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Intertidal shellfish monitoring in the northern North Island region, 2023–24

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Plain language summary

Cockles and pipi are edible shellfish that live in the sand on beaches around New Zealand. People like to dig them up and collect them for food, but if too many are taken, cockle and pipi populations will disappear. To help ensure that they remain, an annual study collects information of cockles and pipi at 12 different beaches across northern New Zealand. This information, such as counts and measurements of the cockles and pipi, can then be used to see if fishing activities need to be limited. This year, in the summer of 2023–24, the beaches were in Auckland (Umupuia Beach, Whangateau Harbour), Bay of Plenty (Bowentown Beach, Little Waihi Estuary), Northland (Mangawhai Harbour, Marsden Bank, Ngunguru Estuary, Ruakākā Estuary, Te Haumi Bay, Whangateau Harbour.), and Waikato (Raglan Harbour, Tairua Harbour, Te Mata and Waipatukahu). Depending on the beach, the number and sizes of cockles and pipi varied, but large individuals were generally scarce at all beaches. Average densities of cockles varied between 132 and over 1800 individuals per square metre; the densities of pipi ranged from 20 to over 5800 individuals per square metre. In Northland, there were large numbers of small pipi, indicating significant recruitment events. This recruitment caused considerable increases in the overall population estimates in this region.

EXECUTIVE SUMMARY

Berkenbusch, K.[1]; Hill-Moana, T.[1] (2024). Intertidal shellfish monitoring in the northern North Island region, 2023–24.

***New Zealand Fisheries Assessment Report 2024/35*. 110 p.**

Recreational and customary fishing is culturally important in New Zealand, including the take of marine species in coastal environments. Two of the main target species in these non-commercial fisheries are cockle (*Austrovenus stutchburyi*) and pipi (*Paphies australis*), which occur throughout the country, often in close proximity to urban centres. This accessibility means that both species are vulnerable to overexploitation, and their presence in coastal environments makes them also susceptible to other human impacts.

To monitor cockle and pipi populations in northern New Zealand, Fisheries New Zealand initiated regular population assessments in the early 1990s. Following refinements and the spatial extension of this programme, the intertidal surveys currently assess bivalve populations at a range of sites in Auckland, Northland, Waikato, and Bay of Plenty. The surveys collect demographic data and document population trends across the northern North Island regions.

This study presents the findings from the most recent survey in the northern North Island monitoring series, providing data from the 2023–24 fishing year. The survey sites were (in alphabetical order): Bowentown Beach, Little Waihi Estuary, Mangawhai Harbour, Marsden Bank, Ngunguru Estuary, Raglan Harbour, Ruakākā Estuary, Tairua Harbour, Te Haumi Bay, Te Mata Bay (Waipatukahu), Umupuia Beach, and Whangateau Harbour. At five of the sites, Marsden Bank, Ngunguru Estuary, Te Mata Bay, Umupuia Beach, and Whangateau Harbour, existing fishery restrictions prevent the take of cockles and pipi.

Nine of the 2023–24 sites contained cockle populations, which varied in total abundance and density, depending on the site. The highest total population abundance was at Whangateau Harbour with an estimated 606.56 (coefficient of variation, CV: 10.68%) million cockles. The smallest total population estimate of 27.60 (CV: 4.65%) million cockles was at Bowentown Beach. At the same time, the Bowentown Beach cockle population had the highest density with 1843 cockles per m^2. Two other sites had similar high-density estimates ($>$1000 individuals per m^2), Ngunguru Estuary and Raglan Harbour. In contrast, the lowest total cockle density was at Umupuia Beach, estimated at 132 (CV: 19.47%) cockles per m^2.

At the same time, Umupuia Beach was the only site with a high proportion and relatively high density of large individuals ($\geq$30 mm shell length). At this beach, large cockles made up over 50% of the population, and occurred at an estimated density of 71 (CV: 22.23%) large cockles per m^2. Other cockle populations contained few large individuals, and their density estimates were markedly lower, typically with high uncertainty (including CV values above 40%).

Length-frequency distributions documented the prevalence of medium-sized cockles (sizes $>$15 mm and $<$30 mm shell length) across the northern populations. This size class largely determined the population size structure with varying proportions of recruits ($\leq$15 mm shell length) contributing to the population overall. In 2023–24, the proportion of recruits varied between 19 and 63% at most sites (i.e., excepting Umupuia Beach), reflecting a marked influx of individuals to existing cockle populations.

Pipi populations were surveyed at ten of the northern sites. Their total population sizes ranged from 0.45 (CV: 15.66%) million pipi at Marsden Bank to 121.15 (CV: 13.48%) million individuals at Ruakākā Estuary. The highest density estimate was also at Ruakākā Estuary with 5857 individuals per m^2, largely caused by a significant recruitment event. The only other site with high pipi densities was Te Mata Bay,

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where this species exceeded 1000 individuals per m^2. The lowest density estimates were at Whangateau Harbour and Raglan Harbour, at 20 individuals per m^2 and 27 individuals per m^2, respectively.

Few of the pipi populations contained notable numbers of large pipi ($\geq$50 mm shell length), and estimates for this size class frequently had high uncertainty. The only site where estimates for large pipi had low uncertainty (i.e., a CV of less than 20%) was Te Mata Bay. At this site, over 10% of the total population consisted of large individuals, and their estimated density was 171 (CV: 12.79%) large pipi per m^2.

The general scarcity of large-sized pipi was also evident in the length-frequency distributions, which were dominated by the medium pipi size class (>20 mm and <50 mm shell length), forming a strong cohort in unimodal populations. Exceptions to this population size structure were three of the four Northland sites, where substantial recruitment led to the prevalence of recruits ($\leq$20 mm shell length) in the populations. At Te Haumi Bay, Ruakākā Estuary, and Marsden Bank, the proportion of recruits varied from 75 to 87%. At Marsden Bank, the strong recruitment indicated some population recovery, following the loss of the pipi population in 2021–22.

Sediment in the cockle strata was characterised by a low organic content (less than 3%) and varying proportions of grain size fractions. The most prevalent grain sizes were fine sand (grain size >125 µm), followed by medium and very fine sands (>250 and >63 µm). A number of sites had relatively high proportions of sediment fines (silt and clay; $\leq$63 µm grain size), which may impact suspension-feeding cockles through increased sediment resuspension. These sites were Ngunguru Estuary, Raglan Harbour, Tairua Harbour, Te Haumi Bay, and Umupuia Beach, where average proportions of sediment fines were between 8 and 10%. Individual samples at Umupuia Beach exceeded 60% of sediment in this grain size fraction.

Sediment data were also used to explore the relationship between sediment grain size fractions and cockle abundance, based on principal component analysis. General patterns from this data exploration indicated that cockle abundance was generally associated with fine sand size fractions, but less so with sediment fines.

Cockle population data were also used in geostatistical models to examine spatio-temporal trends in predicted cockle densities at the survey sites. This analysis allowed the identification of high-density areas within cockle strata, and assessment of changes in these "hotspots" over time. At most of the survey sites, the locations of high-density areas were comparable between the total population and large cockles, although hotspots were typically more restricted for the latter populations. At some sites, Umupuia Beach, Tairua Harbour, and Te Haumi Bay, distinct high-density areas in early surveys became smaller and less pronounced over time. In contrast, three sites were characterised by areas of high cockle densities that persisted over time, Bowentown Beach, Ngunguru Estuary and Raglan Harbour.

1. INTRODUCTION

The collection of marine shellfish for human consumption is a popular activity throughout New Zealand, spanning a number of intertidal and subtidal shellfish species (Guy et al. 2021). In addition to providing food, the recreational and customary take of shellfish is of significant cultural value, and also considered an enjoyable recreational activity. Important aspects for the choice of location for shellfish gathering are their proximity and the quantity of shellfish available for take.

In this context, two of the main target species for non-commercial fishing in New Zealand are cockles/tuangi (*Austrovenus stutchburyi*) and pipi (*Paphies australis*). Both species occur in the intertidal zone of estuaries, beaches, and sheltered bays throughout the country, where their populations often form high-density beds. Their intertidal distributions, combined with their often close proximity to urban centres, makes cockles and pipi easily accessible for recreational and customary fishing.

At the same time, a number of stressors in coastal environments put increasing pressures on these bivalve populations, including fishing, pollution, sediment runoff, and diseases (Grant & Hay 2003). Marked declines in cockle and pipi population have been recorded from a number of New Zealand locations, but causes for these mass mortality events have been difficult to determine (Tricklebank et al. 2021, Howells et al. 2024). Similarly, the general lack of fishing information prevents a direct assessment of potential population impacts from recreational and customary take.

To support the management of these bivalve species, Fisheries New Zealand initiated a regular monitoring programme in the early 1990s, which was focused on beaches in the metropolitan Auckland area. Subsequently, the survey methods were refined and the spatial extent of the programme was expanded to include sites throughout the northern North Island region in Fisheries Management Areas 1 and 9. In these areas, sites are distributed across Auckland, Northland, Waikato, and Bay of Plenty. Since the late 1990s, the survey methods have generally remained consistent, collecting population data annually at usually 12 sites, from an overall pool of over 30 sites.

The surveys provide demographic data of cockle and pipi populations, such as abundance and density estimates, and information of the population size structure, including recruitment events. For frequently-surveyed sites, the survey data also provide time series to assess population trends over time. Since 2021–22, geostatistical modelling of population data has provided an alternative method to survey-based estimates for cockle populations, including the exploration of predicted high-density areas over time.

Starting in 2013–14, the field surveys have also collected data on sediment organic content and grain size composition to gain an understanding of benthic habitat quality across the northern sites. This sediment sampling was amended in 2015–16 to only encompass cockle beds, which are considered less ephemeral than pipi beds; the latter may also extend into subtidal areas that are inaccessible to the intertidal sampling. The refinement of sediment sampling methods also included amendments to allow formal assessment of sediment properties (e.g., see Neubauer et al. 2015). Since 2021–22, this analysis of sediment data has included the exploration of cockle abundance in relation to sediment grain size fractions via principal component analysis (Neubauer et al. 2021).

This report presents the findings from the most recent northern North Island survey in the monitoring series, providing data from the 2023–24 fishing year. The field survey collected demographic data for cockles and pipi across 12 sites in Northland, Waikato, Auckland, and Bay of Plenty. The sites were (in alphabetical order): Bowentown Beach, Little Waihi Estuary, Mangawhai Harbour, Marsden Bank, Ngunguru Estuary, Raglan Harbour, Ruakākā Estuary, Tairua Harbour, Te Haumi Bay, Te Mata Bay (Waipatukahu), Umupuia Beach, and Whangateau Harbour (Figure 1).

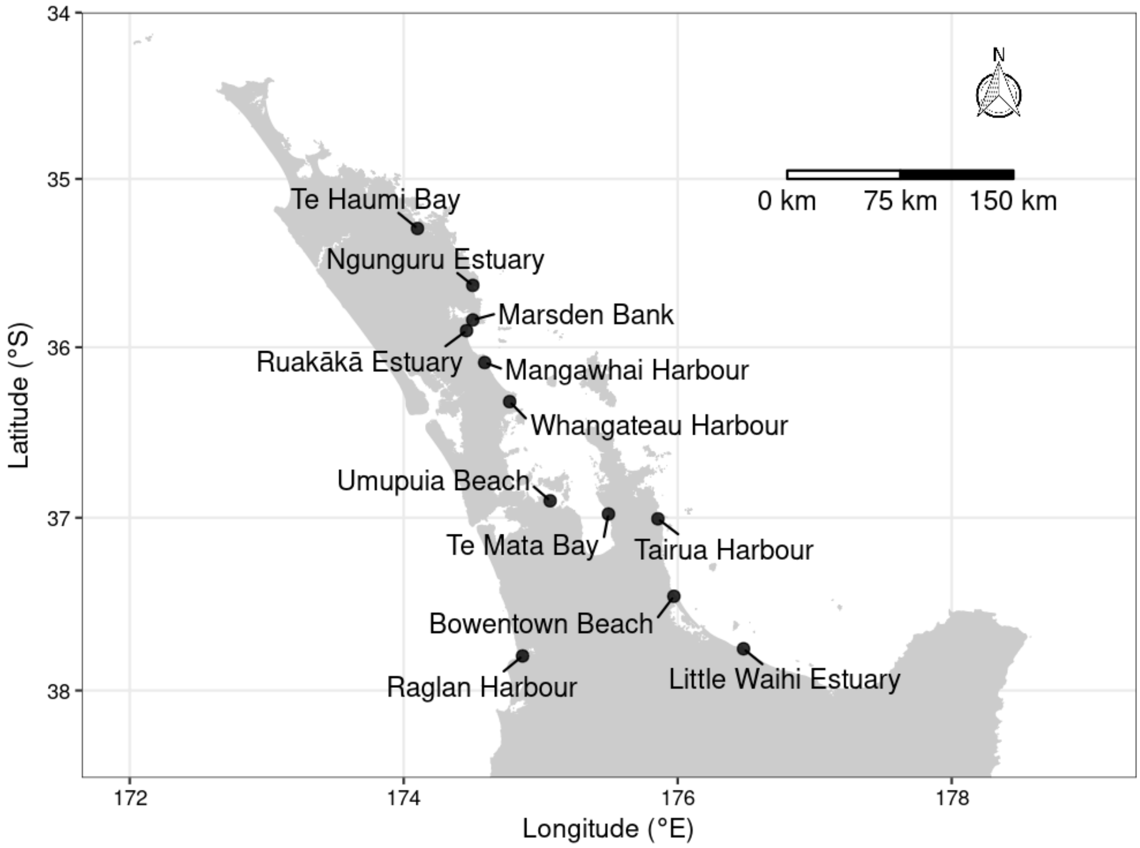


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2023–24.

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 2022–23 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 12 northern North Island sites was conducted in February 2023. The survey sampled bivalve populations at each site 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, $\leq$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 ± 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 (equation 1a). 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 (equation 1b).

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 development of geostatistical models, the current analysis continued this modelling approach in parallel with the survey-based estimation, by using the spatio-temporal models with the 2023–24 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 (PCAs) 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 in 2023–24.

3. RESULTS

3.1 Bowentown Beach

Bowentown is one of the Bay of Plenty monitoring sites, situated in Tauranga Harbour. The 2023–24 assessment was the eighth survey in the monitoring series, with a similar sampling extent to that in previous surveys (see Appendix A, Tables A-1, A-2). Cockle and pipi were sampled at 100 sampling points across three strata.

Sediment samples revealed similar characteristics throughout the cockle strata with a low organic content (i.e., <3.5%) and a generally low proportion of sediment fines (grain size <63 µm), although two samples contained over 6.5% in this grain size fraction (Figure 2; and see details in Appendix B, Table B-1). The cockle strata mostly contained fine and medium sands (>63 µm and >125 µm), with at least 70% of samples consisting of these two grain size fractions.

All three strata at Bowentown Beach contained cockles, with the highest abundance and density in stratum C (Figure 3, Table 1). Their total abundance was estimated at 27.60 million cockles (CV: 4.65%) with an average density of 1843 cockles per m^2 (Table 2). The current estimates were consistent with some of earlier surveys, but marked a significant increase in the population compared to the immediately preceding survey in 2021–22; e.g., total abundance in the preceding survey was estimated at 16.00 million cockles (CV: 7.35%). Although there was a similar increase in large cockles (≥30 mm shell length) in this period, their population remained small, with an estimated 0.18 million (CV: 18.87%) cockles in this size class. Their average density was 12 large individuals per m^2 (Table 2).

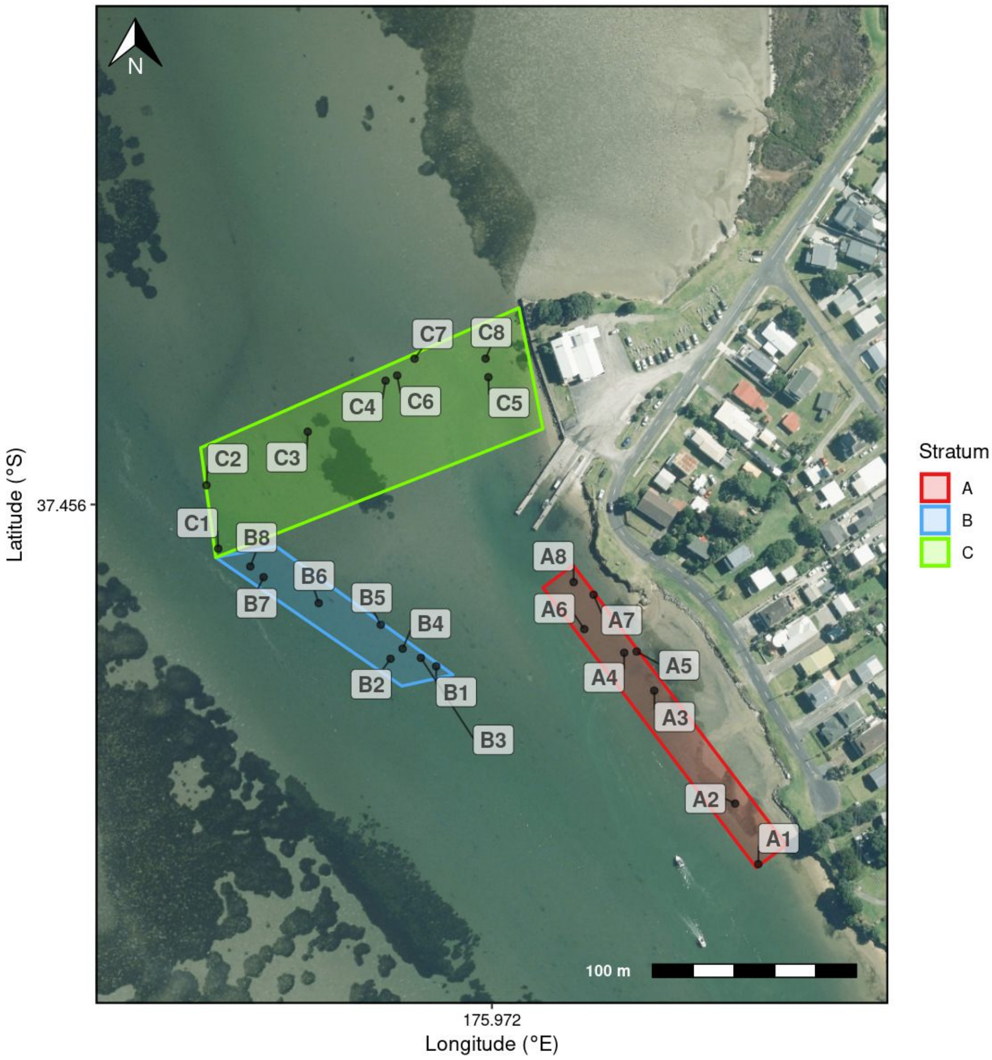
In spite of the recent increase in the large cockle population, this size class contributed less than 1% to the population in recent surveys (Table 3). In comparison, the proportion of recruits (≤15 mm shell length) was 20.87% in 2023–24, signifying an increase in this size class from the two preceding surveys. Although the population remained dominated by medium-sized individuals, the pulse of recruits shifted the mean and modal sizes towards smaller shell lengths of 19.26 mm and 18 mm, respectively. Length-frequency distributions indicated that some of the previous recruits grew into the medium size class, consolidating the unimodal population size structure determined by the medium size class (Figure 4).

In relation to the sediment grain size composition, principal component analysis indicated that cockle abundance (for both the total population and large cockles) was generally associated with sediment fines and finer sand size fractions, and less so with fine sand (Figure 5).

Pipi were sampled in all three strata at Bowentown Beach, but were predominantly in stratum B that sits alongside one of the side channels (Figure 6, Table 4). Their total population was estimated at 0.79 million pipi (CV: 14.46%) with a mean density of 53 individuals per m^2 (Table 5). The pipi population had increased in 2023–24 and was the highest number and density of pipi thus far in the monitoring series, however some of the earlier estimates were often associated with high uncertainty (i.e. CV exceeding 20%).

In 2023–24, the population size structure included a strong cohort of medium-sized pipi in comparison to the two preceding surveys that had a significant presence of recruits (≤20 mm shell length), especially in 2021–22 (i.e. 32.58% recruits). The pipi recruits could have contributed to the medium size class of 2023–24, nonetheless the current population had increased the mean and modal size similar to those in 2019–20 (Figure 7, Table 6).

Consistent with all previous surveys at Bowentown Beach, there were few large pipi (≥50 mm shell length) however estimates were often associated with very high uncertainty (i.e. CV >60%). The large-sized pipi constituted 0.53% of the total population in 2023–24 which was far less than the two preceding surveys (Figure 7, Table 6).



