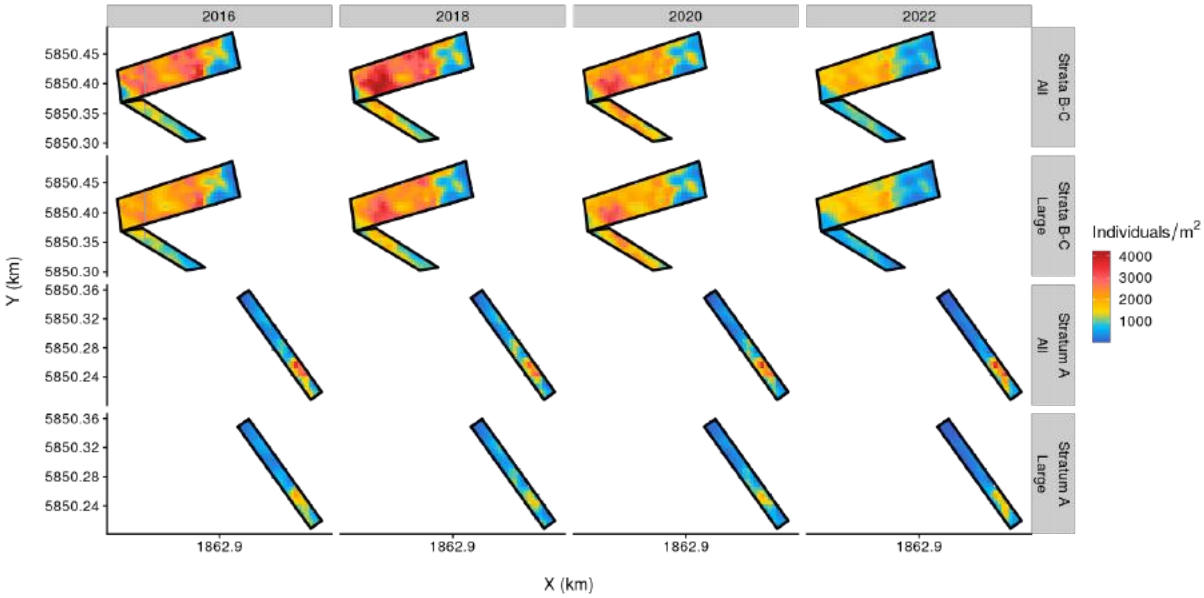

Figure C-1: Predicted cockle densities from the spatio-temporal model for Bowentown Beach. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.2 Cockle Bay

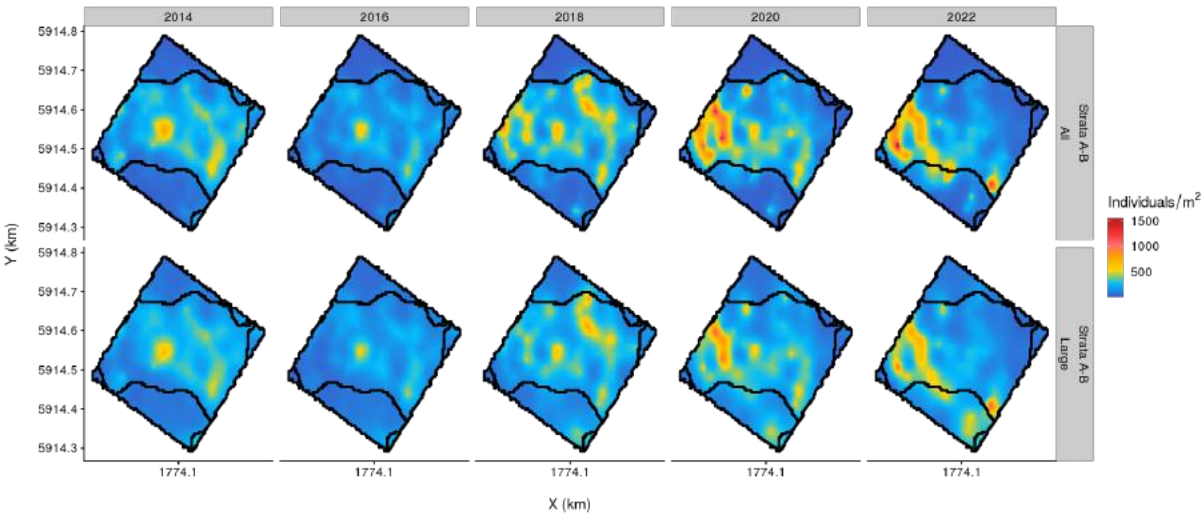

Figure C-2: Predicted cockle densities from the spatio-temporal model for Cockle Bay. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.3 Little Waihi Estuary