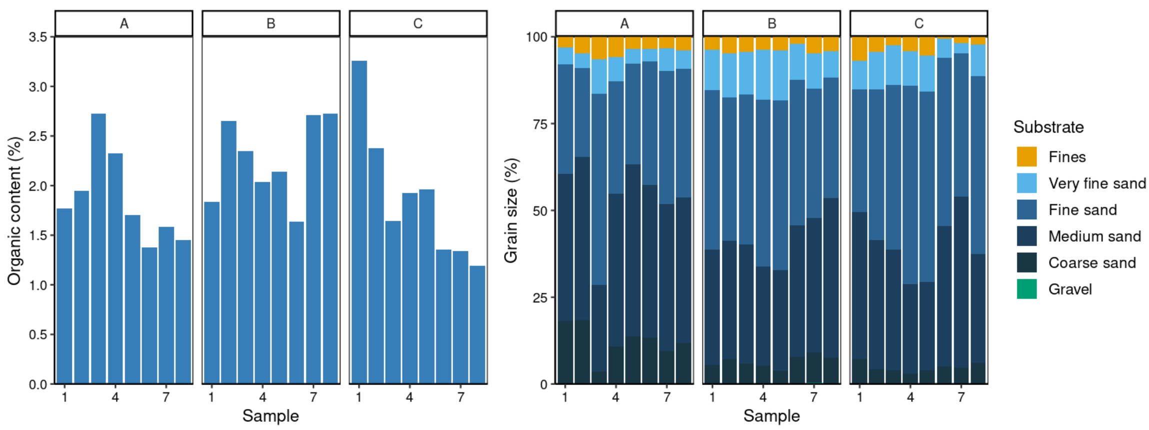


Figure 2: Sediment sample locations and characteristics at Bowentown Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Bowentown Beach

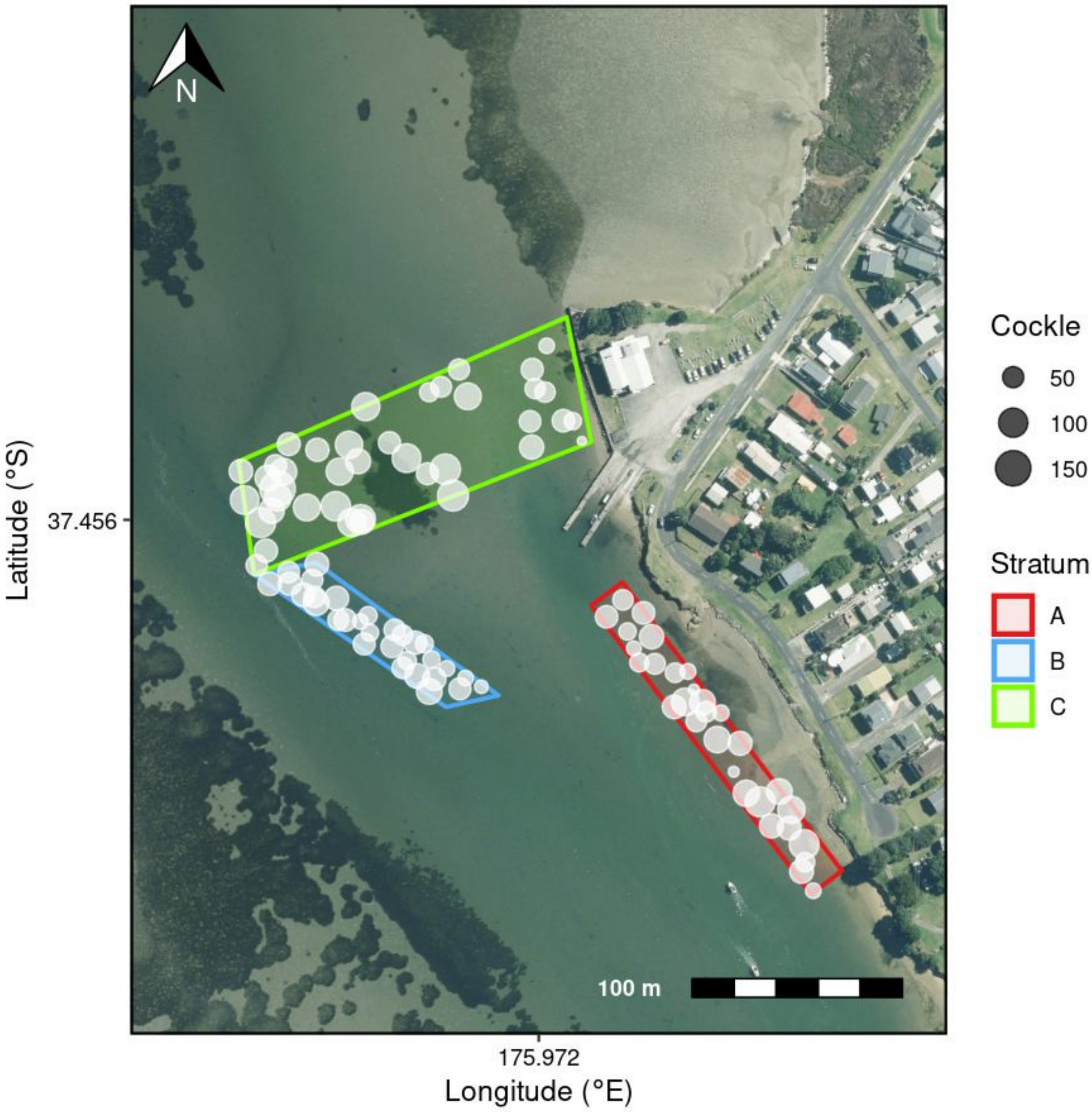


Figure 3: Map of sample strata and individual sample locations for cockles at Bowentown Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Bowentown Beach, by stratum, for 2023–24. Presented are the area surveyed, the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	30	1 667	5.05	1 588	8.36
B	0.2	30	1 501	3.16	1 430	5.82
C	1.0	40	2 832	19.38	2 023	6.18

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	1.6	4.75	301	5.42	1.41	89	7.61
2010–11	1.6	18.56	1 175	9.18	0.08	5	33.18
2012–13	1.6	25.05	1 586	5.59	0.07	4	42.60
2015–16	1.5	26.95	1 799	5.17	0.03	2	34.77
2017–18	1.5	30.07	2 008	6.25	0.16	10	20.55
2019–20	1.5	24.80	1 656	5.97	0.12	8	17.30
2021–22	1.5	16.00	1 068	7.35	0.09	6	22.32
2023–24	1.5	27.60	1 843	4.65	0.18	12	18.87

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Bowentown Beach. The 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 (%)
2019–20	21.01	23	5–34	9.49	0.48
2021–22	20.47	22	5–37	14.19	0.58
2023–24	19.26	18	5–36	20.87	0.64

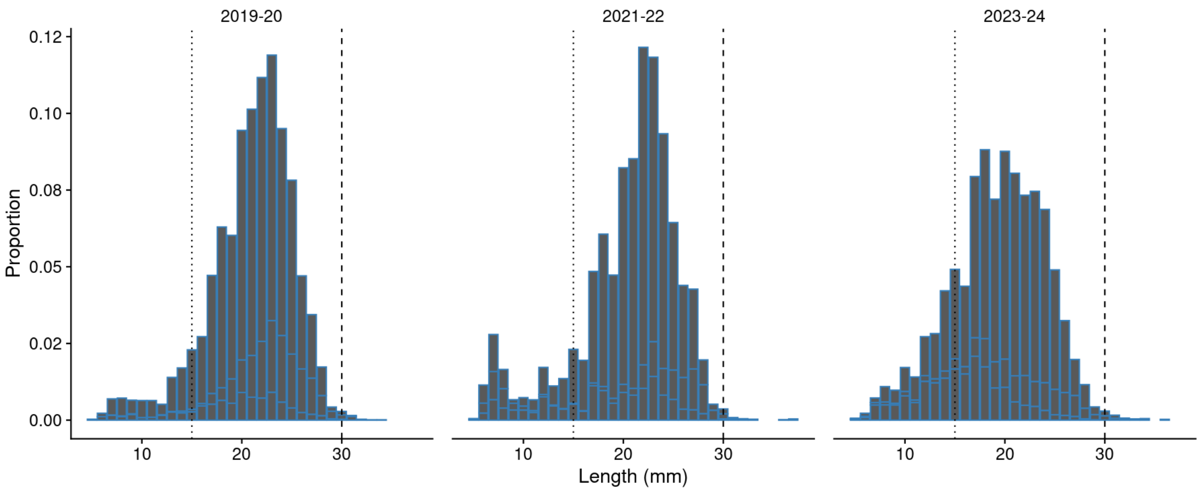


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

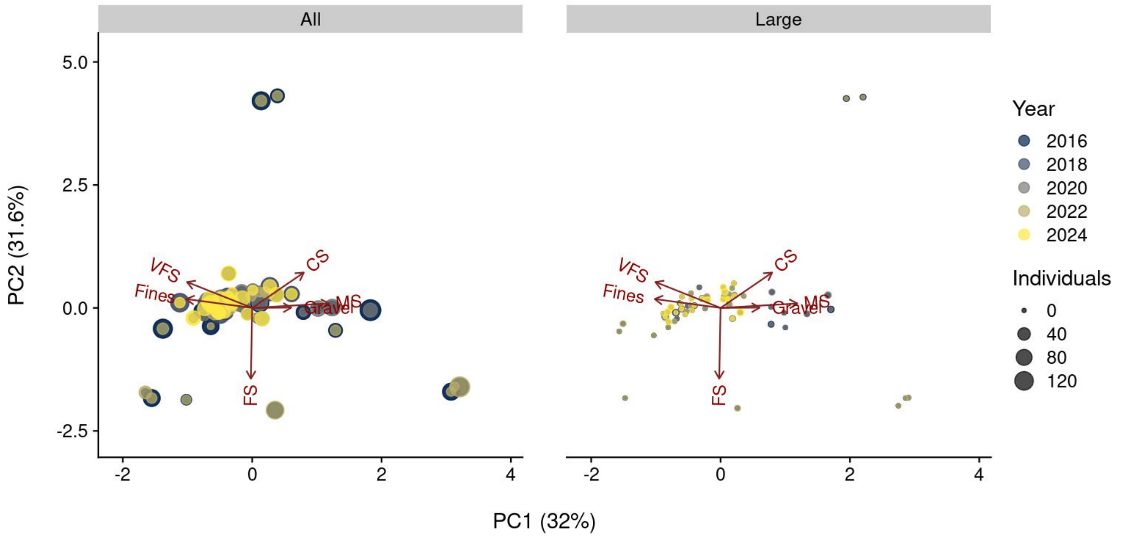


Figure 5: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Bowentown Beach. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm,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

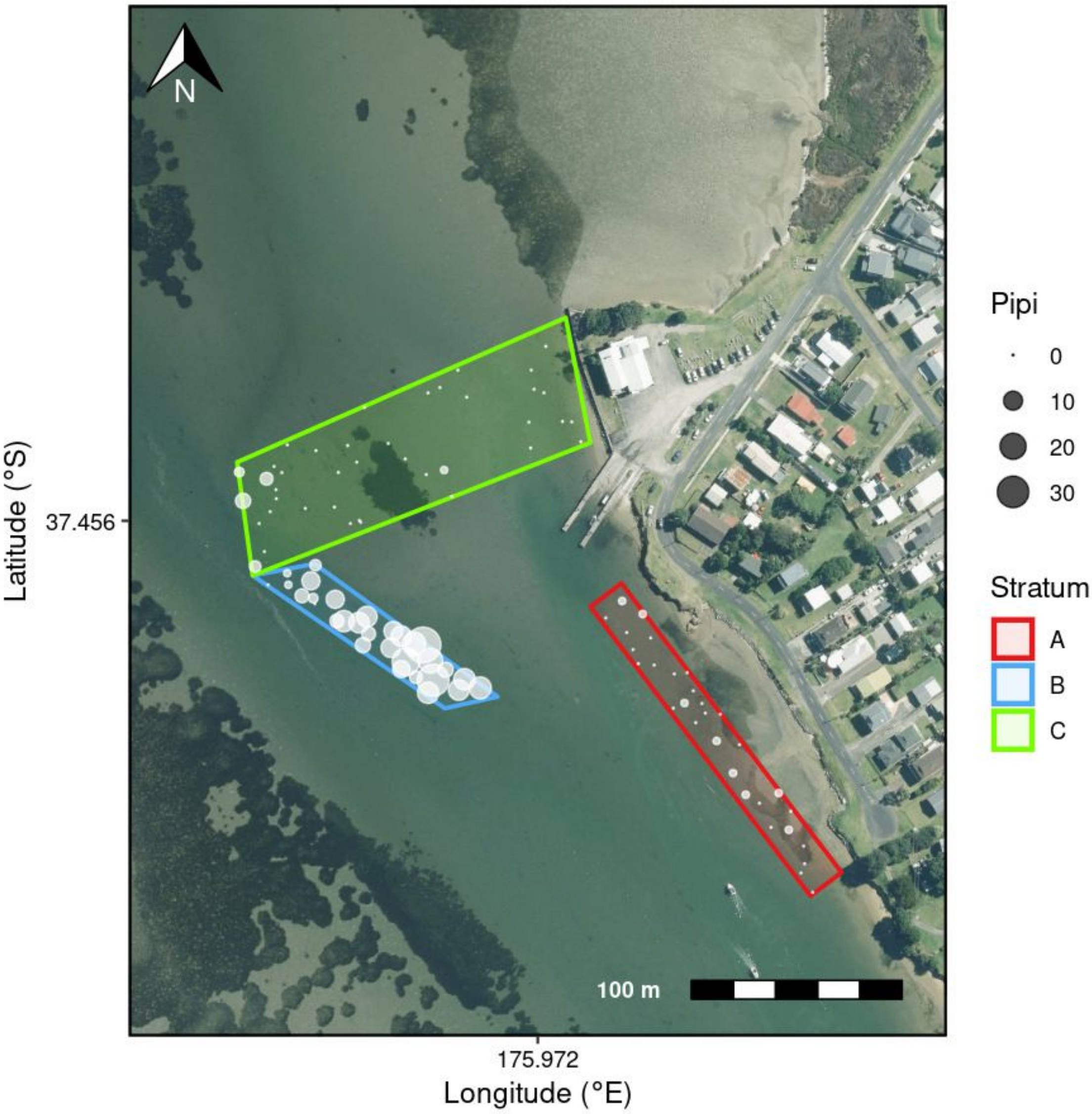


Figure 6: Map of sample strata and individual sample locations for pipi at Bowentown Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of pipi abundance at Bowentown Beach, by stratum, for 2023–24. Presented are the area surveyed, the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	30	8	0.02	8	30.79
B	0.2	30	313	0.66	298	15.34
C	1.0	40	16	0.11	11	48.87

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
2023–24	1.5	0.79	53	14.46	0.00	<1	71.82

Table 6: Summary statistics of the length-frequency (LF) distribution of pipi at Bowentown Beach. The 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 (%)
2019–20	30.62	30	8–56	17.85	1.77
2021–22	26.27	12	10–52	32.58	1.54
2023–24	30.86	30	10–53	4.70	0.53

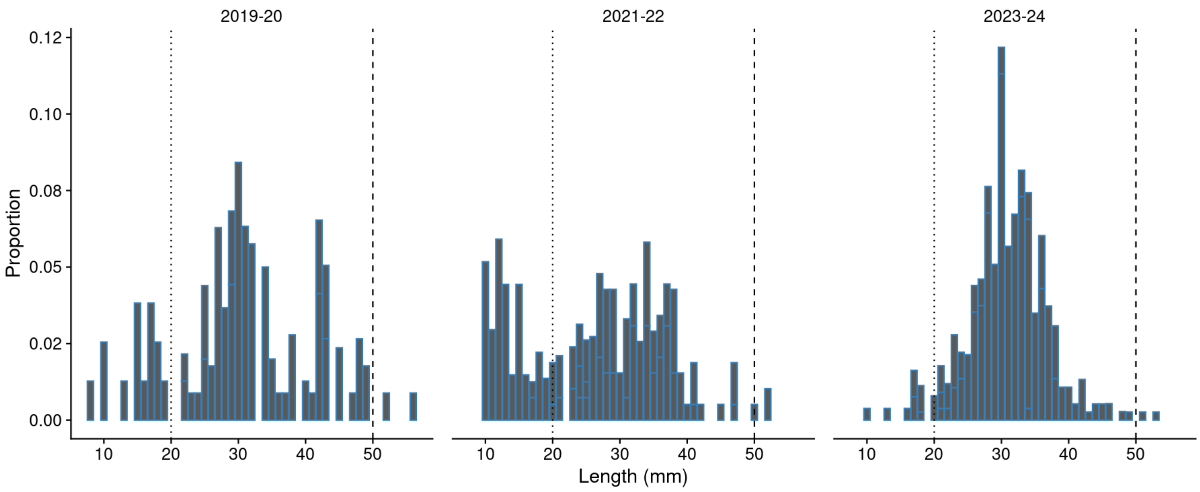


Figure 7: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Bowentown Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.2 Little Waihi Estuary

Little Waihi Estuary is a small estuary between Maketū and Pukehina, in the Bay of Plenty. This site was assessed 13 times since 2001–01, including the current survey. The survey area covers a large part of the lower estuary, and has remained similar over time (see Appendix A, Tables A-1, A-2). In 2023–24, cockle and pipi were sampled at 187 points (including 17 points in phase 2) across two strata.

The sediment in the estuary had little organic content (i.e., no greater than 3.5%) and a low proportion of sediment fines (<63 µm) (Figure 8; and see details in Appendix B, Table B-1). Sediment grain sizes were mainly fine and medium sand fractions (>125 µm and >250 µm), and few samples contained coarse sediment.

Cockles were predominantly in stratum A and were generally restricted to the higher parts of the intertidal areas including the intertidal mudflat (Figure 9, Table 7). The cockle population across this site was estimated to be 34.24 million cockles (CV: 19.55%) occurring at an average density of 206 cockles per m^2 (Table 8). Although the current estimates reflected an increase in the population compared to the preceding survey in 2021–22, there have been considerable fluctuations in the cockle population over time.

There were very few large-sized cockles (≥30 mm) in the current population, and this finding was consistent throughout the survey series (Table 8). Their estimates in 2023–24 were 0.24 million (CV: 74.62%) large individuals, occurring at an average density of 1 large individuals per m^2. The small numbers sampled meant that estimates for this size class usually had relatively high uncertainty (i.e., CV values >50%).

In contrast, there was a notable prevalence of recruits (≤15 mm) at this site, and this size class contributed about 30 to 50% of the total cockle population in recent surveys (Table 9). The length-frequency distributions illustrated the consistent occurrence of recruits (Figure 10). At the same time, the estuary sustained a strong cohort of medium-sized cockles, which consistently formed the strongest cohort. In both the 2021–22 and 2023–24 surveys, the cockle population had similar size structures, following a significant recruitment event in 2019–20, and distinct shift from a bimodal to a unimodal population in 2021–22. Mean and modal sizes remained at an approximate shell length of 18 mm in these two recent surveys.

There were no clear patterns in the principal component analysis exploring the abundance of cockles in relation to sediment grain sizes (Figure 11).

The pipi population at Little Waihi Estuary was generally restricted to the tidal areas of the channels in both strata; stratum A supported a higher abundance of pipi, whereas stratum B supported greater densities of this species (Figure 12, Table 10). The total population size was estimated at 108.92 (CV: 15.50%) million pipi and at a mean density of 655 pipi per m^2 (Table 11). Similar to the cockle population, pipi abundance and density in Little Waihi Estuary fluctuated throughout the monitoring series. In 2023–24, there was a marked population increase relative to the preceding survey in 2021–22, when abundance and density estimates were 65.19 (CV: 20.37%) million pipi and 392 pipi per m^2.

There was a small reduction in the population of large-sized pipi (≥50 mm) at the estuary in 2023–24, with a population estimate of 1.14 million (CV: 39.51%) large individuals and an estimated mean density of 7 large pipi per m^2 (Table 11).

In the most recent surveys, the proportion of large pipi continuously declined from 10.95% in 2019–20 to 1.05% in 2023–24 (Table 12). In contrast, pipi recruits (≤20 mm) were a persistent feature in the population size structure, and their proportion recently increased, i.e., it was 26.87% in 2023–24. Little Waihi Estuary consistently supported a strong cohort of medium-sized pipi, at sizes towards larger shell lengths (i.e. around ≥40 mm); however the recent influx of recruits and the scarcity of large individuals in 2023–24 led to a more unimodal distribution with lower mean and modal sizes of 28.41 mm and 27 mm shell length, respectively.

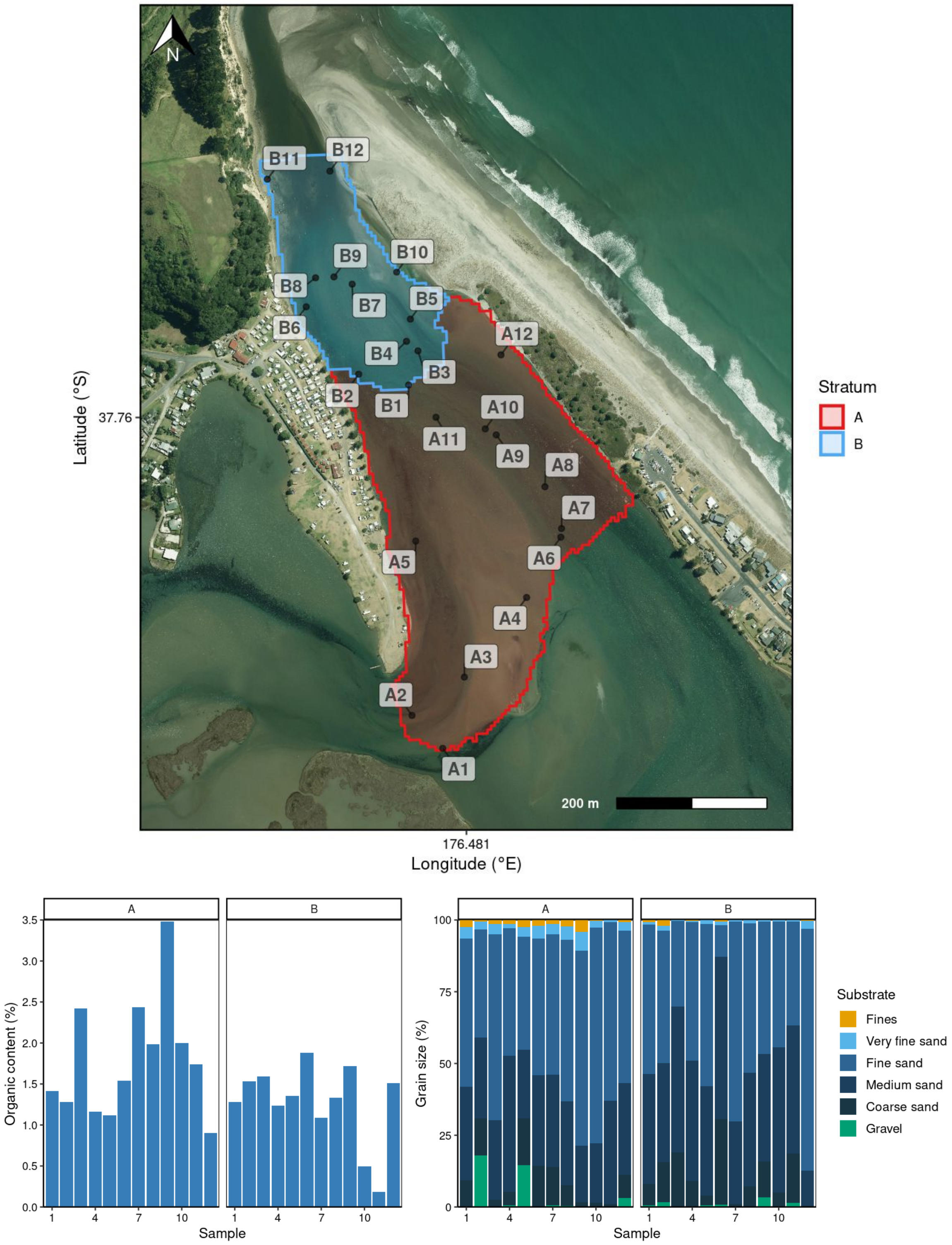


Figure 8: Sediment sample locations and characteristics at Little Waihi Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.2.1 Cockles at Little Waihi Estuary

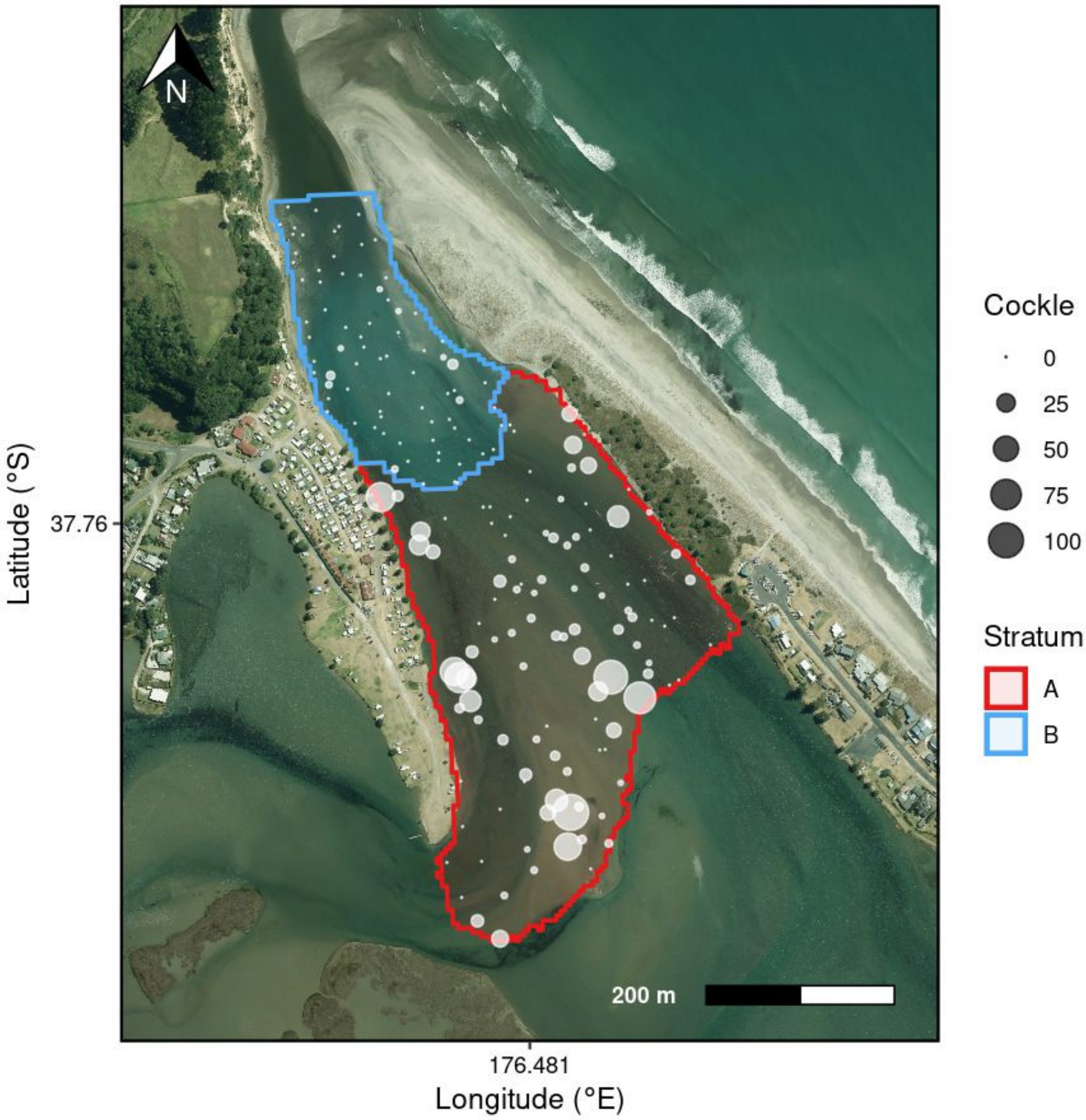


Figure 9: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2023–24. Presented are the area surveyed, 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	12.2	110	1 067	33.91	277	19.74
B	4.4	77	20	0.33	7	39.88

Table 8: 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
2023–24	16.6	34.24	206	19.55	0.24	1	74.62

Table 9: Summary statistics of the length-frequency (LF) distribution of cockles at Little Waihi Estuary. The 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 (%)
2019–20	16.70	7	5–31	43.93	0.66
2021–22	18.18	17	5–40	31.62	1.88
2023–24	17.99	18	5–48	30.24	0.70

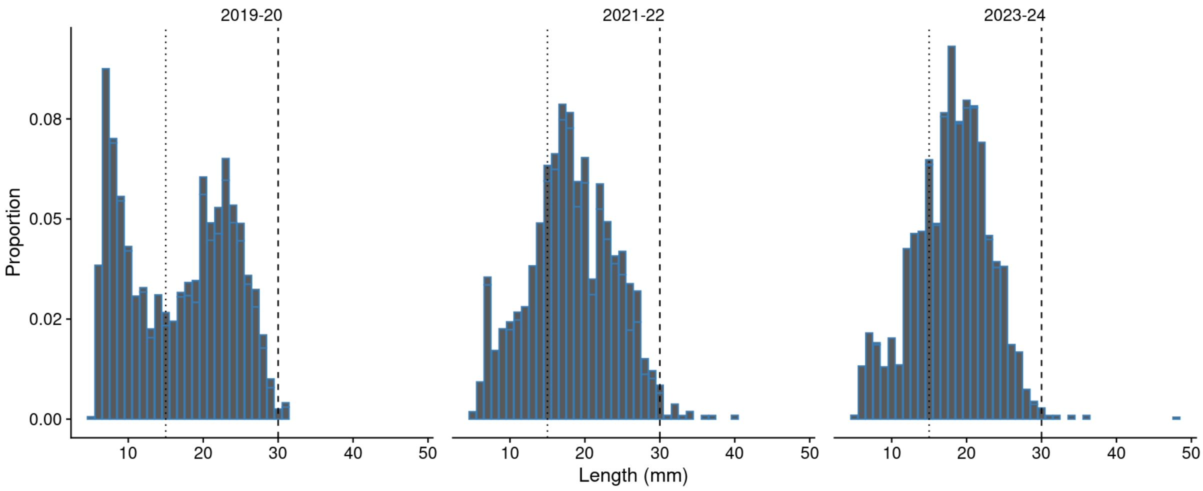


Figure 10: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

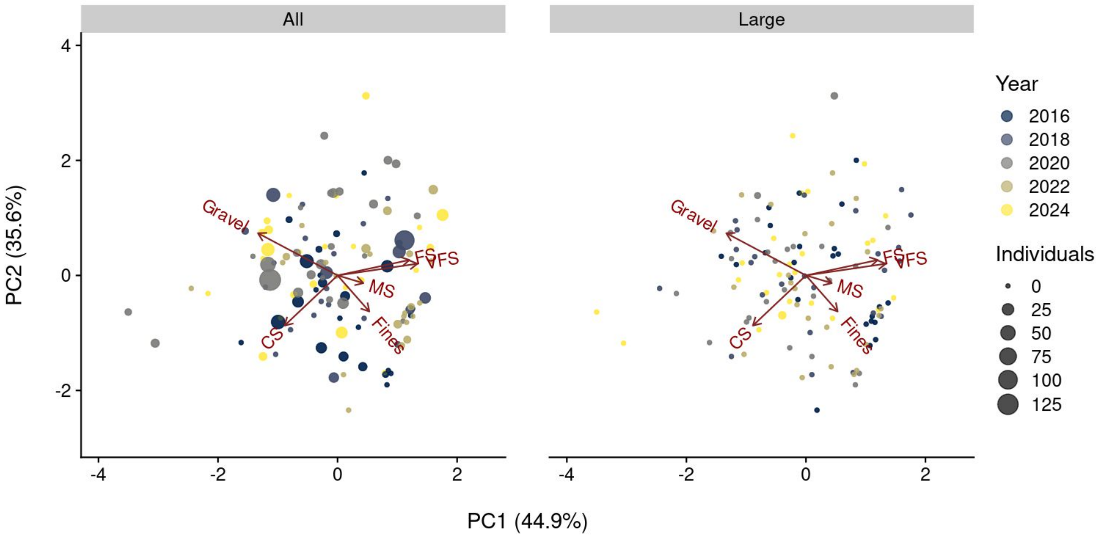


Figure 11: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Little Waihi Estuary. Sediment grain size fractions are defined as fines (silt and clay) ≤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.

3.2.2 Pipi at Little Waihi Estuary

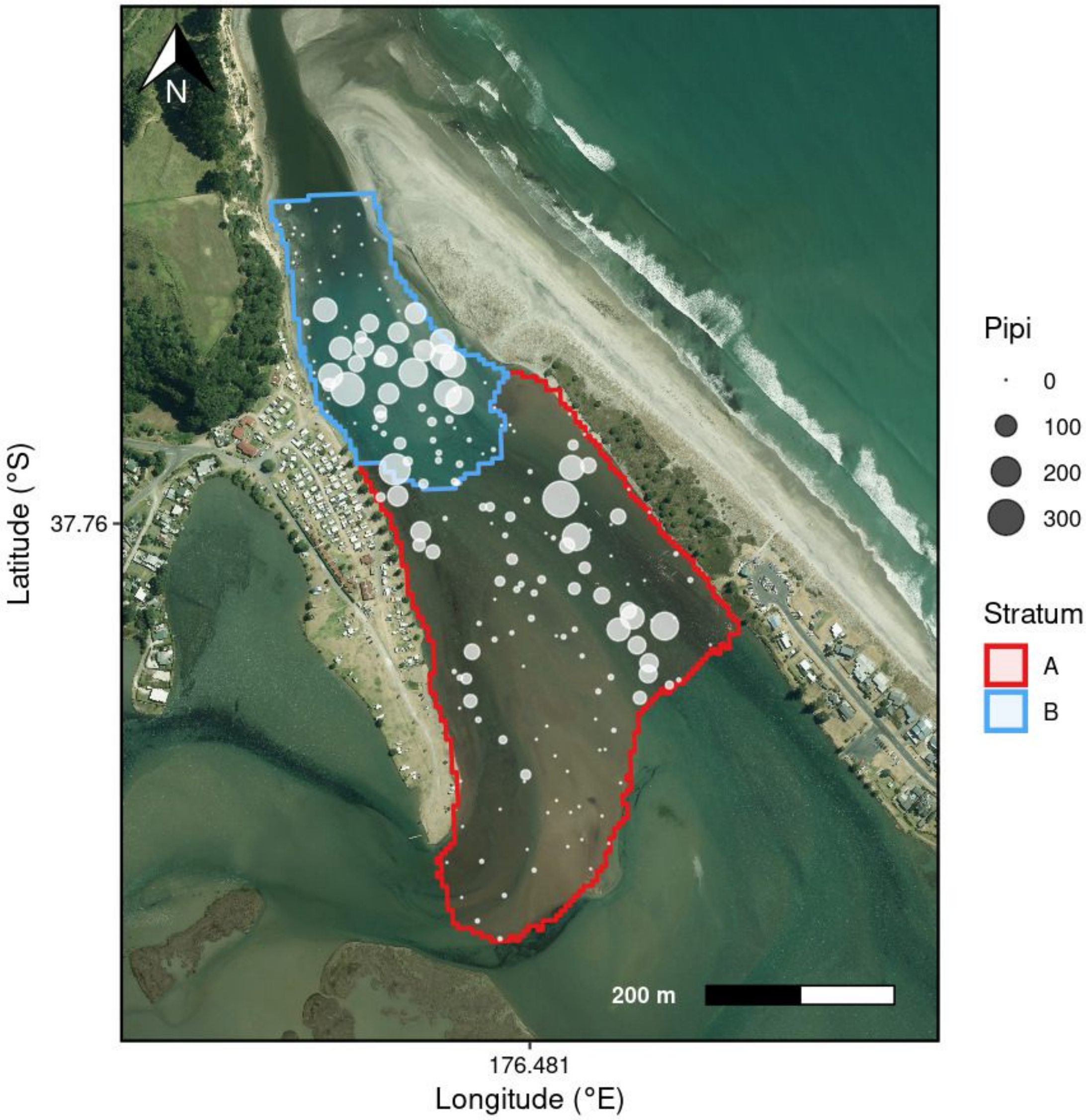


Figure 12: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2023–24. Presented are the area surveyed, 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	12.2	110	2 056	65.35	534	22.22
B	4.4	77	2 671	43.57	991	19.76

Table 11: 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
2023–24	16.6	108.92	655	15.50	1.14	7	39.51

Table 12: Summary statistics of the length-frequency (LF) distribution of pipi at Little Waihi Estuary. The 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 (%)
2019–20	35.41	44	1–58	16.45	10.95
2021–22	31.77	42	6–57	22.03	2.22
2023–24	28.41	27	7–54	26.87	1.05

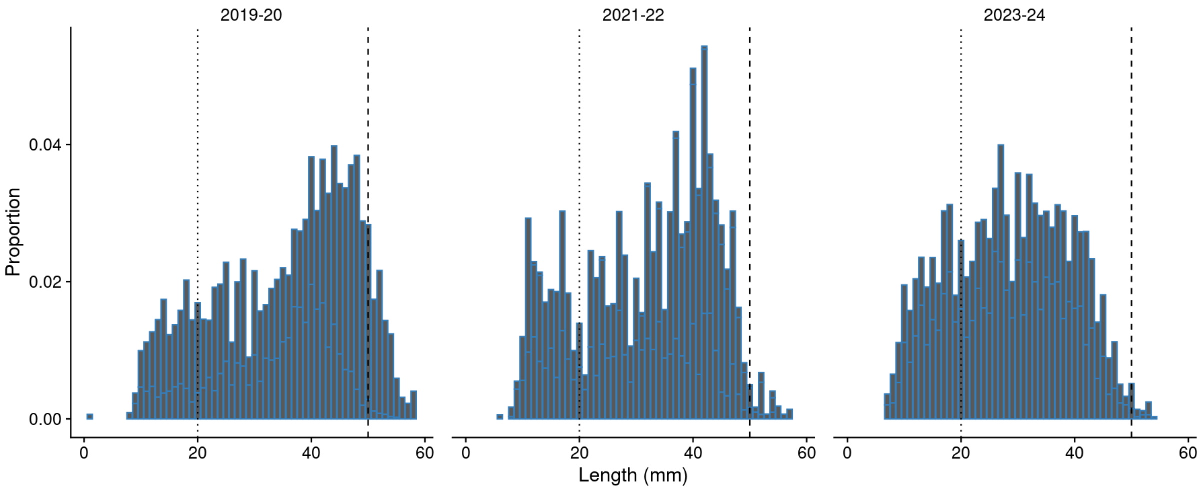


Figure 13: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Mangawhai Harbour

Mangawhai Harbour is on the east coast of Northland. The estuary was first surveyed in 1999–2000 with 10 subsequent surveys including the current assessment in 2023–24 (see Appendix A, Tables A-1, A-2). Previous assessments provided population information for both cockle and pipi; however, the loss of pipi beds led to a focus on cockles only since 2021–22. Since 2018–19, cockles at this site were surveyed within the same sampling extent, with the survey area split between two locations on the western side of Mangawhai Heads peninsula. The sampling extent in 2023–24 was divided into four strata with a total of 135 sampling points.

The sediment at Mangawhai Harbour was characterised by a low organic matter content (i.e., generally less than 1.5%) except for a single sample in stratum B exceeding 2.5% (Figure 14; and see details in Appendix B, Table B-1). Similar, the proportion of sediment fines (grain size <63 µm) was low, not exceeding 3% across all samples. The sediment in the cockle strata largely consisted of fine and medium sand fractions (>125 µm and >250 µm), and these two grain size classes varied in relative proportions across the different strata; for example, the composition of sediment in stratum D was over 70% fine sand.

The cockle population was dispersed across the entire sampling extent, but occurred at higher densities in strata A and D (Figure 15, Table 13). Current estimates indicated a total population abundance of 50.38 (CV: 10.83%) million cockles, and an average density of 702 cockles per m^2 (Table 14). These estimates signified a decline in the total cockle population since the previous survey in 2011–22. There was a similar decline in the population of large cockles (≥30 mm), although this size class has been consistently small at this site. In 2023–24, the population estimate for this size class was 2.09 (CV: 18.32%) large individuals, and the estimated average density was 29 large cockles per m^2 (Table 14).

Considering large cockles within the overall population, these individuals made up a small proportion in recent surveys, with their recent decline also reflected in the population size structure (Table 15, Figure 16). In 2023–24, large cockles contributed 4.15% of total individuals compared with 8.66% in 2021–22. Length-frequency distributions revealed a strong cohort of medium-sized cockles and considerable numbers of recruits (≤15 mm). There was a significant recruitment event in 2018–19 (i.e. 33.73% of the population consisted of recruits), and recruits represented 19.47% of the total population in 2023–24. Based on the current size structure, the mean and modal cockle sizes remained similar to shell lengths in the preceding survey, with a mean shell length of 20.47 mm and modal size of 24 mm.

Exploration of cockle abundance in relation to sediment grain size via principal component analysis indicated relatively higher abundance of all size classes and of large cockles associated with coarse and medium sand size fractions, particularly in recent surveys (Figure 17).

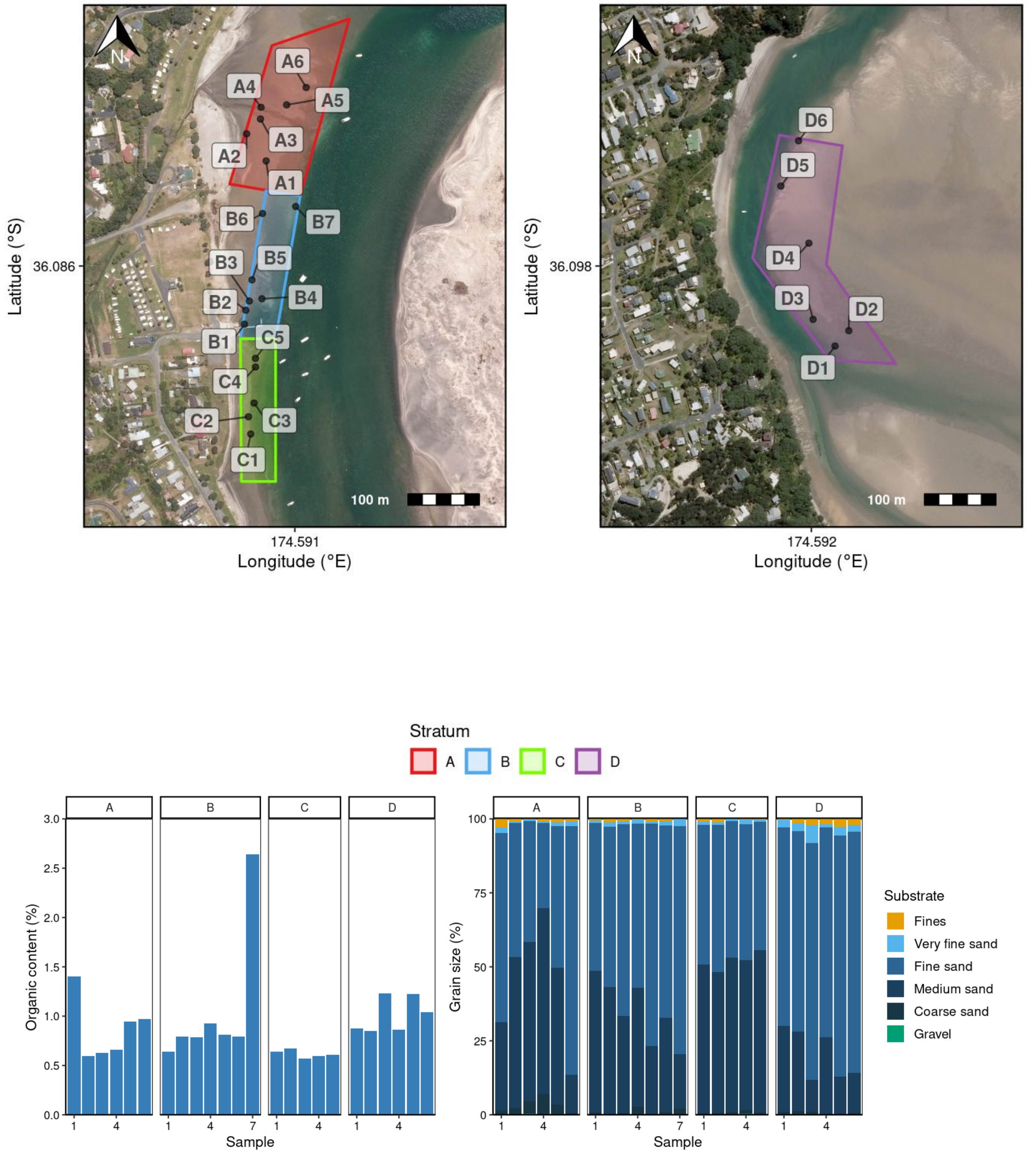


Figure 14: Sediment sample locations and characteristics at Mangawhai Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.3.1 Cockles at Mangawhai Harbour

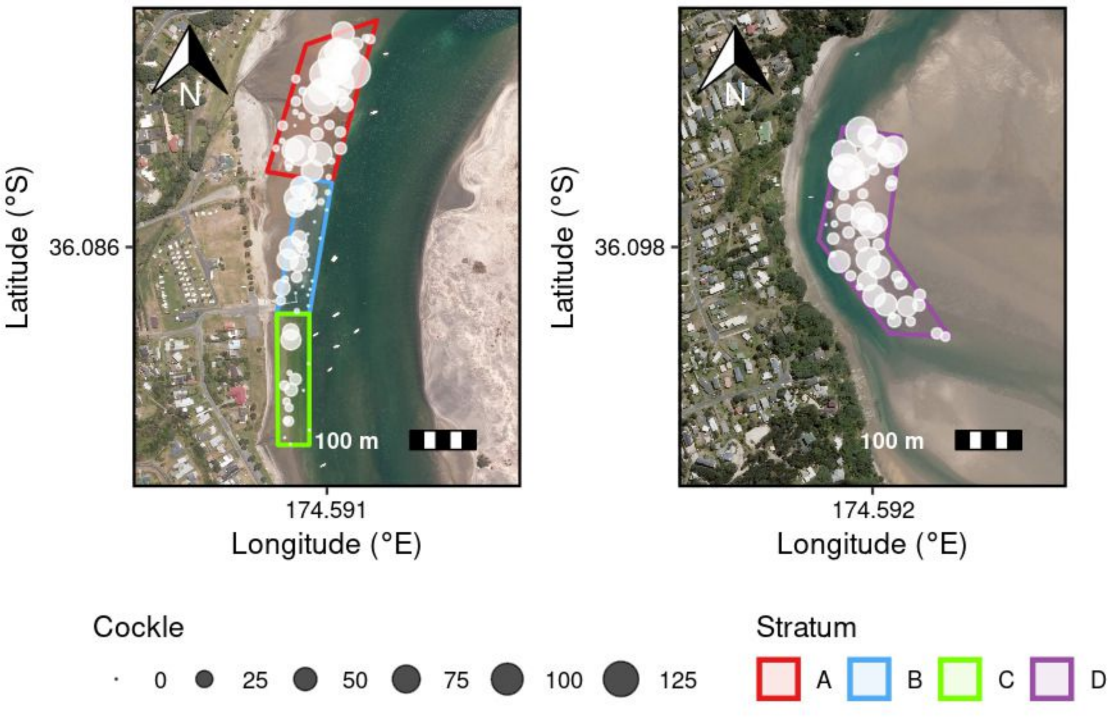


Figure 15: Map of sample strata and individual sample locations for cockles at Mangawhai Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m²) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of cockle abundance at Mangawhai Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	1 342	21.34	959	19.00
B	1.0	30	375	3.59	357	26.46
C	1.0	15	106	1.97	202	38.23
D	3.0	50	1 385	23.48	791	14.65