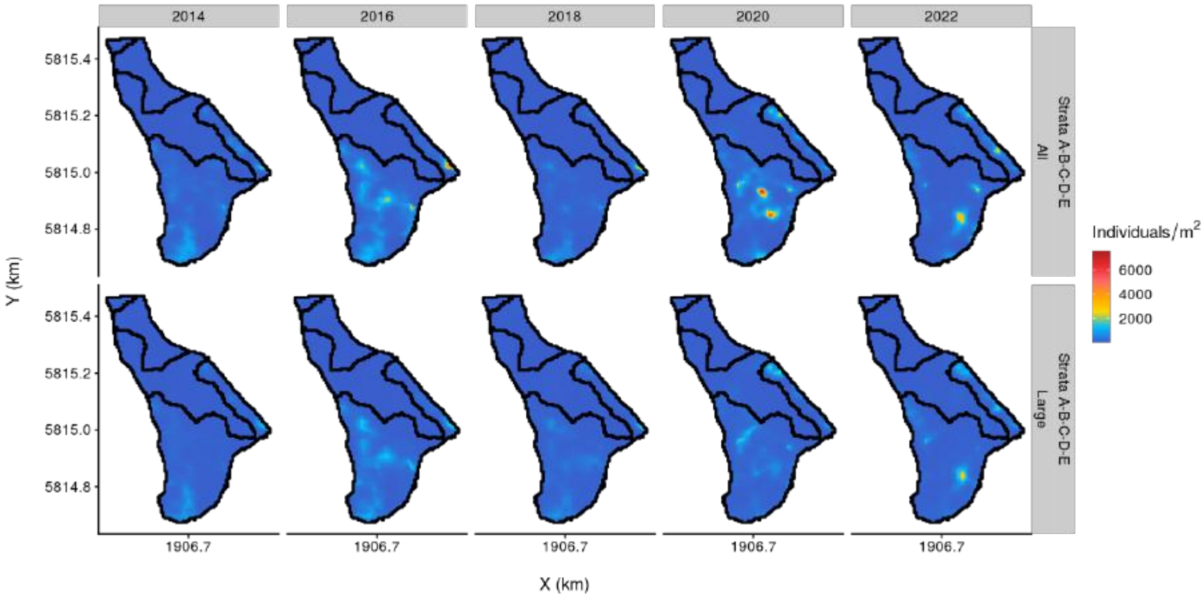

Figure C-3: Predicted cockle densities from the spatio-temporal model for Little Waihi Estuary. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.4 Mangawhai Harbour

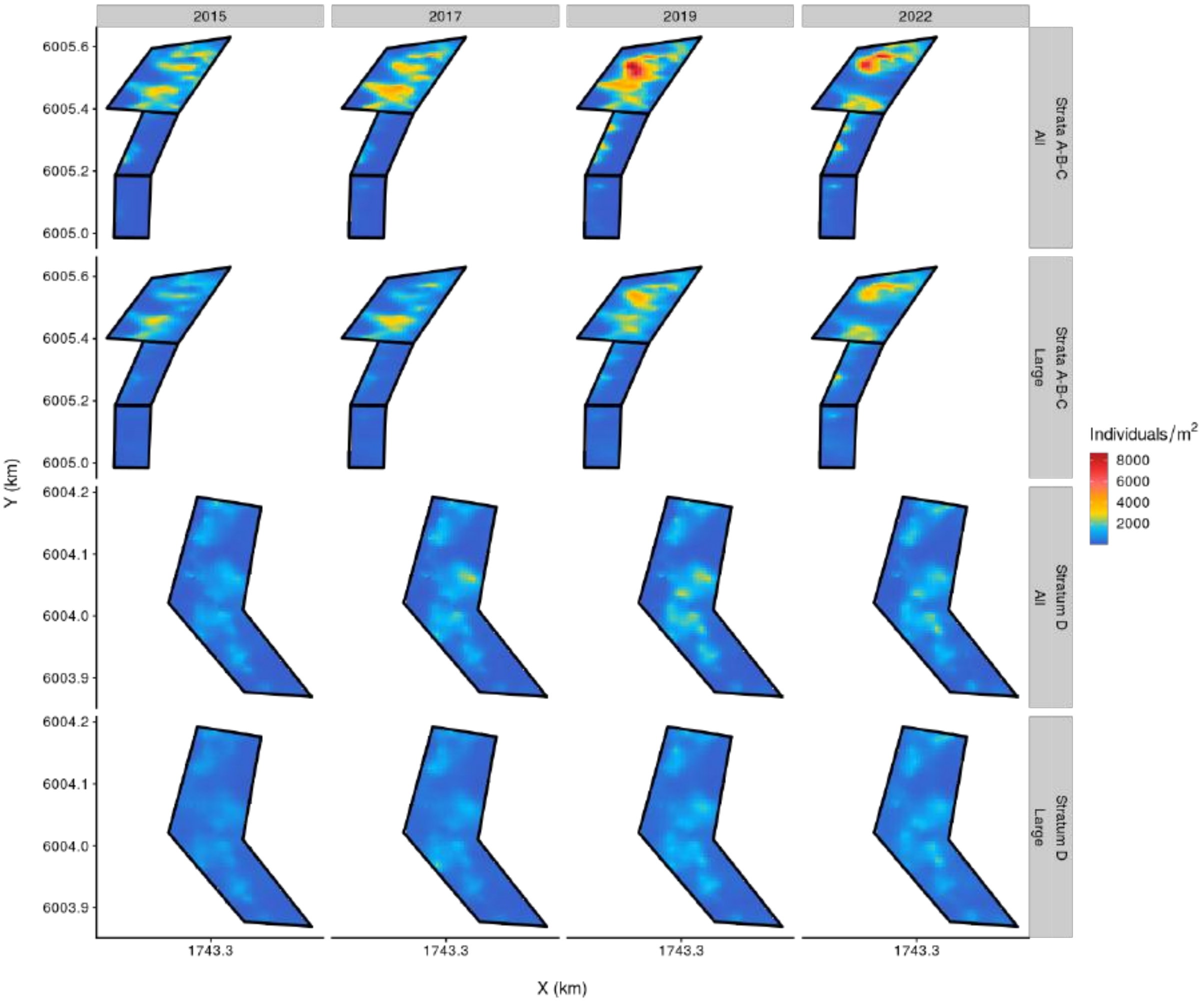

Figure C-4: Predicted cockle densities from the spatio-temporal model for Mangawhai Harbour. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.5 Mill Bay