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	9.4	98.71	1 050	4.54	28.56	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
2023–24	7.2	50.38	702	10.83	2.09	29	18.32

Table 15: Summary statistics of the length-frequency (LF) distribution of cockles at Mangawhai Harbour. The 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 (%)
2018–19	18.55	20	5–36	33.73	3.14
2021–22	22.33	23	6–39	10.62	8.66
2023–24	20.47	24	4–37	19.47	4.15

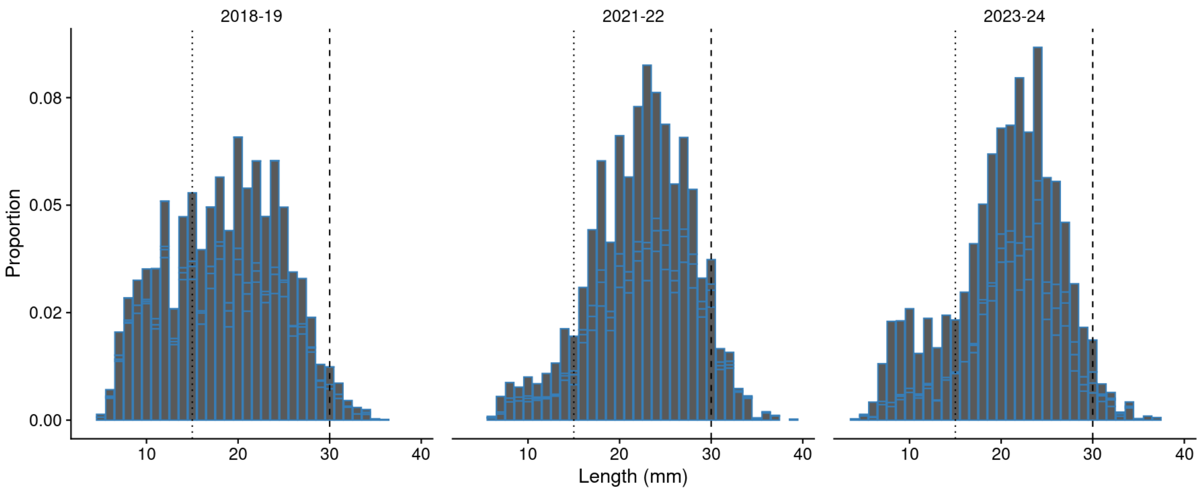


Figure 16: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mangawhai Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

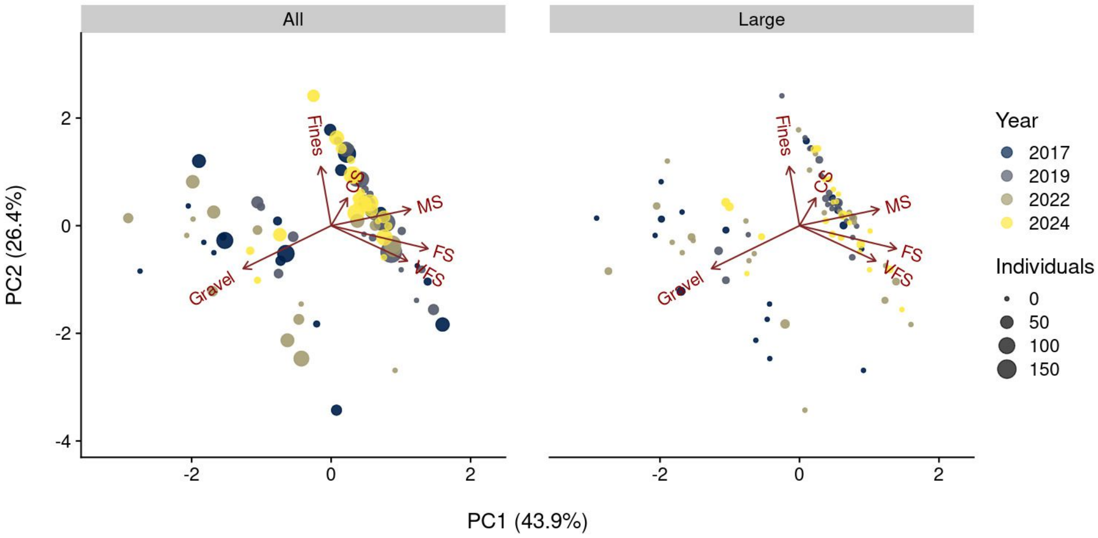


Figure 17: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Mangawhai Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 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.

3.4 Marsden Bank

Marsden Bank is in Northland, situated at the southern entrance of Whangārei Harbour. This bank, and neighbouring Mair Bank, are temporarily closed to all shellfish collections ((Department of Internal Affairs 2022a)). Starting in 2009–10, there have been six assessments at Marsden Bank, including the current assessment in 2023–24 (see Appendix A, Tables A-1, A-2). The surveys at this site are only focused on pipi as there are no cockle beds present. Pipi at this site have also been surveyed by Te Patuharakeke Te Iwi Trust Board (e.g., Shirkey 2019).

Throughout the survey series, the sampling extent has changed notably, mostly through marked reductions in the area surveyed, particularly since 2017–18. In 2023–24, pipi were sampled at a total of 60 points in a relatively small area at the north-eastern corner of Marsden Bank (Figure 18, Table 16).

Following the absence of pipi at this site in the preceding survey in 2021–22, the current survey documented an estimated total pipi abundance of 0.45 (CV: 15.66%) million individuals (Table 17). Their estimated mean density was 120 pipi per m^2.

The current population consisted almost exclusively of recruits ($\leq$20 mm shell length) which made up 87.57% of the total population (Table 18, Figure 19). Their prevalence indicated a substantial recruitment event prior to the survey, after their absence in 2021–22. In addition, there was a small proportion of medium-sized pipi in 2023–24, reflecting some growth of recruits into the next size class. Nevertheless, current mean and modal sizes corresponded to the shift in the population size structure towards recruits. For example, modal size shifted from 32 mm in 2017–18 to 13 mm shell length in 2023–24.

The significant recruitment pulse evident in the current survey indicated some recovery of the pipi population at this site. Nevertheless, re-establishment of this population will require persistence and growth of recruits to larger sizes. This aspect is particularly relevant considering the overall decline in the spatial extent and population estimates of pipi throughout the survey series at this site.

3.4.1 Pipi at Marsden Bank

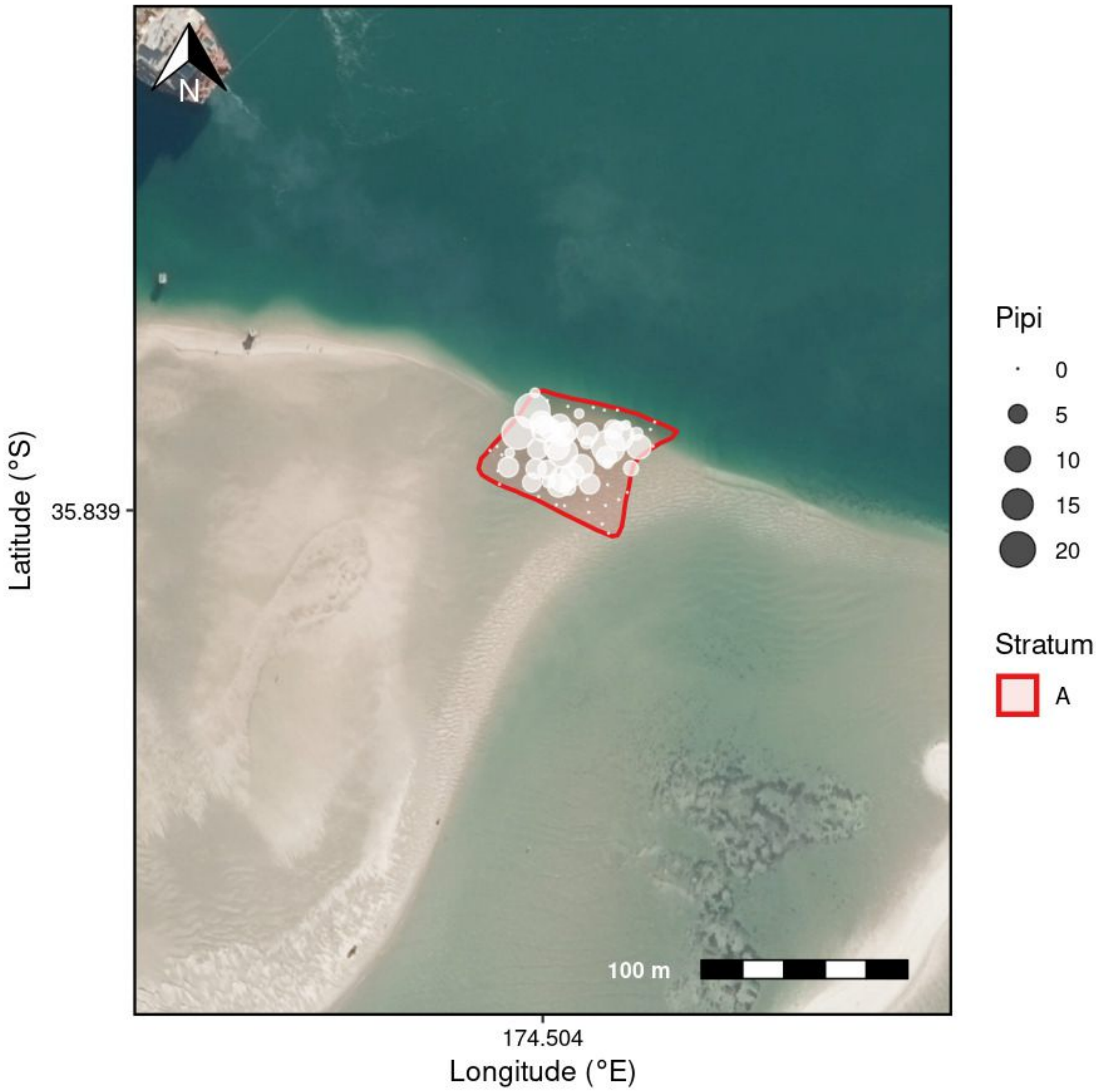


Figure 18: Map of sample strata and individual sample locations for pipi at Marsden Bank, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of pipi abundance at Marsden Bank, by stratum, for 2023–24. Presented are the area surveyed, 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	60	252	0.45	120	15.66

Table 17: 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	
2023–24	0.4	0.45	120	15.66	0.00	0	

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Marsden Bank. The 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	26.47	32	8–47	22.52	0.00
2023–24	15.49	13	7–34	87.57	0.00

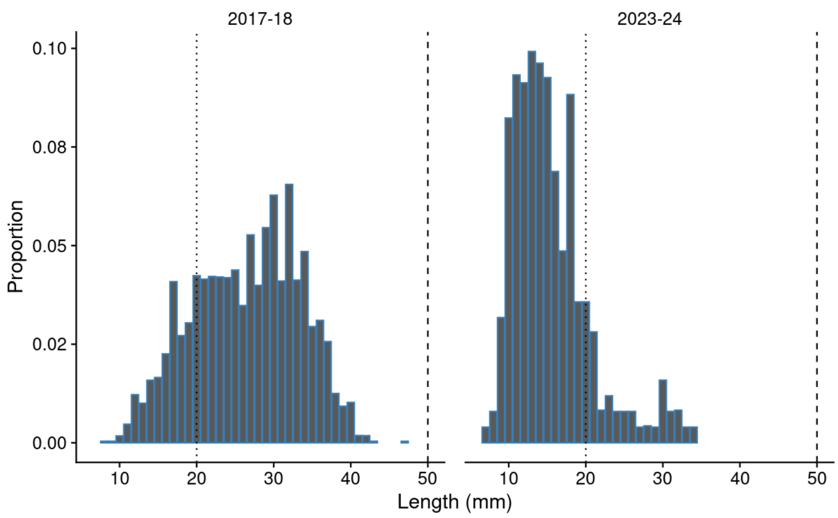


Figure 19: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Marsden Bank. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Ngunguru Estuary

Ngunguru Estuary is a small estuary north-east of Whangārei Harbour, in the Northland region. Since January 2016, the estuary has been closed to cockle and pipi collections (Department of Internal Affairs 2015a). Bivalve populations at this site have been monitored seven times before the current assessment, with a similar sampling extent since 2014–15 (see Appendix A, Tables A-1, A-2). The sampling effort in 2023–24 encompassed a total of 110 points across four distinct strata, including one designated pipi stratum. During the field survey in 2023–24, a number of recently-dead and moribund cockles were found across the cockle strata. (see Appendix D, Figure D-1).

Sediment within the cockle strata generally had a low organic content, but two samples contained over 4% of organics (Figure 20; and see details in Appendix B, Table B-1). The sediment grain size composition was dominated by fine sand (grain size >125 µm), and the proportion of sediment fines (<63 µm) was generally small, but exceeded 5% in several samples.

Cockles were distributed throughout all strata in the estuary, including the upper intertidal area of the pipi stratum (Figure 21, Table 19). The total abundance estimate was 75.02 (CV: 8.44%) million cockles, and the estimated average density was 1247 cockles per m^2 (Table 20). These estimates signified a marked reduction in the total population relative to the two preceding surveys in 2018–19 and 2021–22, when abundance estimates exceeded 100 million cockles. Nevertheless, the density of cockles remained above 1000 individuals per m^2 for most of the monitoring series, including the current assessment.

The current cockle population included a small number of large cockles (≥30 mm), and this finding was consistent throughout the survey series. Current estimates for this size class were 0.45 (CV: 28.75%) large cockles, occurring at an average density of 8 large individuals per m^2 (Table 20).

The general scarcity of large individuals was reflected in their minor proportion within the total population (i.e., consistently less than 1%) and in the length-frequency distributions (Table 21, Figure 22). The latter illustrated a strong cohort of medium-sized cockles, augmented by considerable proportions of recruits (≤15 mm) over time. Although there was a reduction in the proportion of recruits in the two most recent surveys from over 40% in 2018–19, this size class still constituted over a quarter of the population in 2021–22 and 2023–24. Compared with the 2018–19 survey, the mean and modal sizes slightly increased to 18.65 mm and 20 mm shell length, respectively, corresponding with the smaller proportion of recruits in these later surveys.

There were no clear pattern in cockle abundance in relation to sediment grain size fractions evident in the principal component analysis (Figure 23).

The pipi population at Ngunguru Estuary was mainly in the pipi stratum, stratum D, with few individuals in other strata (Figure 24, Table 22). The current estimates indicated a further decline in the population in recent surveys, from a comparatively large population size in 2018–19 of 42.39 (CV: 11.76%) million pipi to the current estimate of 23.84 (CV: 12.56%) million pipi (Table 23). There was a corresponding decline in pipi density from 655 pipi per m^2 to 396 pipi per m^2 over the same period.

Large pipi (≥50 mm) continued to be present in small numbers, with their abundance estimated at 0.40 (CV: 24.64%) million pipi, and a density estimate of 7 large individuals per m^2. This size class represented a minor proportion (1.69%) of the pipi population, and also underwent a decline compared with the preceding survey (Table 24, Figure 25).

In contrast, the population consisted primarily of recruits (≤20 mm shell length), with 63.40% of all individuals in this size class in 2023–24. Their prevalence in the current population resulted from a significant increase in recruits from already relatively high proportions (i.e., 30 to 40%) in the two preceding surveys. The high proportion of recruits, particular in 2021–22 and 2023–24, strongly influenced the shift in the population size structure towards two distinct cohorts, with a concomitant shift in mean and modal sizes to comparatively small shell lengths of 22.10 mm and 14 mm, respectively.

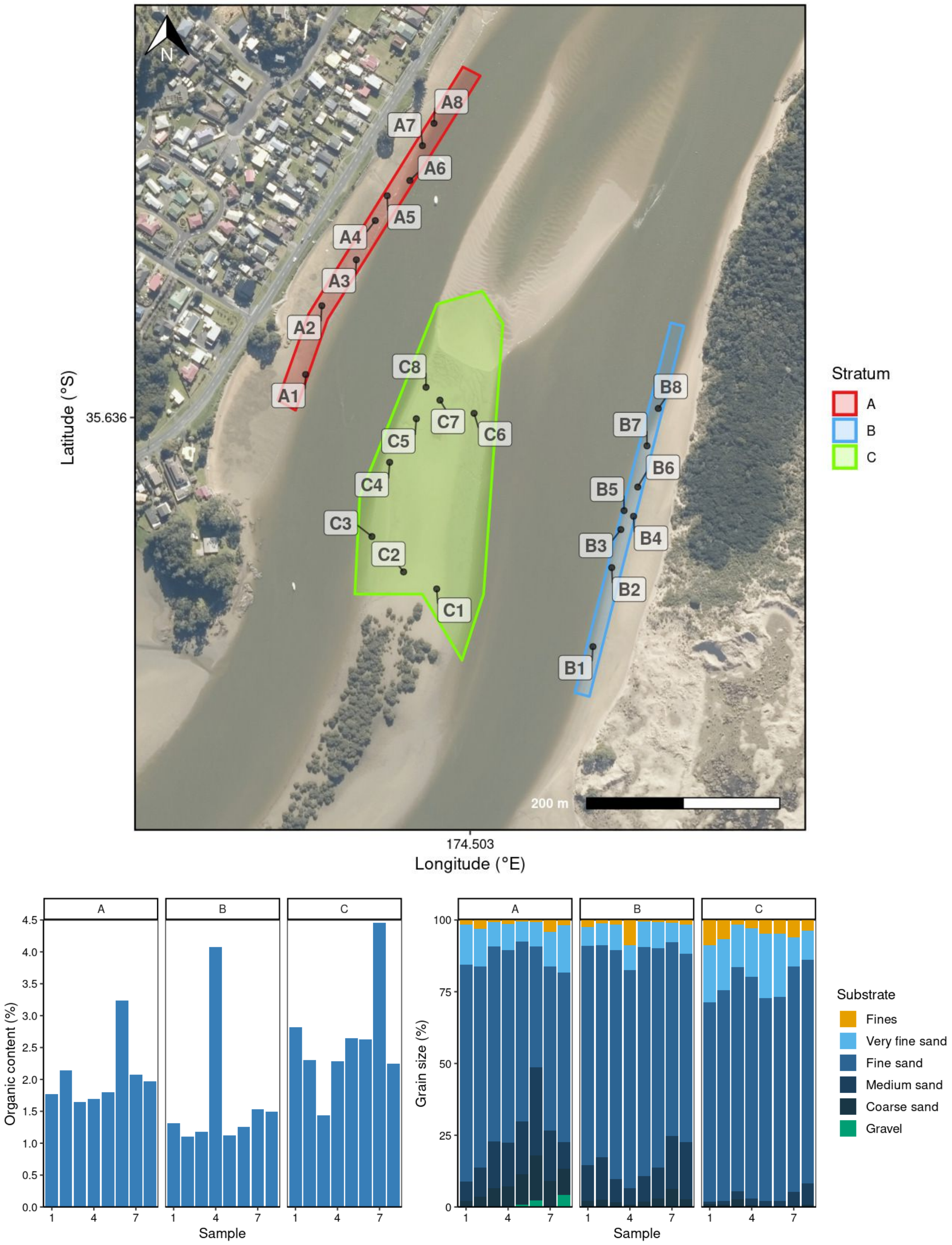


Figure 20: Sediment sample locations and characteristics at Ngunguru Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.5.1 Cockles at Ngunguru Estuary

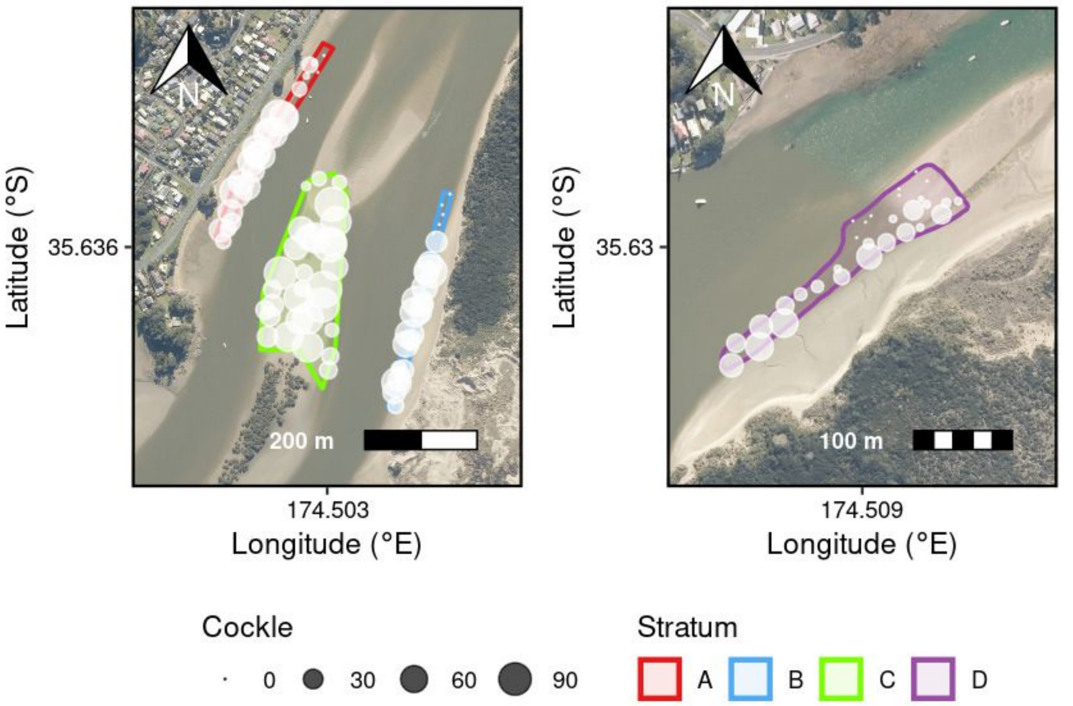


Figure 21: Map of sample strata and individual sample locations for cockles at Ngunguru Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of cockle abundance at Ngunguru Estuary, by stratum, for 2023–24. Presented are the area surveyed, 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	25	1 008	9.18	1 152	15.98
B	0.6	25	894	5.98	1 022	15.07
C	3.6	30	1 590	55.23	1 514	10.87
D	1.0	30	494	4.63	470	22.37

Table 20: 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
2023–24	6.0	75.02	1 247	8.44	0.45	8	28.75

Table 21: Summary statistics of the length-frequency (LF) distribution of cockles at Ngunguru Estuary. The 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 (%)
2018–19	16.52	15	4–45	42.75	0.22
2021–22	18.35	17	5–34	26.39	0.61
2023–24	18.65	20	5–34	25.59	0.60