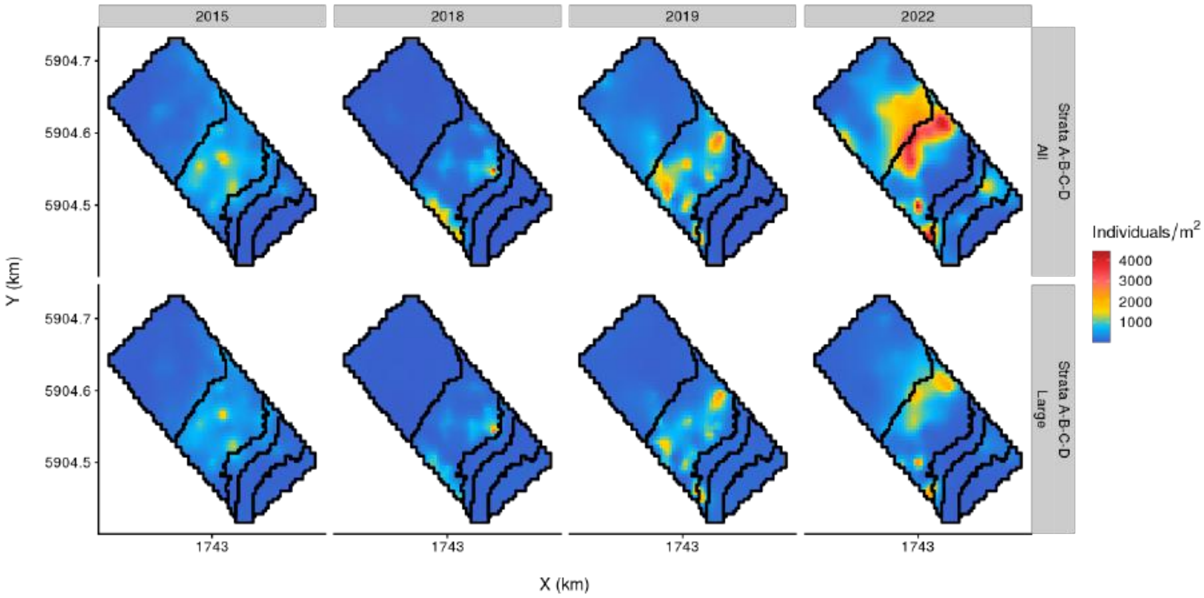

Figure C-5: Predicted cockle densities from the spatio-temporal model for Mill Bay. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.6 Ngunguru Estuary

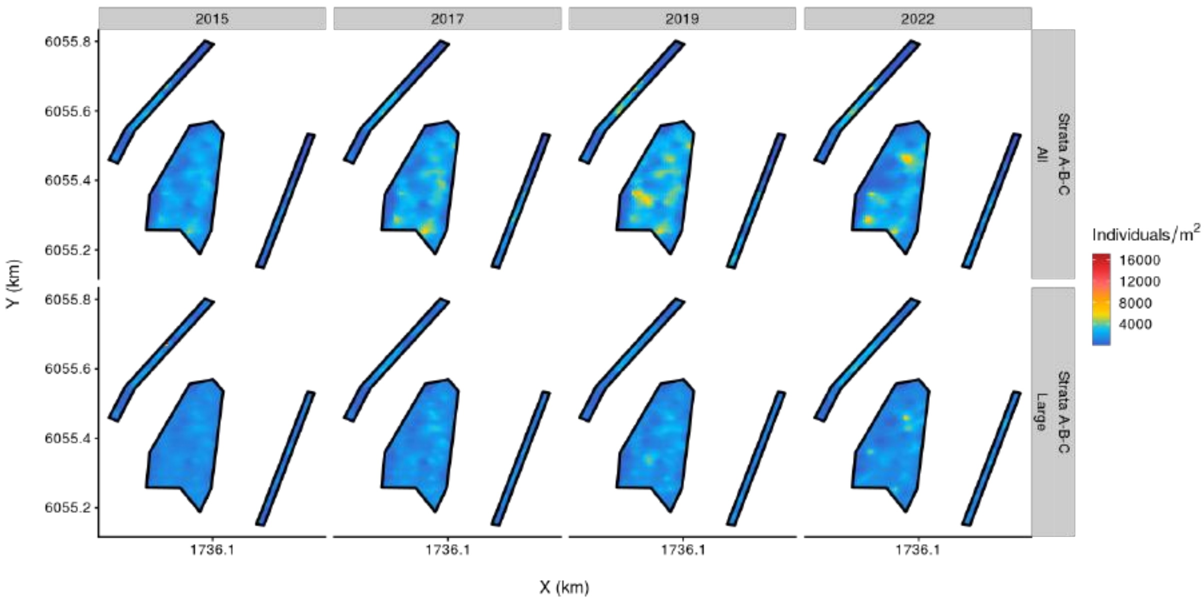

Figure C-6: Predicted cockle densities from the spatio-temporal model for Ngunguru Estuary. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.7 Pataua Estuary