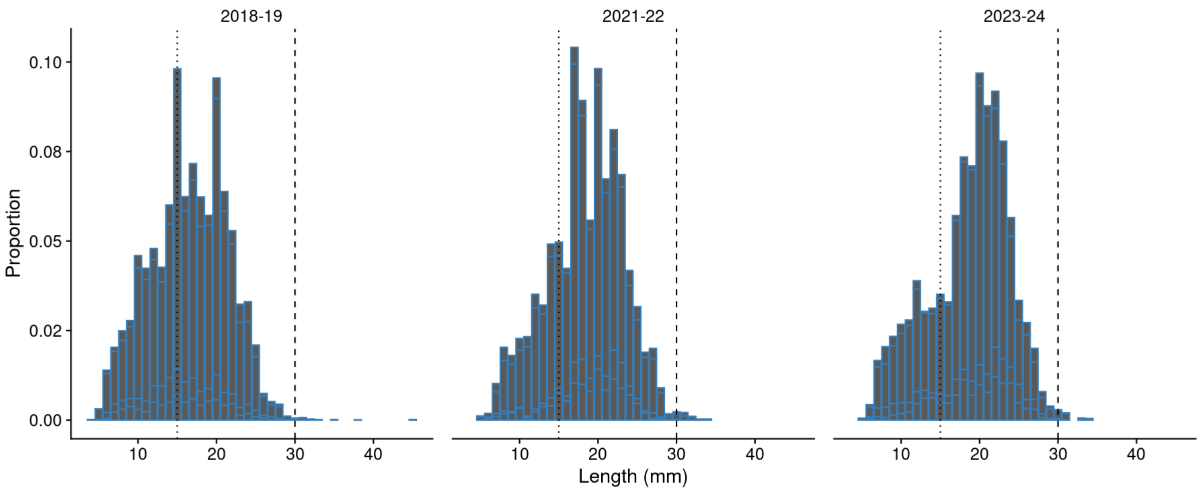


Figure 22: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

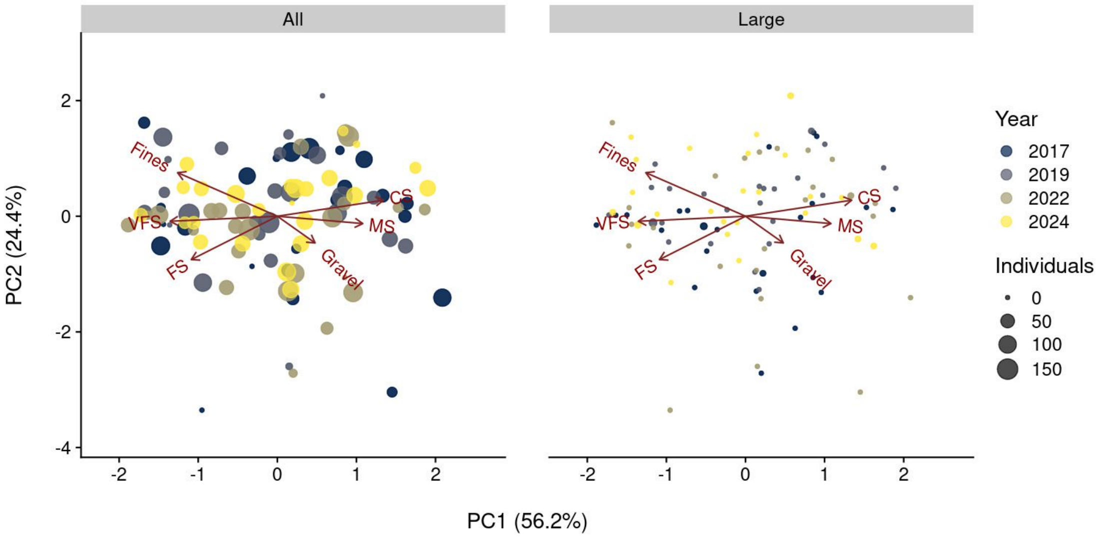


Figure 23: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Ngunguru Estuary. Sediment grain size fractions are defined as fines (silt and clay) ≤63 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.

3.5.2 Pipi at Ngunguru Estuary

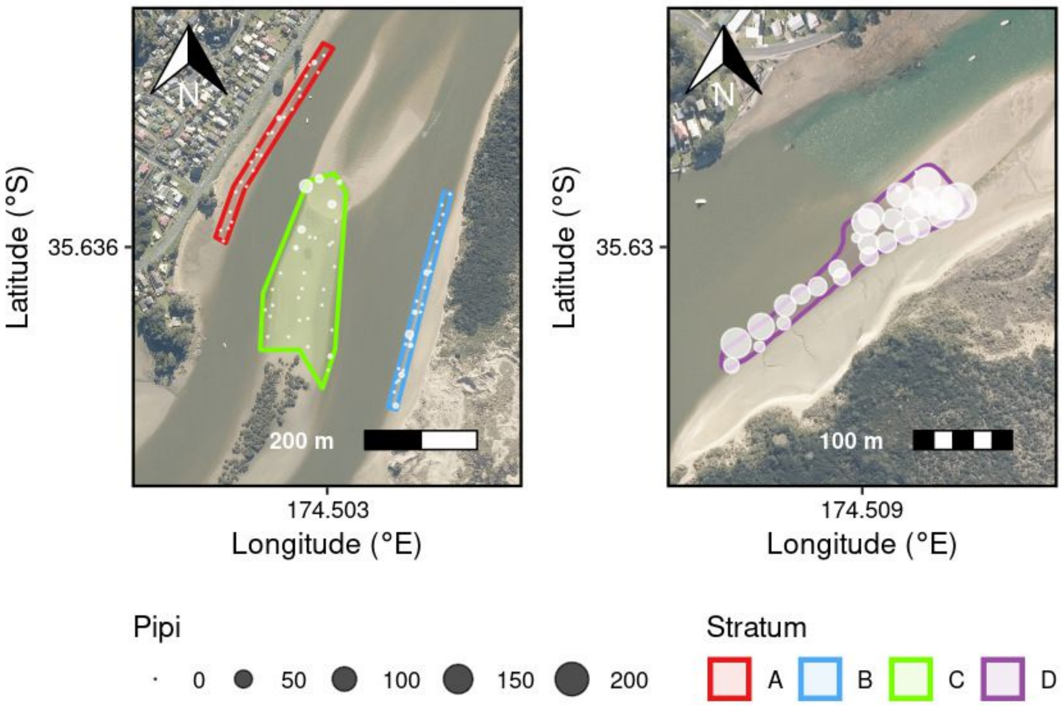


Figure 24: Map of sample strata and individual sample locations for pipi at Ngunguru Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of pipi abundance at Ngunguru Estuary, by stratum, for 2023–24. Presented are the area surveyed, 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	25	2	0.02	2	69.22
B	0.6	25	15	0.10	17	50.00
C	3.6	30	43	1.49	41	54.73
D	1.0	30	2 370	22.22	2 257	12.96

Table 23: 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
2023–24	6.0	23.84	396	12.56	0.40	7	24.64

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2018–19	26.75	18	6–53	33.19	0.94
2021–22	29.79	14	7–59	40.49	7.93
2023–24	22.10	14	7–55	63.40	1.69

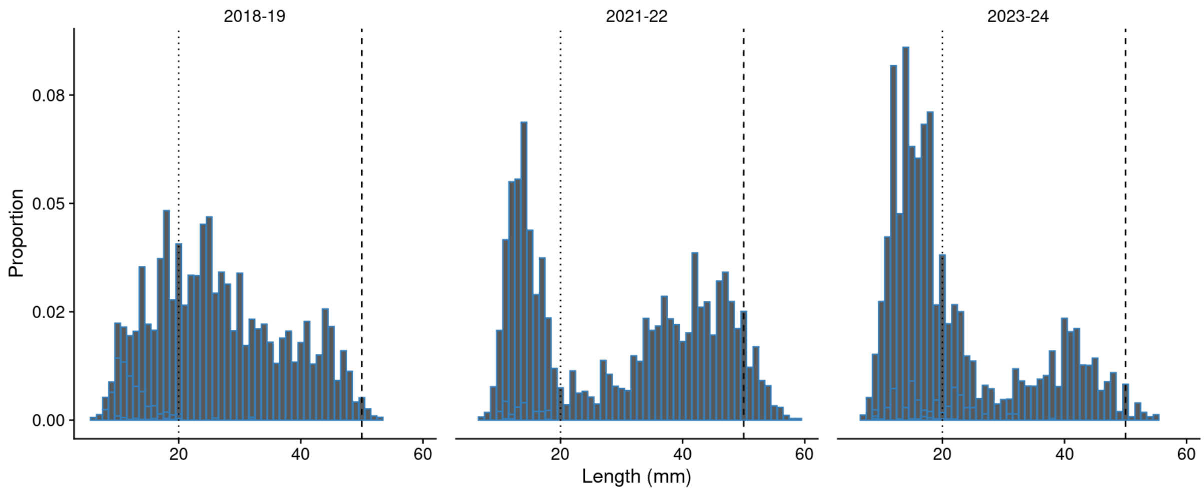


Figure 25: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ngunguru Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Raglan Harbour

Raglan Harbour is on the west coast of the Waikato region. Within the monitoring series, cockle and pipi populations were assessed a total of 11 times, with the most recent previous assessment in 2021–22 (see Appendix A, Tables A-1, A-2). The field sampling consistently encompassed two separate areas near the harbour's entrance, with a similar sampling extent since 2014–15. In 2023–24, there were a total of 90 sampling points distributed across two cockle strata and one pipi stratum.

In general, sediment in the cockle strata in Raglan Harbour was characterised by a low organic content (up to 4%) (Figure 26; and see details in Appendix B, Table B-1). The proportion of sediment fines (grain size <63 µm) varied and exceeded 10% in eight samples, with up to 17% of sediment in this grain size fraction. Overall, the sediment composition was predominantly fine sand (>125 µm).

The cockle population was dispersed across the cockle strata, with a small number of cockles also in the pipi bed, in stratum C (Figure 27, Table 25). The total cockle abundance estimate was 111.85 (CV: 7.50%) million individuals, and the estimated density was 1497 cockles per m^2 (Table 26). Current estimates showed a slight decrease in abundance compared with the previous survey in 2021–22. Nonetheless, the current population continued to retain a high cockle density (i.e., >1000 individuals per m^2), comparable to estimates throughout the entire survey series.

There were few large cockles (≥ 30 mm) in 2023–24, and this size class also underwent a recent decline (i.e., since 2017–18). The estimated population size of large cockles was 1.01 (CV: 28.09%) million individuals in 2023–24, and their average density 14 large cockles per m^2.

The small number of large cockles was reflected in their overall contribution to the population, representing less than 2% of all individuals between 2019–20 and 2023–24 (Table 27, Figure 28). In contrast, the size class of recruits (≤ 15 mm) remained similar, constituting 19.77% of the population in 2023–24. This aspect was evident in the overall size composition of the cockle population, with a unimodal structure, centred on the medium size class (i.e., at modal sizes around 20 mm shell length).

The principal component analysis illustrated a shift in the general pattern of total cockle abundance in relation to sediment grain sizes. In recent surveys, abundance was associated with fine sand and finer sediment grain size fractions compared with coarser sands and gravel (Figure 29).

Pipi at Raglan Harbour were almost exclusively in the pipi stratum, stratum C (Figure 30, Table 28). The current total population estimate for this species was 2.00 (CV: 15.29%) million pipi, and their estimated density was 27 individuals per m^2 (Table 29). The current estimates indicated an increase in population size from the preceding survey in 2021–22.

The large pipi (≥ 50 mm) population continued to be small with similar abundance and density estimates since 2009–10. In 2023–24, there were an estimated 0.15 million large pipi included in the total population, but this estimate had high uncertainty (CV: 30.39%) (Table 29).

The proportion of large pipi in the overall population was consistently small in recent surveys; it was 7.73% in the current assessment (Table 30, Figure 31). The proportion of recruits (≤ 20 mm) was also small at 6.85% in 2023–24, signifying a 50% reduction from the two preceding surveys. Although the medium size class consistently characterised the pipi population at this site, the growth of pipi towards the larger size class and regular recruitment led to changes in the population size structure in recent surveys. This change consisted of a shift from a unimodal to an increasingly distinct bimodal population, with increases in mean and modal sizes from around 30 mm to 40–45 mm shell length reflecting the prevalence and growth of medium-sized pipi.

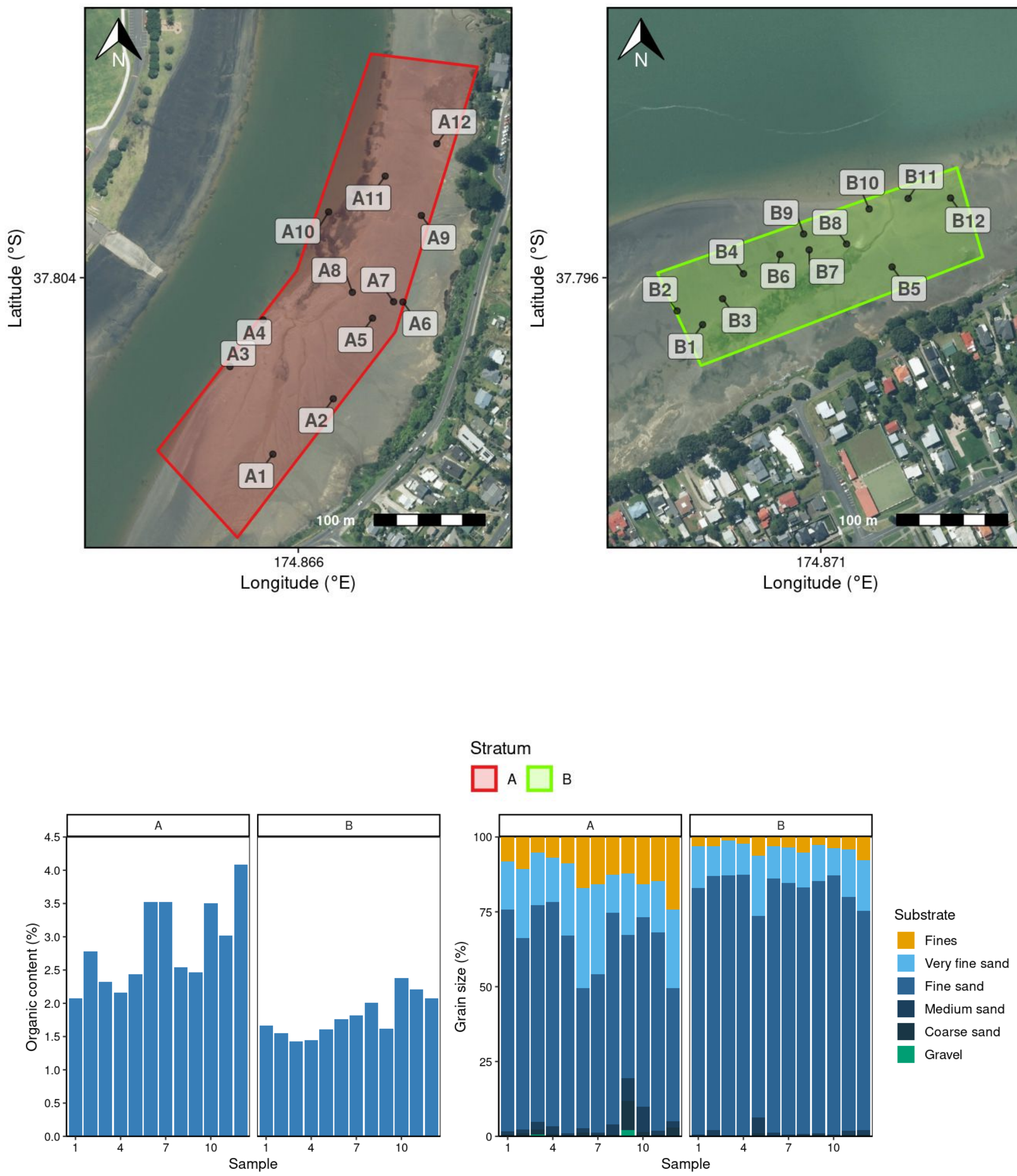


Figure 26: Sediment sample locations and characteristics at Raglan Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.6.1 Cockles at Raglan Harbour

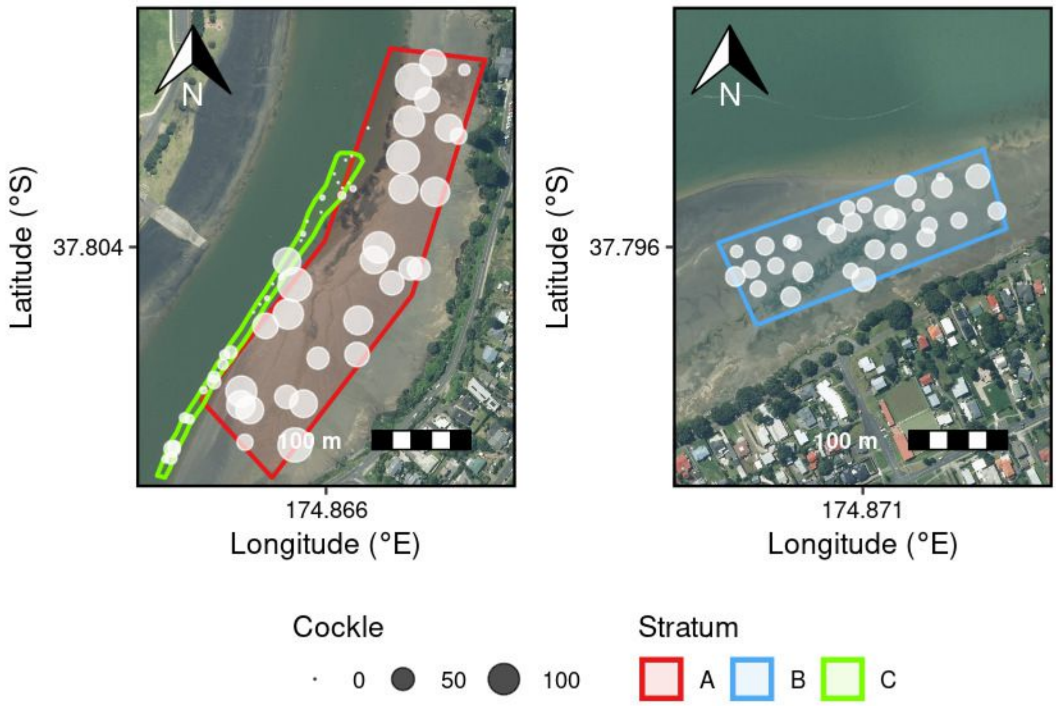


Figure 27: Map of sample strata and individual sample locations for cockles at Raglan Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Raglan Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	2 096	90.88	1 996	9.04
B	2.5	30	856	20.10	815	8.18
C	0.5	30	204	0.88	194	38.57

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.1	184.49	1 827	3.64	6.56	65	12.56
2000–01	10.0	220.43	2 195	3.34	17.28	172	6.50
2002–03	8.2	92.26	1 120	3.78	4.17	51	9.47
2003–04	8.2	89.79	1 090	3.50	3.76	46	7.49
2009–10	9.2	125.59	1 365	5.23	5.90	64	20.79
2012–13	8.2	129.04	1 566	6.84	6.08	74	19.74
2014–15	7.2	109.56	1 513	4.95	2.44	34	15.20
2017–18	7.2	109.16	1 508	7.11	3.21	44	22.20
2019–20	7.4	126.74	1 716	6.07	2.15	29	22.01
2021–22	7.3	115.66	1 579	8.25	1.65	23	26.29
2023–24	7.5	111.85	1 497	7.50	1.01	14	28.09

Table 27: Summary statistics of the length-frequency (LF) distribution of cockles at Raglan Harbour. The 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 (%)
2019–20	20.02	20	4–36	17.71	1.70
2021–22	20.69	23	6–37	12.23	1.43
2023–24	19.50	20	5–38	19.77	0.90

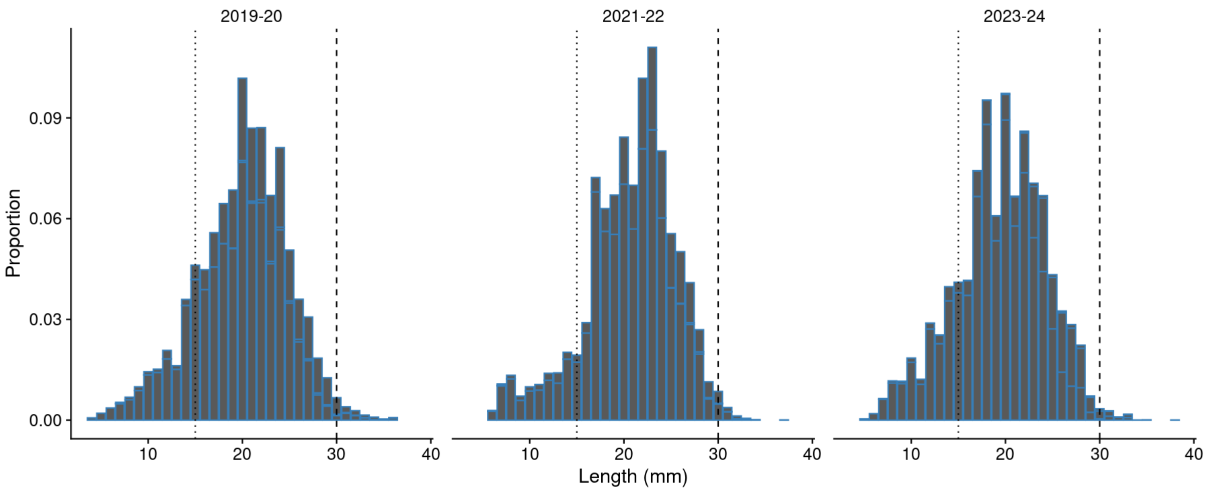


Figure 28: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

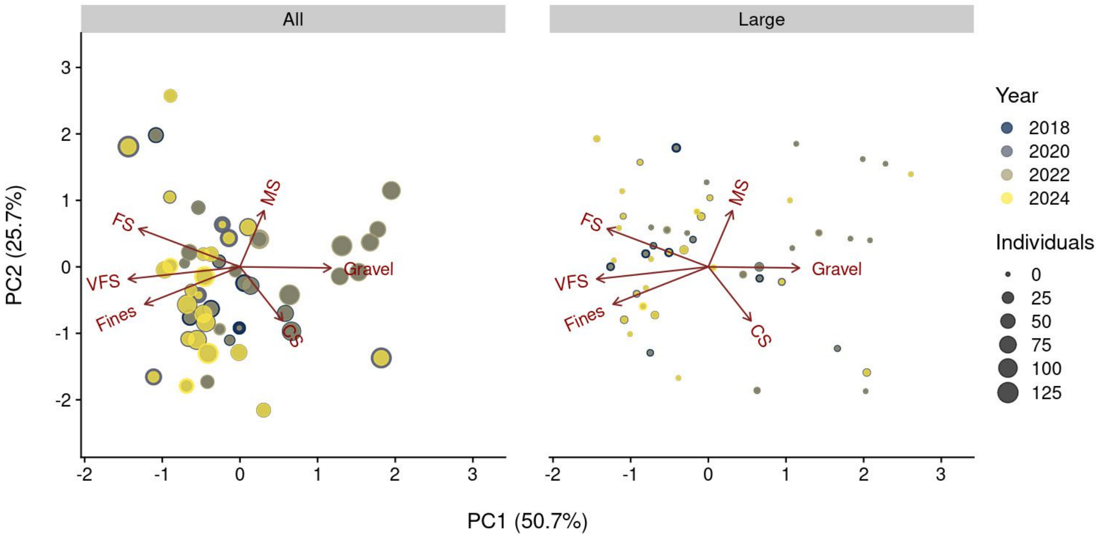


Figure 29: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Raglan Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, 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.

3.6.2 Pipi at Raglan Harbour

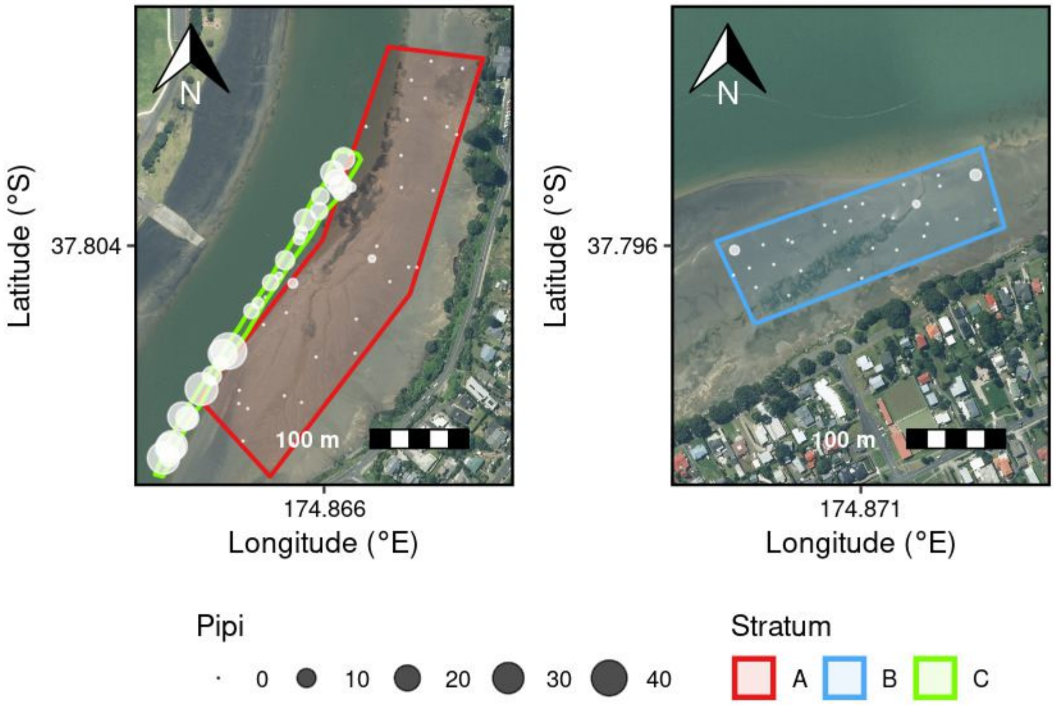


Figure 30: Map of sample strata and individual sample locations for pipi at Raglan Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Raglan Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	5	0.22	5	58.13
B	2.5	30	6	0.14	6	60.65
C	0.5	30	381	1.64	363	16.15

Table 29: 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
2023–24	7.5	2.00	27	15.29	0.15	2	30.39

Table 30: Summary statistics of the length-frequency (LF) distribution of pipi at Raglan Harbour. The 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 (%)
2019–20	34.12	32	10–57	11.09	3.95
2021–22	40.00	43	8–56	12.14	9.26
2023–24	36.53	45	10–55	6.85	7.73

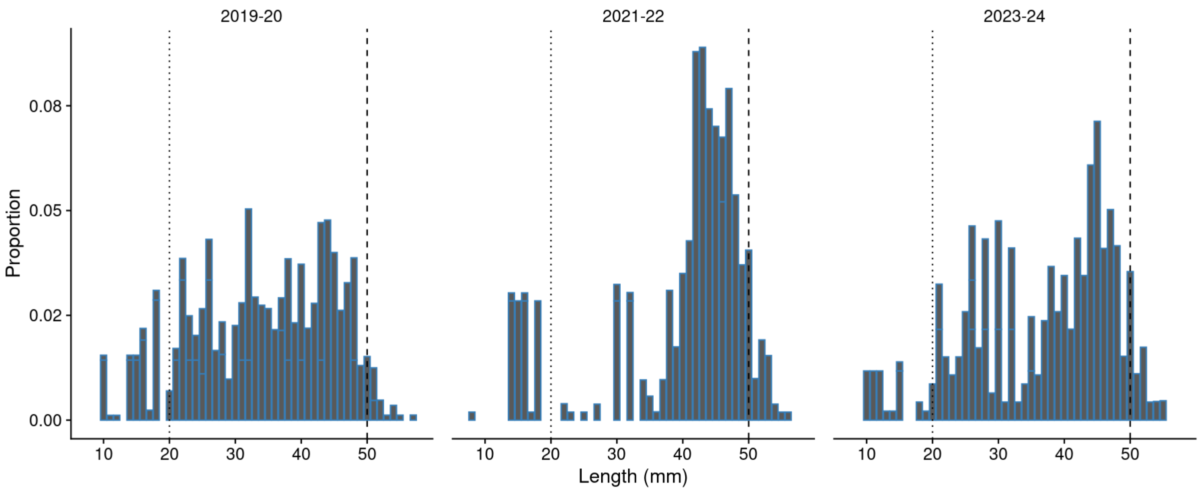


Figure 31: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Raglan Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.7 Ruakākā Estuary

Ruakākā Estuary is a small estuary in Northland, south of Whangārei. It was first surveyed in 2006–07, with six surveys since then, including the current assessment (see Appendix A, Tables A-1, A-2). Sampling in this estuary has been primarily focused on the main channel, including the resident pipi bed and small cockle beds on its fringes. There was a continued reduction in the latter species in recent surveys, so the 2023–34 assessment focused on pipi only. Pipi at this site are also monitored by Te Patuharakeke Te Iwi Trust Board (e.g., see Shirkey 2019).

In 2023–24, there were significant changes to the main estuary channel since the previous survey in 2021–22. These changes included substantial sedimentation in the upper main channel area, resulting in the loss of relatively deep, high-flow areas. In addition, the extension of a previously dead-ended northern side channel resulted in its opening to the coast, connecting it to the southern main channel (please see Figure 32 for the 2023–24 sampling strata indicating the current channel areas in relation to the underlying satellite image illustrating the previous course of the channel; see also Appendix D, Figure D-2). Other changes to the estuary topography resulted in marked flow reductions in another small northern arm that previously contained a small cockle bed but had turned anoxic.

The 2023–24 sampling extent incorporated these changes, assessing the pipi population in the reduced main channel area that was unaffected by the sedimentation, and also in the northern side channel opening to the coast. The overall sampling extent was smaller than in recent preceding surveys, and incorporated two strata with a total of 60 sampling points (Figure 32, Table 31)

Pipi were distributed throughout the sampling extent, with considerable numbers and densities recorded in the field survey, particularly in stratum B, the northern side channel. The current pipi population was estimated at 121.15 (CV: 13.48%) million individuals (Table 32). This estimate signified a reduction in the total pipi population relative to the preceding survey (i.e., 166.06 (CV: 14.54%) million pipi in 2021–22); however, it was accompanied by the reduction in the sampling extent. In comparison, the density estimate revealed a marked population increase from 4061 individuals per m^2 in 2021–22 to 5857 individuals per m^2 in 2023–24; the current estimate represented the highest pipi population density recorded in the monitoring series at this site.

Considering pipi size classes in the current population highlighted the lack of large pipi (≥50 mm shell length) and the prevalence of recruits (≤20 mm shell length) (Table 33, Figure 33). Recruits made up over 50% of the population in the two preceding surveys, with the remainder consisting of medium-sized pipi. The increase in recruits in 2023–24 resulted in their overall proportion increasing to 74.08%, consolidating the single cohort in the population at a modal size of 14 mm shell length, below the recruit size class cut-off.

The findings from the present survey confirmed that the pipi population in this estuary is largely dependent on regular recruitment events.

3.7.1 Pipi at Ruakākā Estuary

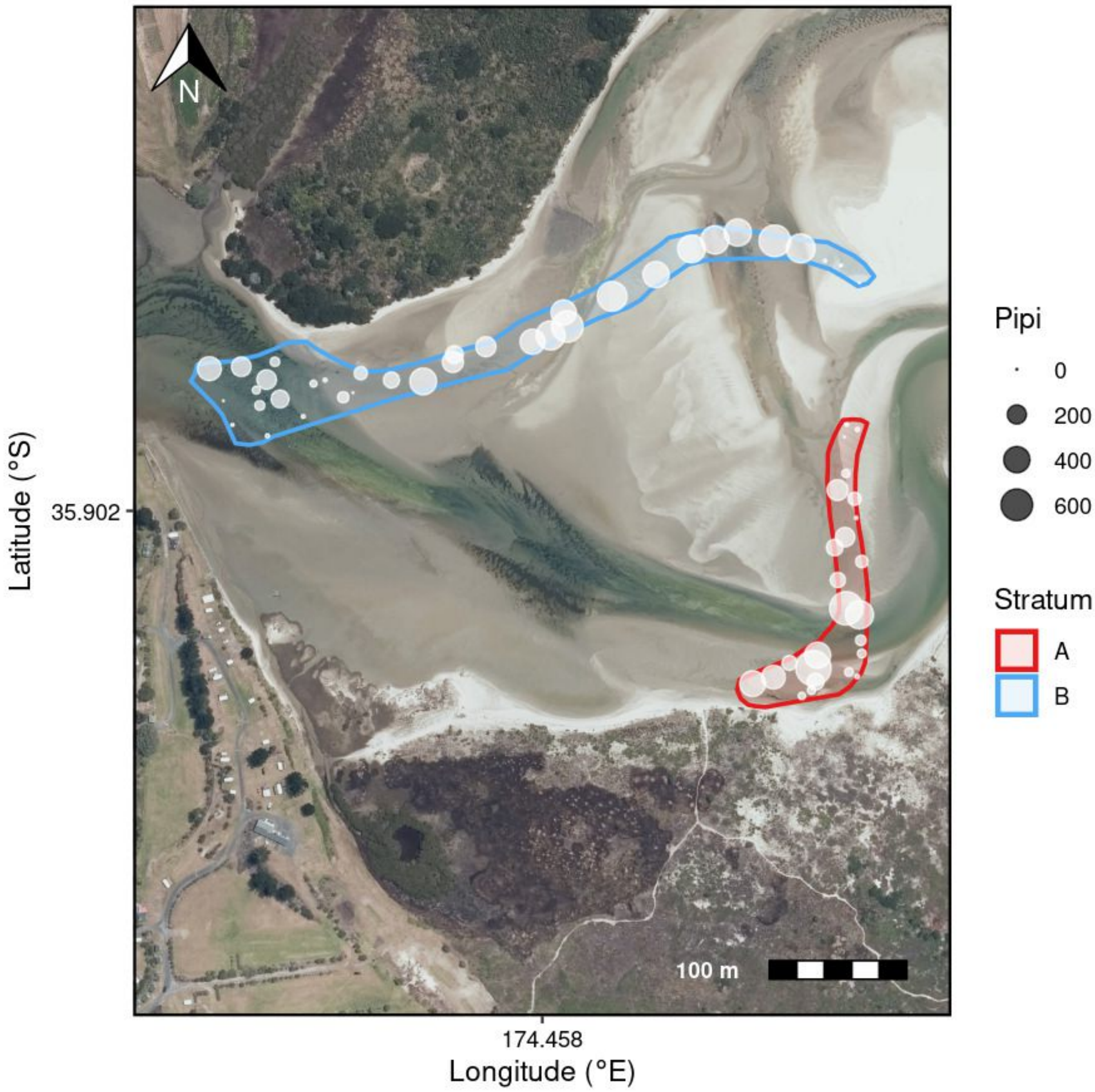


Figure 32: Map of sample strata and individual sample locations for pipi at Ruakākā Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of pipi abundance at Ruakākā Estuary, by stratum, for 2023–24. Presented are the area surveyed, the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.6	25	4 364	31.42	4 987	24.47
B	1.4	35	7 642	89.74	6 238	16.06

Table 32: 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
2023–24	2.1	121.15	5 857	13.48	0.00	0	

Table 33: Summary statistics of the length-frequency (LF) distribution of pipi at Ruakākā Estuary. The LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2018–19	21.01	15	7–52	51.11	0.16
2021–22	19.69	12	5–57	64.21	0.01
2023–24	17.88	14	6–49	74.08	0.00

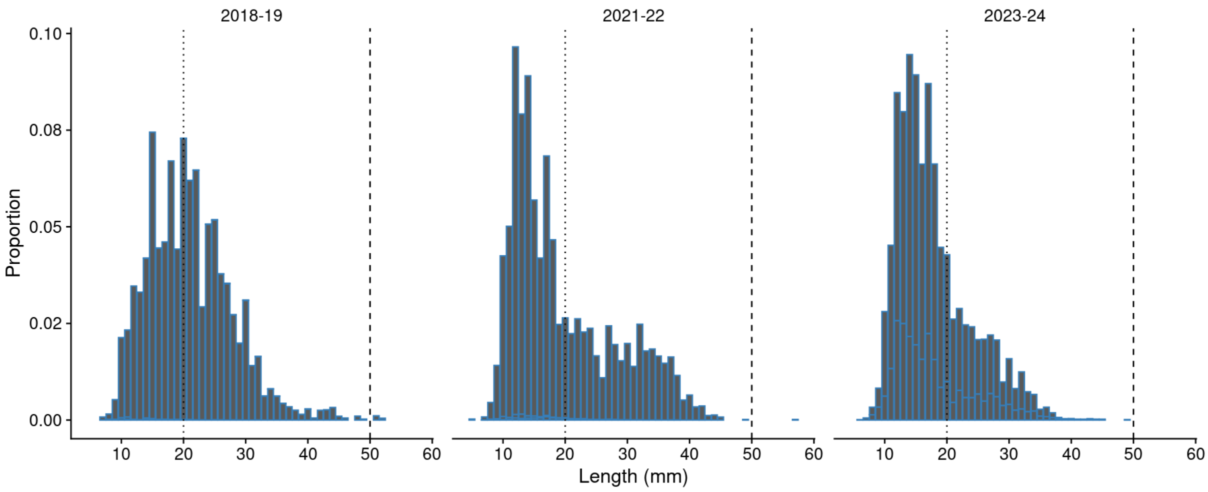


Figure 33: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ruakākā Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Tairua Harbour

Tairua Harbour is on the east coast of Coromandel Peninsula, in the Waikato region. Bivalves have been sampled in the harbour since 1999-2000 with the preceding survey in 2021–22 (see Appendix A, Tables A-1, A-2). The sampling extent has varied throughout the monitoring series, primarily caused by changes in the size and location of the pipi beds. This change was evident in 2023–24, when a previous pipi bed (close to the entrance and the marina) had disappeared, after progressively diminishing in size over the two preceding surveys. The field survey in this assessment was based on a sampling effort of 84 points, including seven points in phase-2 sampling. The sampling points were distributed across three cockle strata and one pipi stratum.

The sediment organic content at Tairua Harbour was low, ranging from 1.3 to 4.8% (Figure 34; and see details in Appendix B, Table B-1). The proportion of sediment fines (grain size <63 µm) was variable, with this grain size composition exceeding 5% in about a third of all samples. Overall, fine and medium sands (>63 µm and >125 µm) were the dominant grain size fractions at this site.

Cockles were concentrated in the cockle strata (strata A to B) (Figure 35, Table 34). The population estimate for this species was 45.47 (CV: 11.78%) million cockles, and the density estimate was 834 cockles per m^2 (Table 35). Current estimates reflected a decline in the total population, although cockle density remained relatively high.

Included in the total population was a small population of large cockles (>30 mm), and their abundance was an estimated 0.45 (CV: 25.90%) million individuals. The current density estimate for this size class was 8 large cockles per m^2. This size class underwent a similar decline as the total population.

Corresponding to their low numbers, large cockles contributed a minor proportion (0.99%) of individuals to the overall population (Table 36, Figure 36). In contrast, medium-sized cockles and recruits (≤15 mm) determined the population size composition in recent surveys. Over this period, the Tairua Harbour population was characterised by considerable recruitment; in 2023–24, 36.41% of the population were recruits. The recent increase in this size class reduced the mean and modal sizes to 17.41 mm and 18 mm shell length, respectively.

In relation to sediment grain size, the principal component analysis indicated that high cockle abundance was generally associated with finer sands (Figure 37).

Tairua Harbour pipi were sampled across the entire sampling extent, and occurred at relatively high numbers and densities in the eastern area of the cockle strata (Figure 38, Table 37). The total abundance estimate for pipi was 41.66 (CV: 22.26%) million individuals in 2023–24, and their estimated average density was 764 pipi per m^2 (Table 38).

The current estimates signified a considerable increase in the pipi population, also reflected in the highest density estimate in the entire monitoring series. In contrast to this trend, the small population of large pipi (≥50 mm) underwent a notable decrease, from 1.48 (CV: 39.66%) million large pipi and an average density of 25 large individuals per m^2 in 2021–22 to 0.22 (CV: 24.66%) large individuals occurring at an average density of 4 large pipi per m^2 in 2023–24 (Table 38).

The small number of large pipi meant that this size class was only a minor component (0.53%) of the total population in 2023–24, compared with medium-sized pipi and also recruits (≤20 mm) (Table 39). A significant influx of recruits (59.23%) largely determined the overall increase in the pipi population in 2023–24. The recent increase in recruits almost tripled the contribution of this size class to the overall population, changing it from a bimodal to a unimodal size structure (Figure 39). The dominance of recruits was augmented by a general loss of medium-sized individuals. There was a concomitant decrease in mean and modal sizes; e.g., modal length decreased from 47 mm in 2021–22 to 13 mm shell length in 2023–24.

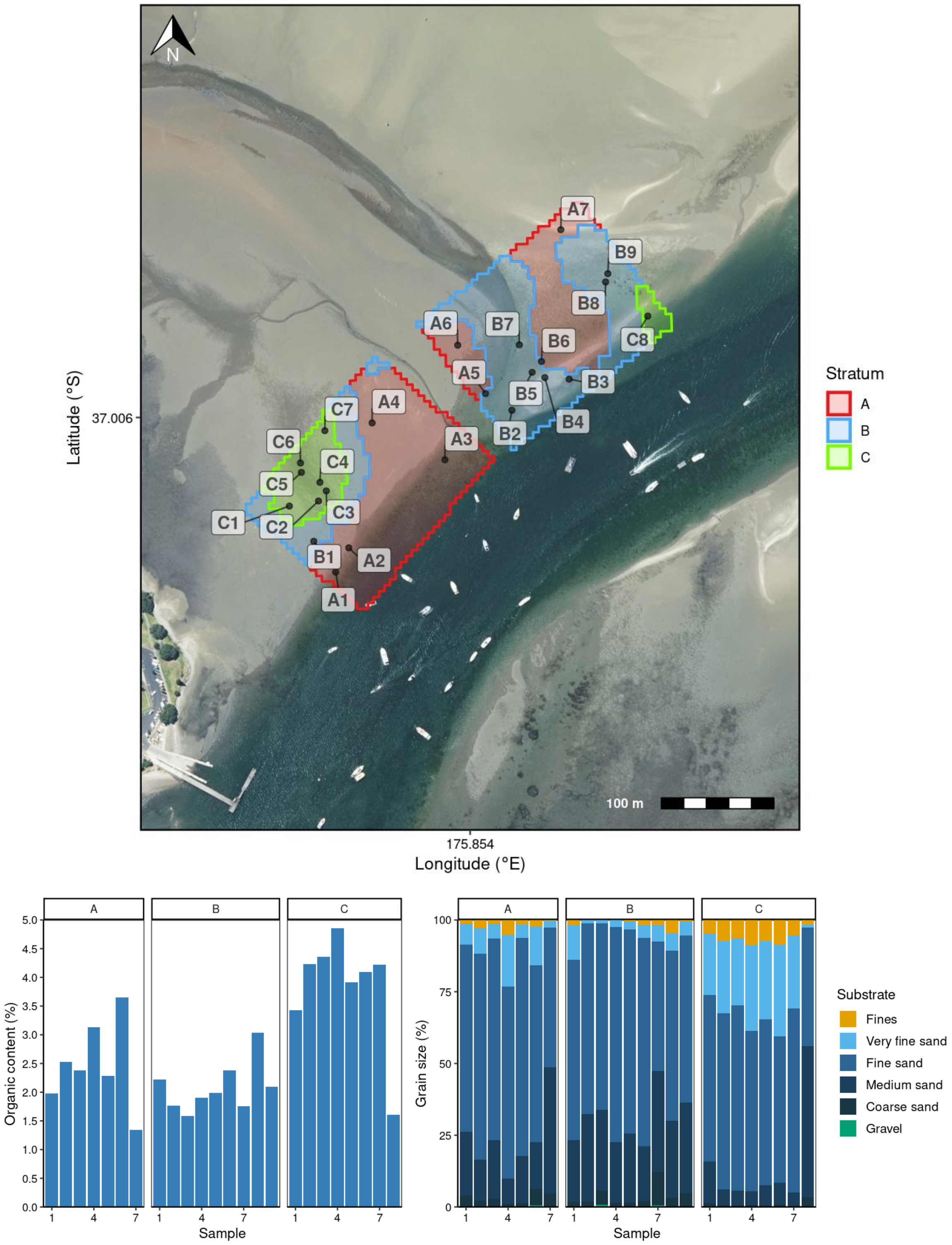


Figure 34: Sediment sample locations and characteristics at Tairua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.8.1 Cockles at Tairua Harbour