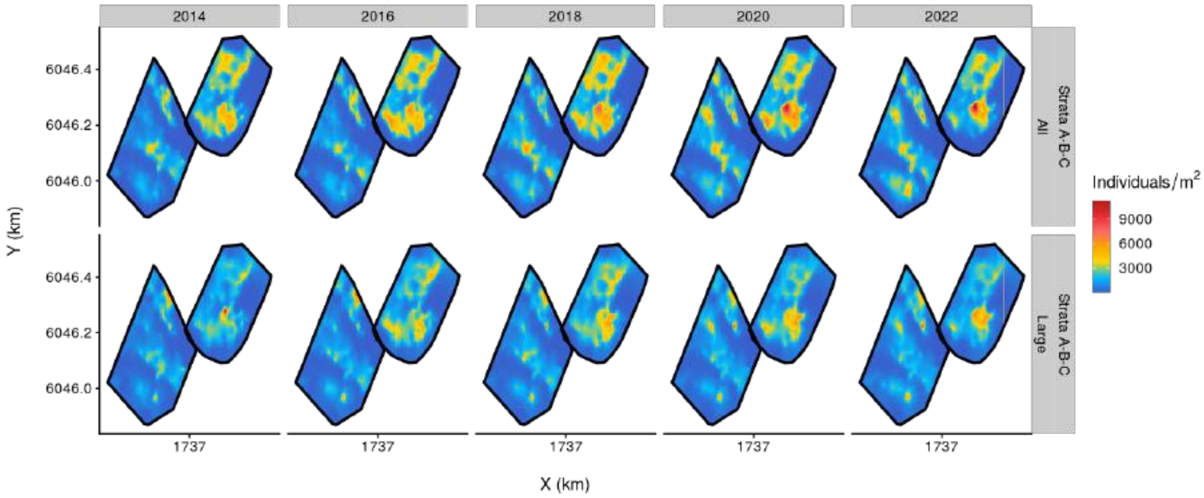

Figure C-7: Predicted cockle densities from the spatio-temporal model for Pataua Estuary. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.8 Raglan Harbour

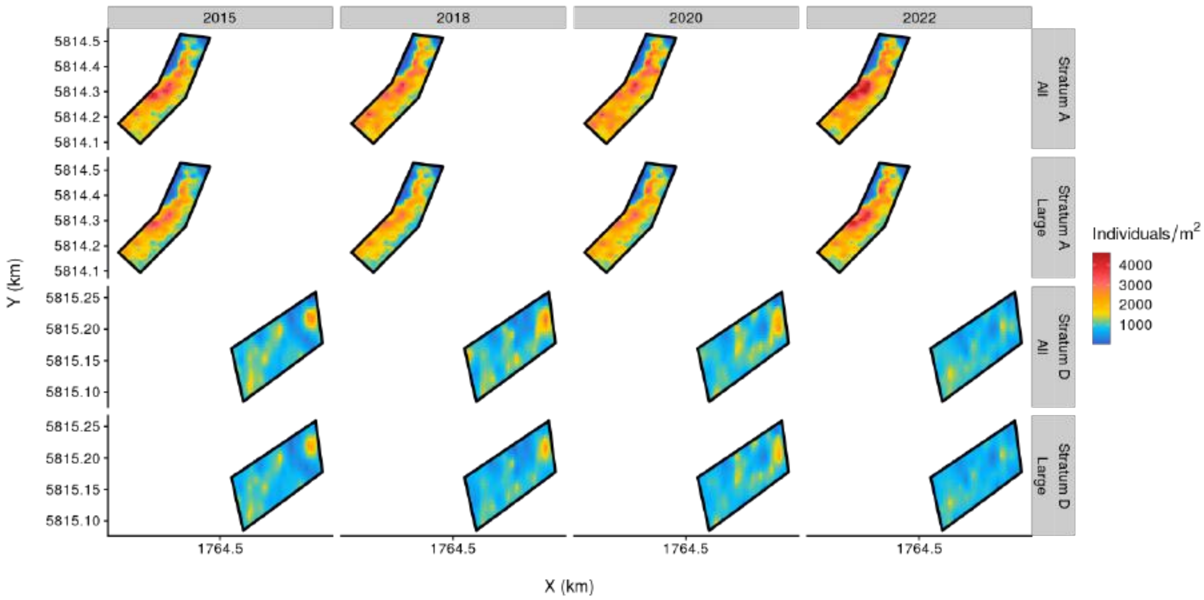

Figure C-8: Predicted cockle densities from the spatio-temporal model for Raglan Harbour. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.9 Tairua Harbour