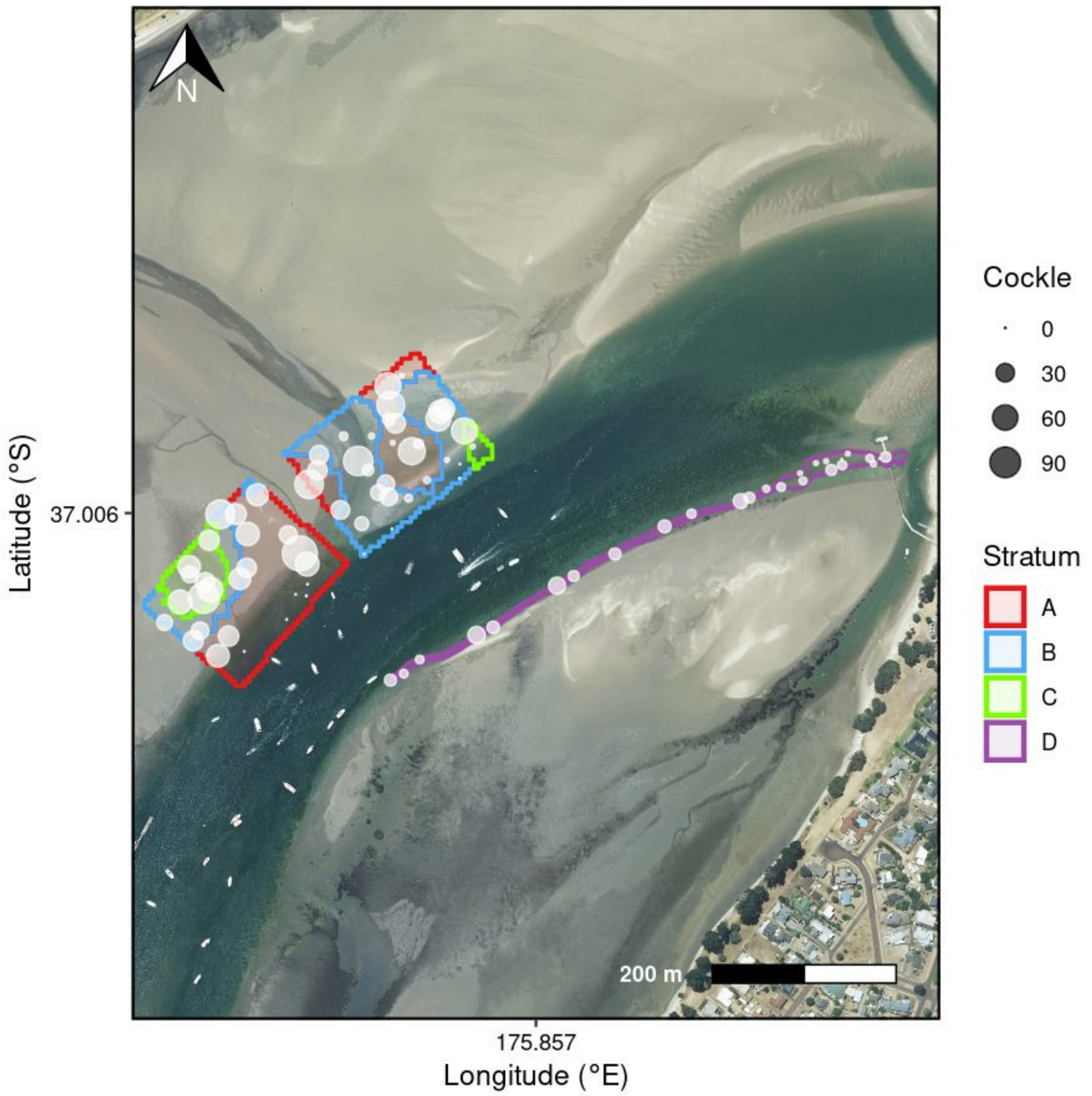


Figure 35: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	27	888	23.92	940	17.70
B	2.0	22	545	13.96	708	21.63
C	0.5	9	405	6.70	1 286	18.98
D	0.4	26	195	0.88	214	18.27

Table 35: 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
2023–24	5.5	45.47	834	11.78	0.45	8	25.90

Table 36: Summary statistics of the length-frequency (LF) distribution of cockles at Tairua Harbour. The 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 (%)
2019–20	19.14	20	5–34	20.64	0.92
2021–22	19.09	23	5–37	30.98	2.44
2023–24	17.41	18	5–35	36.41	0.99

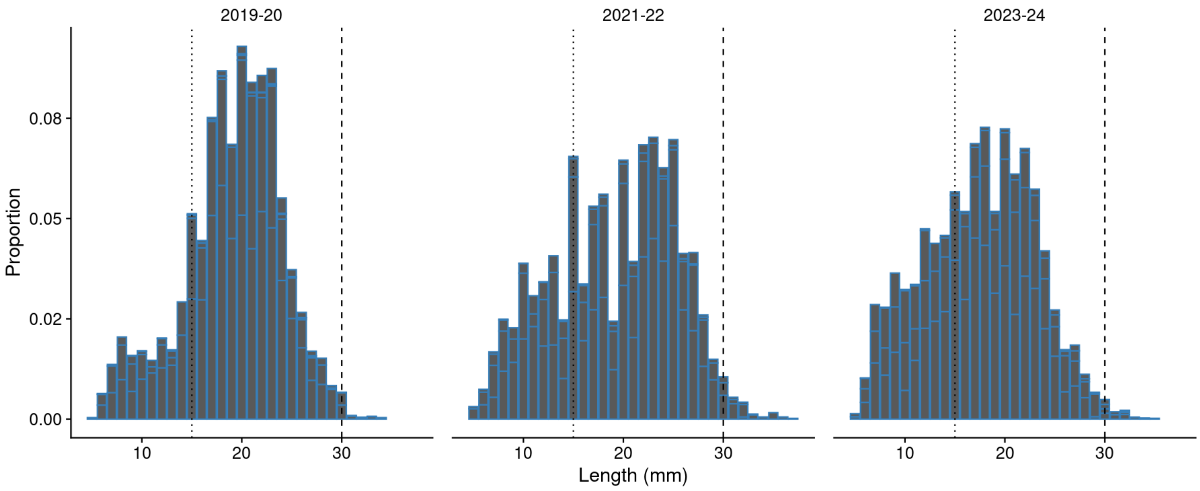


Figure 36: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

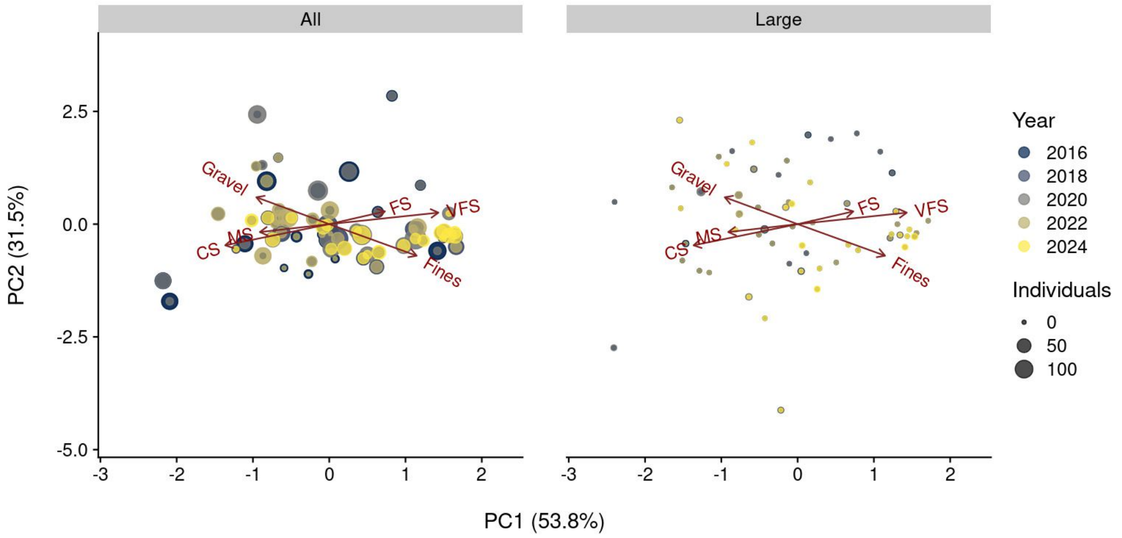


Figure 37: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Tairua Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm,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

3.8.2 Pipi at Tairua Harbour

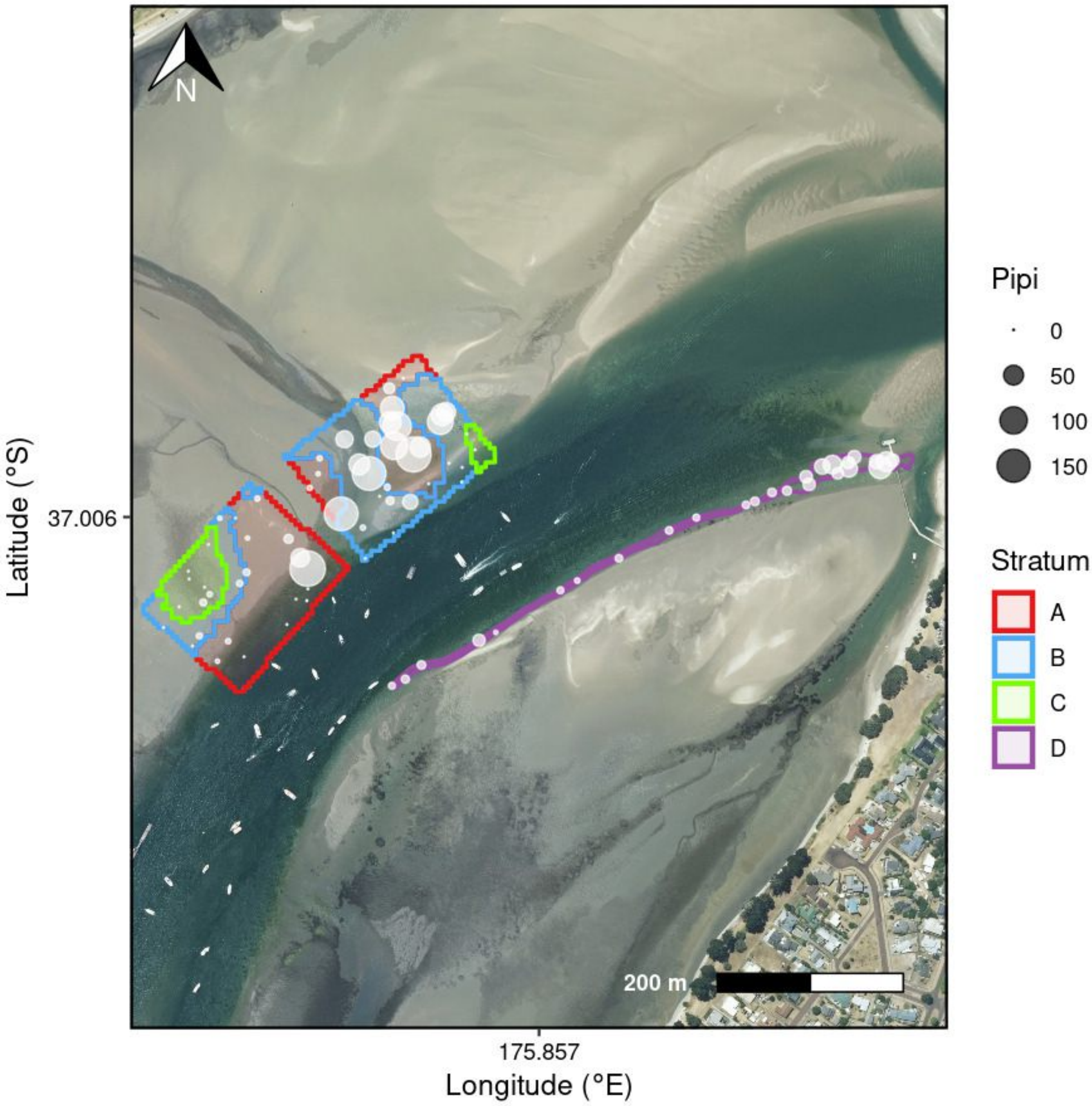


Figure 38: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	27	975	26.26	1 032	30.39
B	2.0	22	521	13.35	677	35.27
C	0.5	9	6	0.10	19	70.71
D	0.4	26	432	1.96	475	19.57

Table 38: 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
2023–24	5.5	41.66	764	22.26	0.22	4	24.66

Table 39: Summary statistics of the length-frequency (LF) distribution of pipi at Tairua Harbour. The 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 (%)
2019–20	33.70	40	5–55	15.44	1.83
2021–22	35.56	47	7–59	21.99	9.05
2023–24	20.03	13	8–64	59.23	0.53

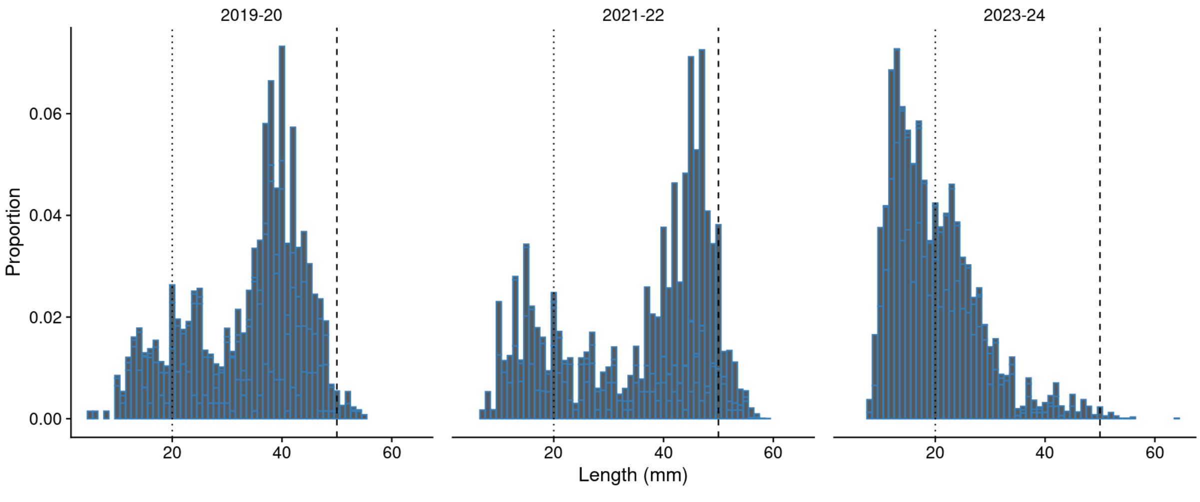


Figure 39: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Te Haumi Bay

Te Haumi Bay is south of Paihia, on the east coast of Northland. Cockle and pipi populations at this site have been surveyed 12 times, starting in 1999–2000 (see Appendix A, Tables A-1, A-2). There has been some variation in the sampling extent over time, mostly related to changes in the pipi beds at this site. The 2023–24 bivalve assessment sampled a total of 129 points across five strata, including two separate pipi strata.

Sediment samples from the cockle strata were low in organic content with a maximum of 3.5% (Figure 40, and see details in Appendix B, Table B-1). The proportion of sediment fines (grain size <63 µm) varied between 1.5% and 8.5%. Depending on the stratum, there were varying proportion of the two most prevalent grain size classes, fine and medium sands (>125 µm and >250 µm).

The cockle population at Te Haumi Bay was distributed throughout most of the cockle strata on the eastern intertidal sandflat area; cockles were also present in the pipi bed on the western side (Figure 41, Table 40). The total population estimates included an abundance of 56.63 (CV: 13.42%) million cockles and an average density of 564 cockles per m^2 (Table 41). Following an increasing trend in the three preceding assessments, the current estimates signified a marked decrease in the cockle population at this site. This decrease was also evident in the population of large cockles (≥30 mm shell length), and the current estimated abundance of size class was 1.55 (CV: 22.66%) large individuals in 2023–24. Their density underwent a similar decline with the current estimate of 15 large cockles per m^2.

The large cockle size class made up a small proportion (2.74%) of the total population, which was largely influenced by varying recruitment events and medium-sized cockles (Table 42, Figure 42). In 2023–24, recruits (≤15 mm) dominated the cockle population with 62.78% of all individuals in this size class. Although the population size structure remained bimodal in the recent assessment, there was a change in the relative proportions of the two main cohorts, with recruits dominating the size structure. Their dominance reduced mean and modal sizes; e.g., the latter was 8 mm shell length.

There were no clear associations between cockle abundance and sediment grain sizes in the principal component analysis, neither for all cockles nor for large individuals (Figure 43)

The pipi population at Te Haumi Bay was widely distributed across all strata, with relatively few pipi in the eastern pipi bed, stratum D (Figure 44, Table 43). Current estimates of pipi abundance and density were 72.11 (CV: 14.15%) million pipi and 718 individuals per m^2, reflecting a significant population increase compared with the two preceding surveys (Table 44). For example, the total population estimate in 2021–22 was 41.89 (CV: 14.45%) million pipi.

The general scarcity of large pipi (≥50 mm shell length) continued in 2023–24, with an estimated abundance of 0.60 million individuals in this size class, and a corresponding density of 6 large individuals per m^2; the uncertainty for both estimates was high (CV: 21.43%).

Large pipi contributed few individuals to the total population in recent surveys, and the current study documented a reduction in medium-sized pipi accompanied by a strong recruitment event; 74.39% of pipi were recruits (≤20 mm shell length)(Table 45, Figure 45). The prevalence of recruits skewed the population size structure towards smaller mean and modal sizes between 17 and 18 mm shell length. The previously bimodal population changed to a single cohort of small pipi centred around the small size class cut off.

The strong recruitment documented in this study also explained the spatial distribution of the pipi population, with recruits initially settling across the general bay area. At the same time, medium-sized pipi disappeared from the eastern pipi bed.

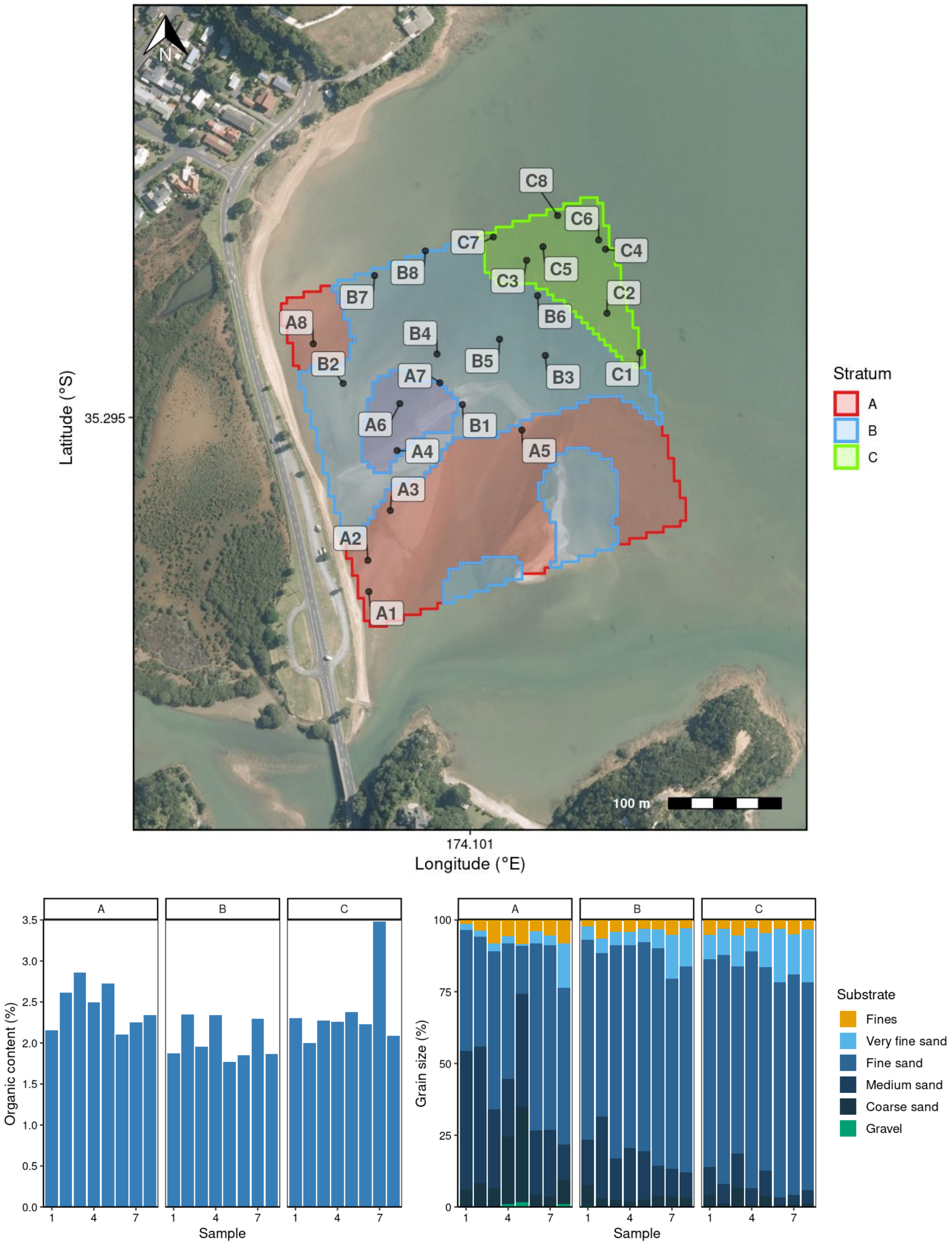


Figure 40: Sediment sample locations and characteristics at Te Haumi Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.9.1 Cockles at Te Haumi Bay