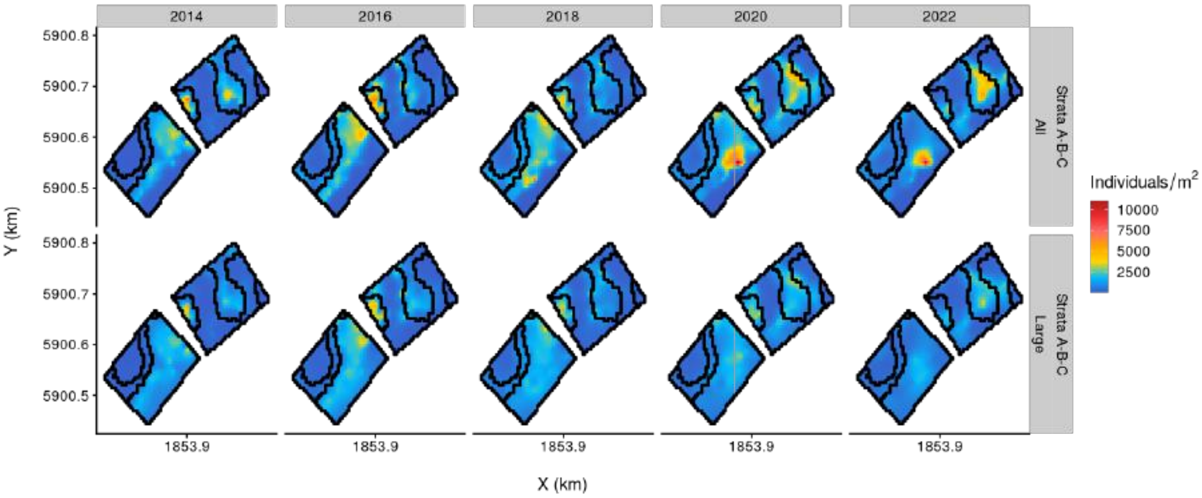

Figure C-9: Predicted cockle densities from the spatio-temporal model for Tairua Harbour. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.10 Te Haumi

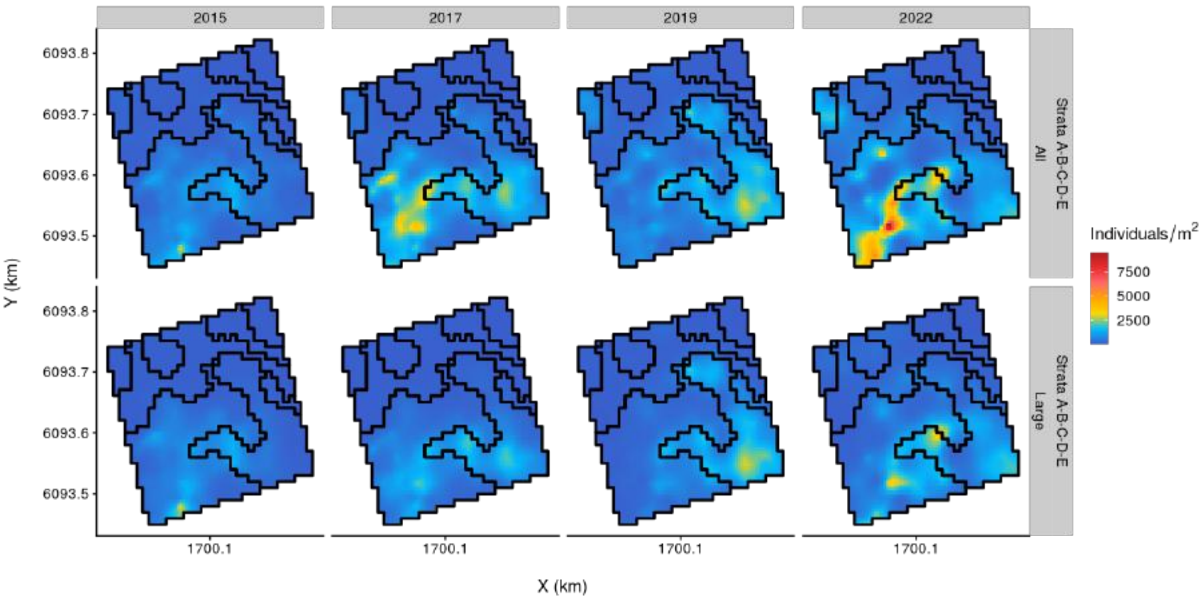

Figure C-10: Predicted cockle densities from the spatio-temporal model for Te Haumi. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.11 Umupuia Beach

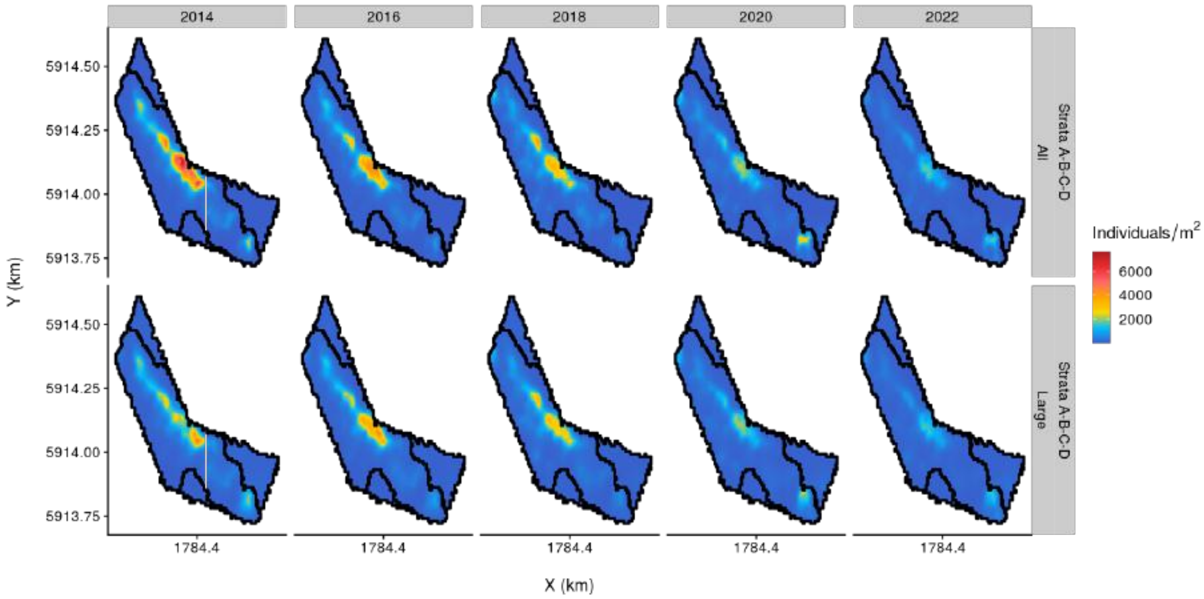

Figure C-11: Predicted cockle densities from the spatio-temporal model for Umupuia Beach. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.12 Whangateau Harbour

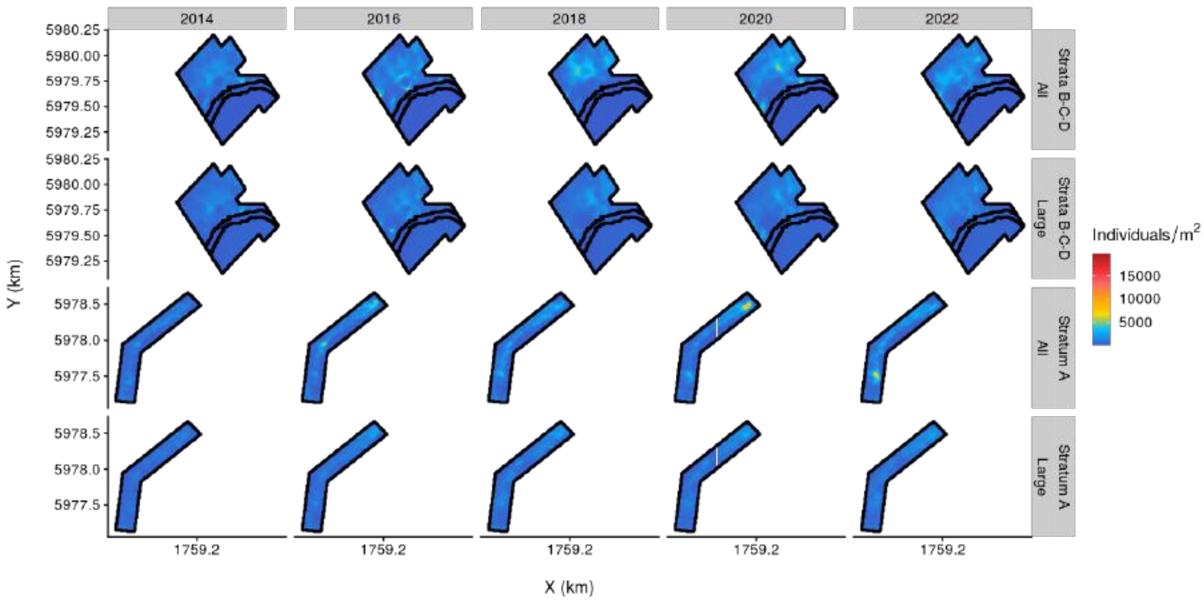

Figure C-12: Predicted cockle densities from the spatio-temporal model for Whangateau Harbour. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.

C.13 Whitianga Harbour

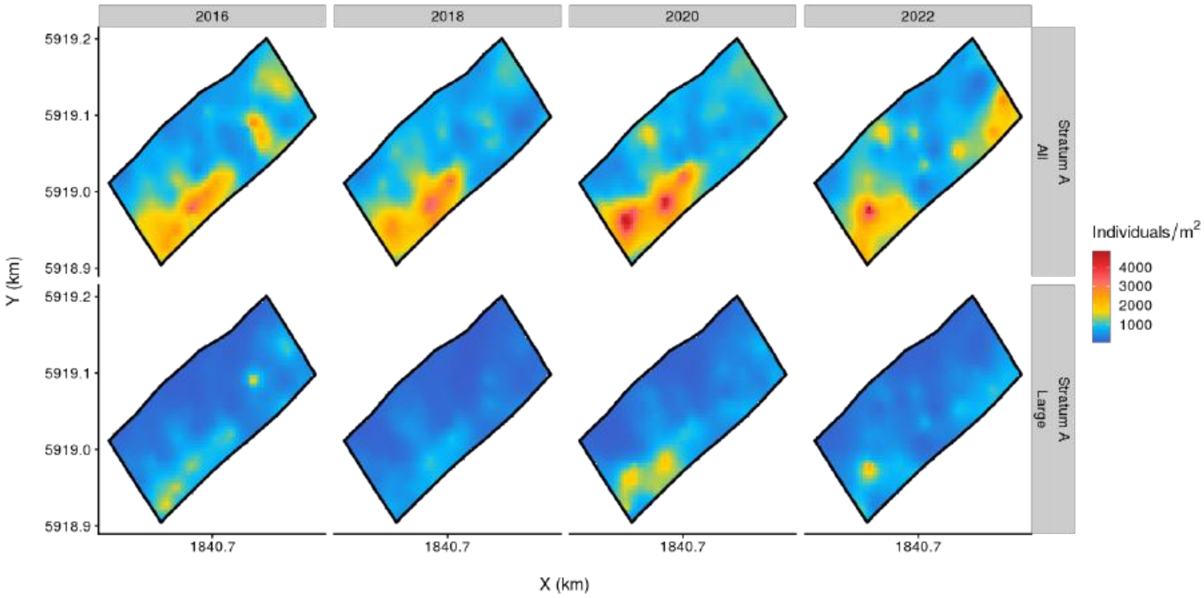

Figure C-13: Predicted cockle densities from the spatio-temporal model for Whitianga Harbour. Predictions are shown for all and for large cockles (>30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2022 refers to the 2021–22 fishing year.