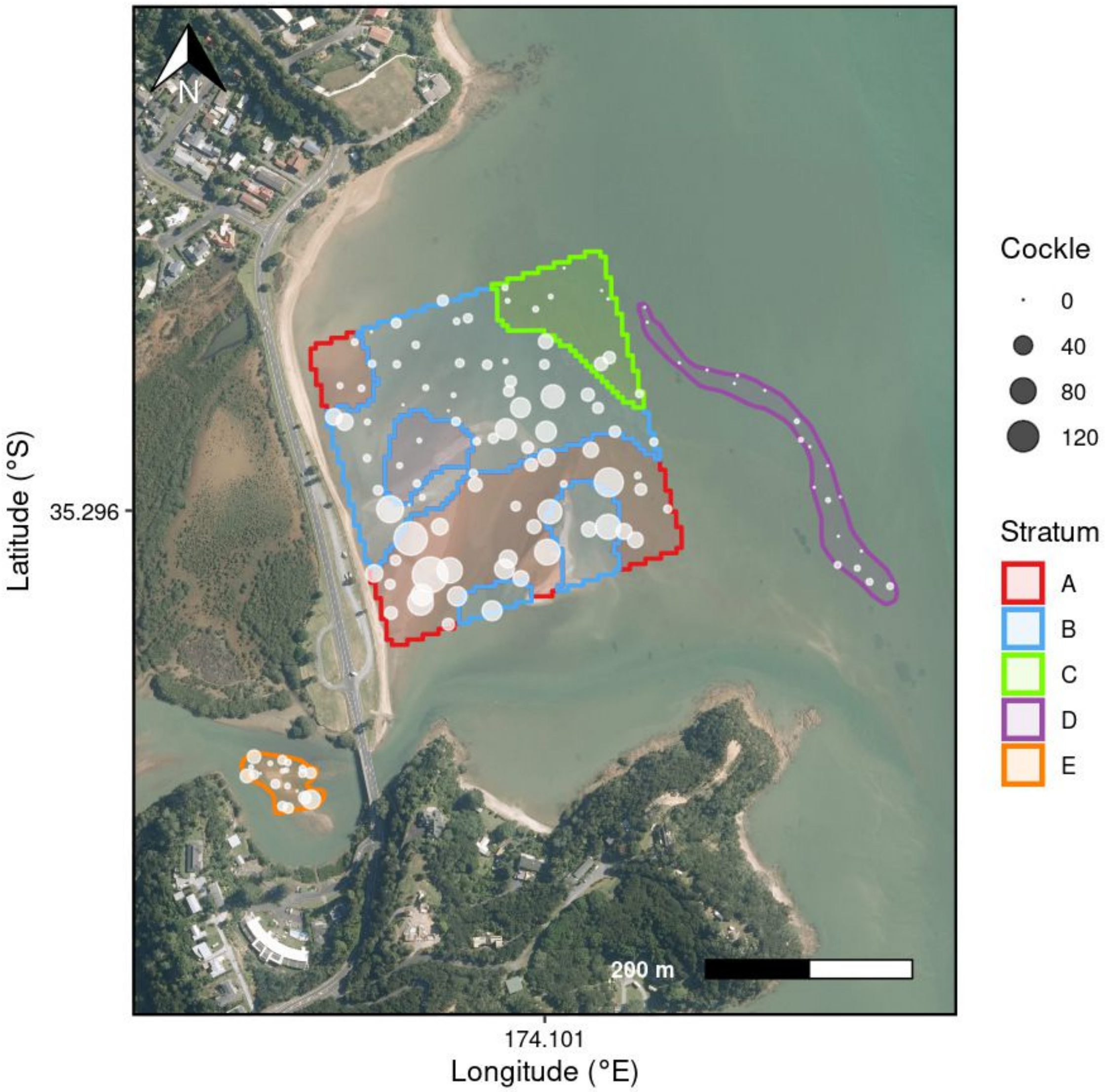


Figure 41: Map of sample strata and individual sample locations for cockles at Te Haumi Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of cockle abundance at Te Haumi Bay, by stratum, for 2023–24. Presented are the area surveyed, 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	3.7	39	1 243	33.35	911	18.87
B	4.3	40	690	21.20	493	19.85
C	1.0	10	44	1.28	126	47.33
D	0.8	20	14	0.16	20	36.05
E	0.3	20	158	0.64	226	26.83

Table 41: Estimates of cockle abundance at Te Haumi 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	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
2023–24	10.0	56.63	564	13.42	1.55	15	22.66

Table 42: Summary statistics of the length-frequency (LF) distribution of cockles at Te Haumi Bay. The 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 (%)
2018–19	20.71	20	5–39	17.72	4.65
2021–22	17.69	12	4–39	46.00	4.79
2023–24	14.48	8	5–39	62.78	2.74

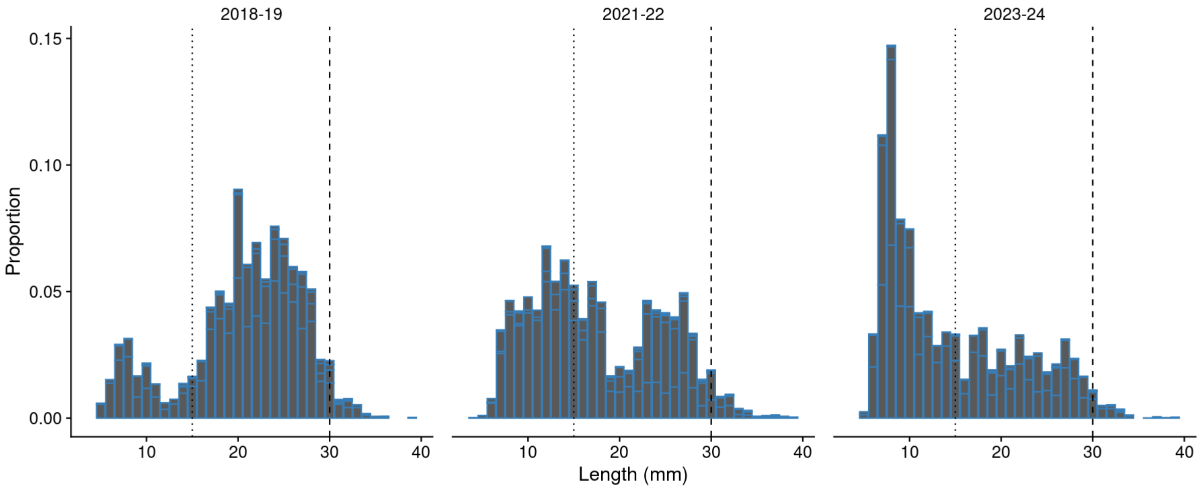


Figure 42: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Te Haumi Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

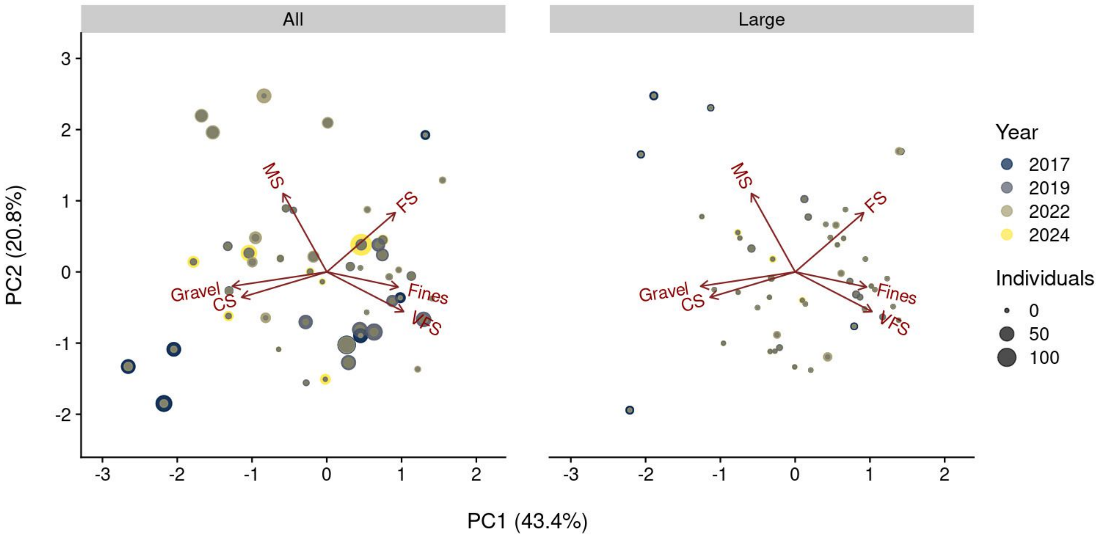


Figure 43: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Te Haumi Bay. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm,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

3.9.2 Pipi at Te Haumi Bay

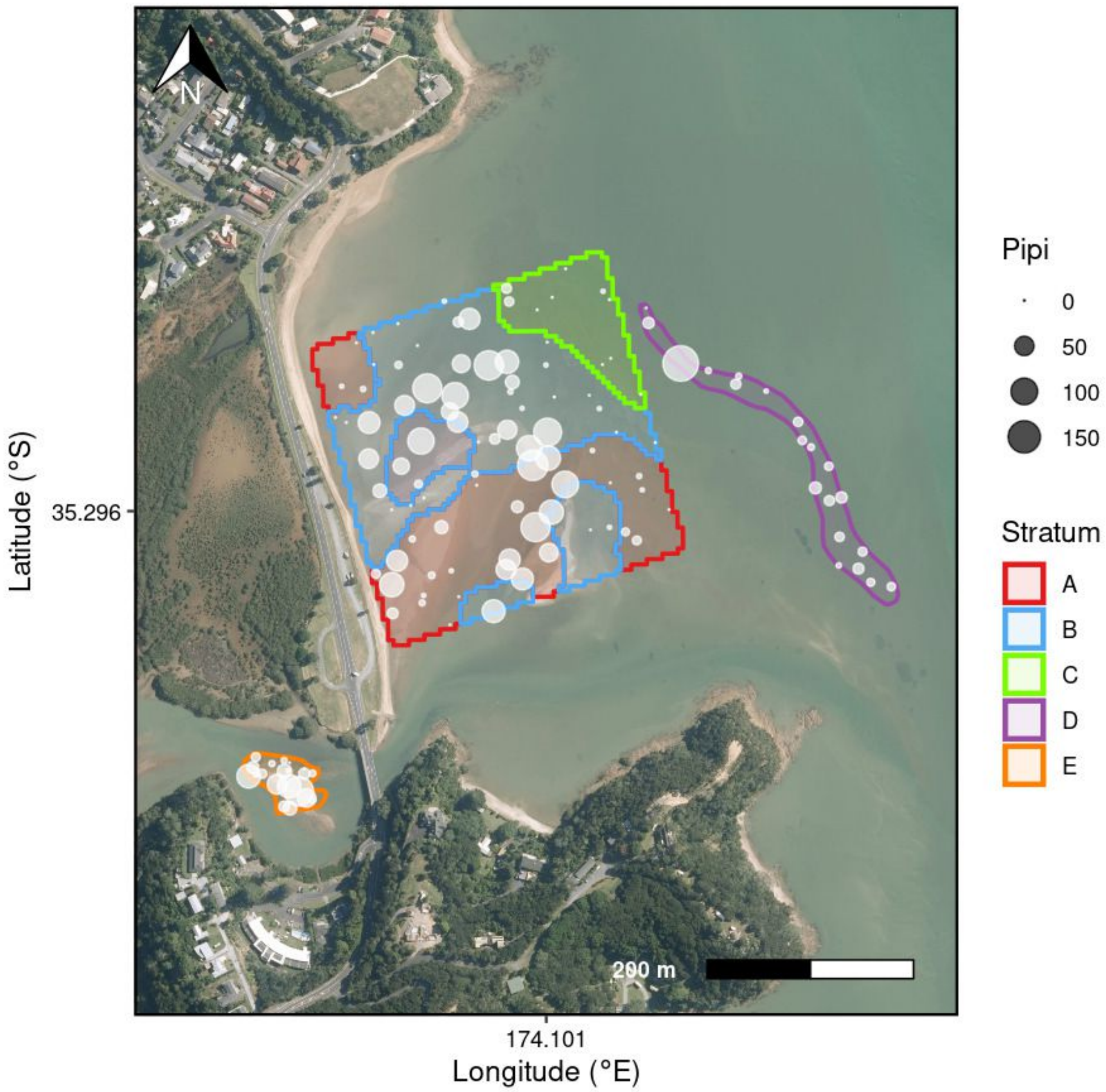


Figure 44: Map of sample strata and individual sample locations for pipi at Te Haumi Bay, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of pipi abundance at Te Haumi Bay, by stratum, for 2023–24. Presented are the area surveyed, 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	3.7	39	1 168	31.34	856	20.96
B	4.3	40	1 123	34.51	802	21.80
C	1.0	10	20	0.58	57	62.80
D	0.8	20	329	3.66	470	53.97
E	0.3	20	500	2.02	714	30.04

Table 44: Estimates of pipi abundance at Te Haumi Bay for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	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
2023–24	10.0	72.11	718	14.15	0.60	6	21.43

Table 45: Summary statistics of the length-frequency (LF) distribution of pipi at Te Haumi Bay. The LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2018–19	30.42	42	6–58	26.62	0.92
2021–22	24.97	17	5–57	46.76	1.49
2023–24	18.38	17	6–63	74.39	0.84

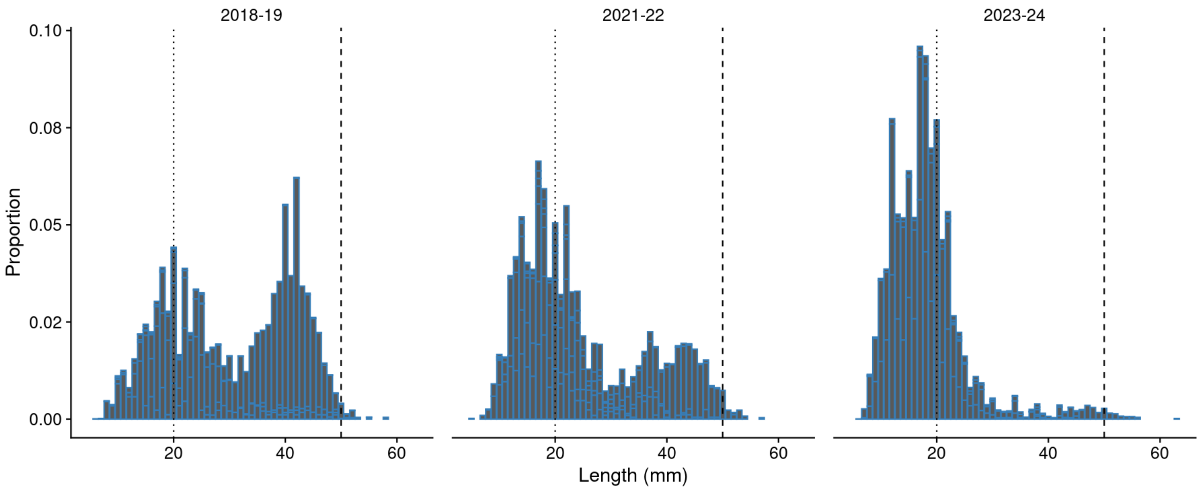


Figure 45: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Haumi Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Te Mata Bay (Waipatukahu)

Te Mata and Waipatukahu ("Te Mata Bay") are on the western coast of Coromandel Peninsula, in Waikato. The survey area is situated within a temporary fishing closure (Department of Internal Affairs 2022b), prohibiting the collection of several bivalve species including cockle and pipi. The bay has only been assessed two times prior to the current survey (see Appendix A, Tables A-1, A-2). Recent sampling at this site had a similar extent to the preceding survey (2021–22), encompassing two separate strata associated with Te Mata River and Tapu River, respectively. A total of 75 points were sampled between these strata in 2023–24.

Pipi abundance and densities were relatively similar between the two pipi beds, with combined estimates showing an increase in the total pipi population from the previous survey (Figure 46, Table 46, Table 47). The estimated total abundance in 2023–24 was 10.10 (CV: 7.99%) million pipi at a density of 1383 individuals per m^2.

Corresponding to the increase in the total population, the population of large pipi ($\geq$50 mm) also notably increased, and both estimated abundance and density of individuals in this size class were the highest values in the series to date; their abundance was estimated at 1.25 (CV: 12.79%) million pipi, and their density was 171 large pipi per m^2 (Table 47).

Some of the recent increase was related to recruitment, with the proportion of recruits almost tripling to 31.41% of the total population in 2023–24 compared with the previous assessment in 2021–22 (Table 48). This size class affected the overall population size structure, changing it from a bimodal population to a trimodal structure that included an additional strong cohort of recruits (Figure 47). At the same time, there were markedly fewer medium-sized pipi at sizes close to upper size class cut off, with most individuals in the medium size class representing relatively small-sized individuals. The strong influence of recruits on the population size structure was also reflected in the modal size that changed from 43 mm shell length in 2021–22 to 12 mm shell length in 2023–24.

3.10.1 Pipi at Te Mata Bay (Waipatukahu)

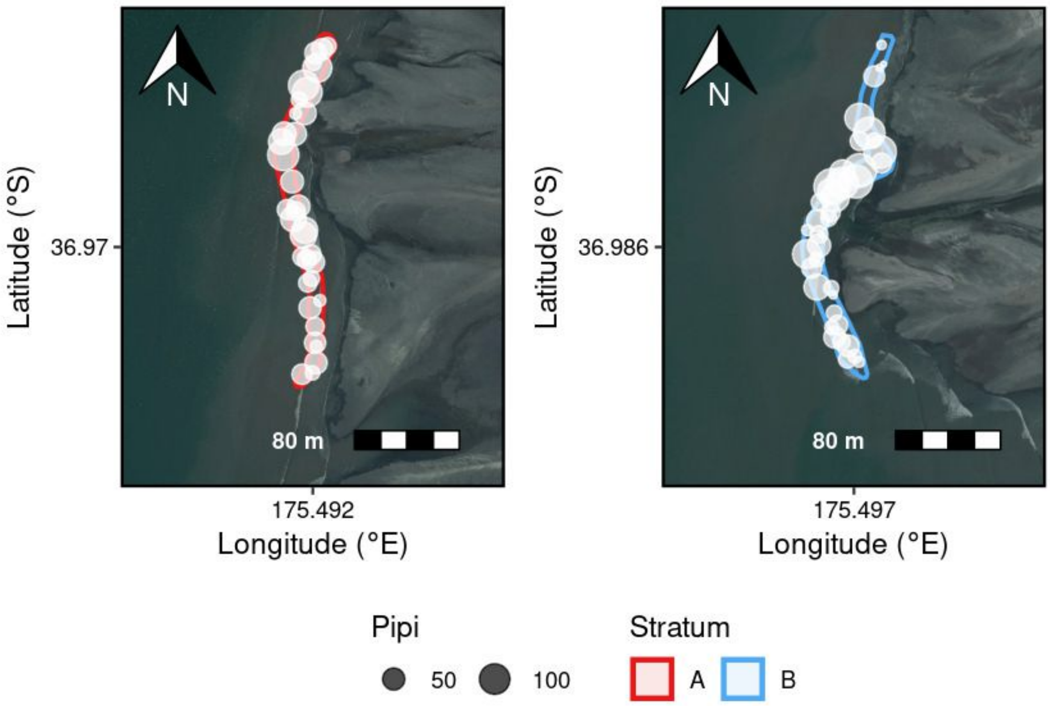


Figure 46: Map of sample strata and individual sample locations for pipi at Te Mata Bay (Waipatukahu), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of pipi abundance at Te Mata Bay, by stratum, for 2023–24. Presented are the area surveyed, 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	35	1 691	4.43	1 380	8.56
B	0.4	40	1 939	5.67	1 385	12.56

Table 47: Estimates of pipi abundance at Te Mata Bay (Waipatukahu) 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
2023–24	0.7	10.10	1 383	7.99	1.25	171	12.79

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2020–21	39.39	42	9–61	4.48	9.29
2021–22	36.33	43	7–61	11.27	8.94
2023–24	29.64	12	5–64	31.41	12.39

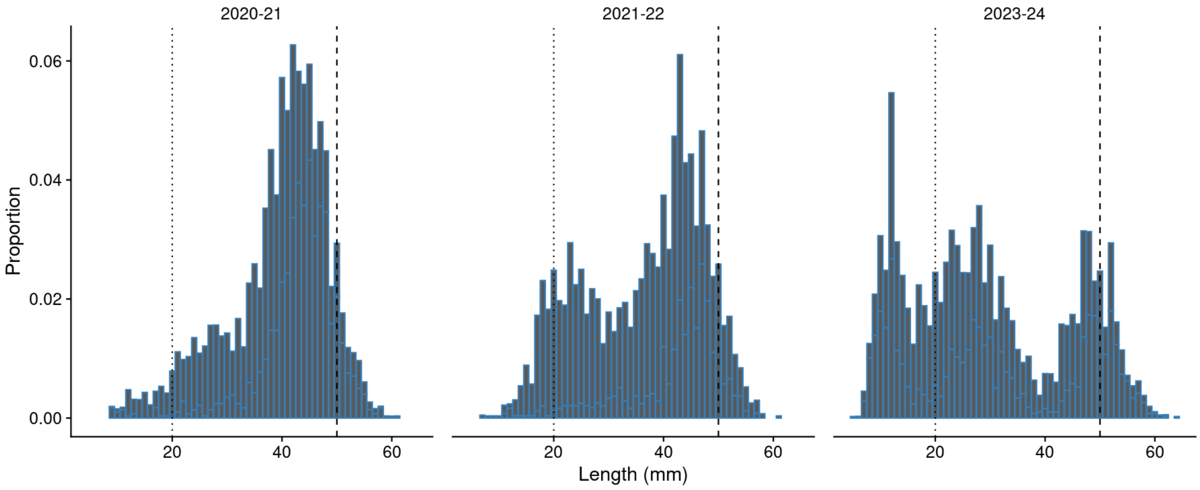


Figure 47: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Mata Bay (Waipatukahu). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Umupuia Beach

Umupuia Beach is one of the Auckland monitoring sites, sheltered within Tīkapa Moana (Hauraki Gulf). This beach is temporarily closed to the collection of cockles (Department of Internal Affairs 2022c). Umupuia Beach has a long-established monitoring record with a total of 17 assessments at this site, focused on cockles (see Appendix A, Tables Table A-1, A-2). Throughout the survey series, the sampling extent has remained largely unchanged, with the 2023–24 field survey based on 80 sampling points across two strata.

Sediment samples indicated a relatively low organic content at Umupuia Beach, although it exceeded 4% in two samples (Figure 48, and see details in Appendix B, Table B-1). Sediment fines (grain size <63 µm) generally made up a small proportion of the sediment, but this grain size fraction exceeded 60% and 70% in two of the samples. The prevalent grain size fractions were very fine sand (>63 µm) and fine sand (>125 µm), with varied proportions of other grain size classes.

The cockle population was mostly confined to stratum B (Figure 49, Table 49). The estimated total cockle abundance was 44.86 million (CV: 19.47%) individuals, with a density estimate of 132 cockles per m^2 (Table 50). These estimates marked a further continuation of the population decline that started in 2015–16. Nevertheless, there was a slight increase in the number of large cockles (≥30 mm shell length) to 24.14 (CV: 22.23%) million large individuals in 2023–24; however, this population estimate was low overall compared to earlier surveys; e.g., it was about 50% of their population abundance in 2012–13. The corresponding density estimate was 71 large individuals per m^2.

Considering the population size structure, large cockles contributed over half (53.92%) of the total population in 2023–24 (Table 51). This finding was consistent with the two preceding surveys where large cockles represented a considerable proportion (>30%) of the population. Together with medium-sized cockles they formed a strong cohort, with a recent influx in recruits (≤15 mm shell length) forming a small second cohort in 2023–24 (Figure 50). The latter size class made up less than 1% of the population in 2019–20 and 2021–22, but the recent recruitment increased their proportion to 6.81% of the overall population in 2023–24. Although there was a small concomitant decrease in the mean size to 28.73 mm shell length, the influence of large cockles resulted in an increase in modal size from 27-mm in the two preceding surveys to 34 mm shell length in this survey year.

Principal component analysis indicated that total cockle abundance in 2023–24 was mostly associated with medium and fine grain sizes, as distinguished by PC1, which explained 49.4% of the variance (Figure 51).

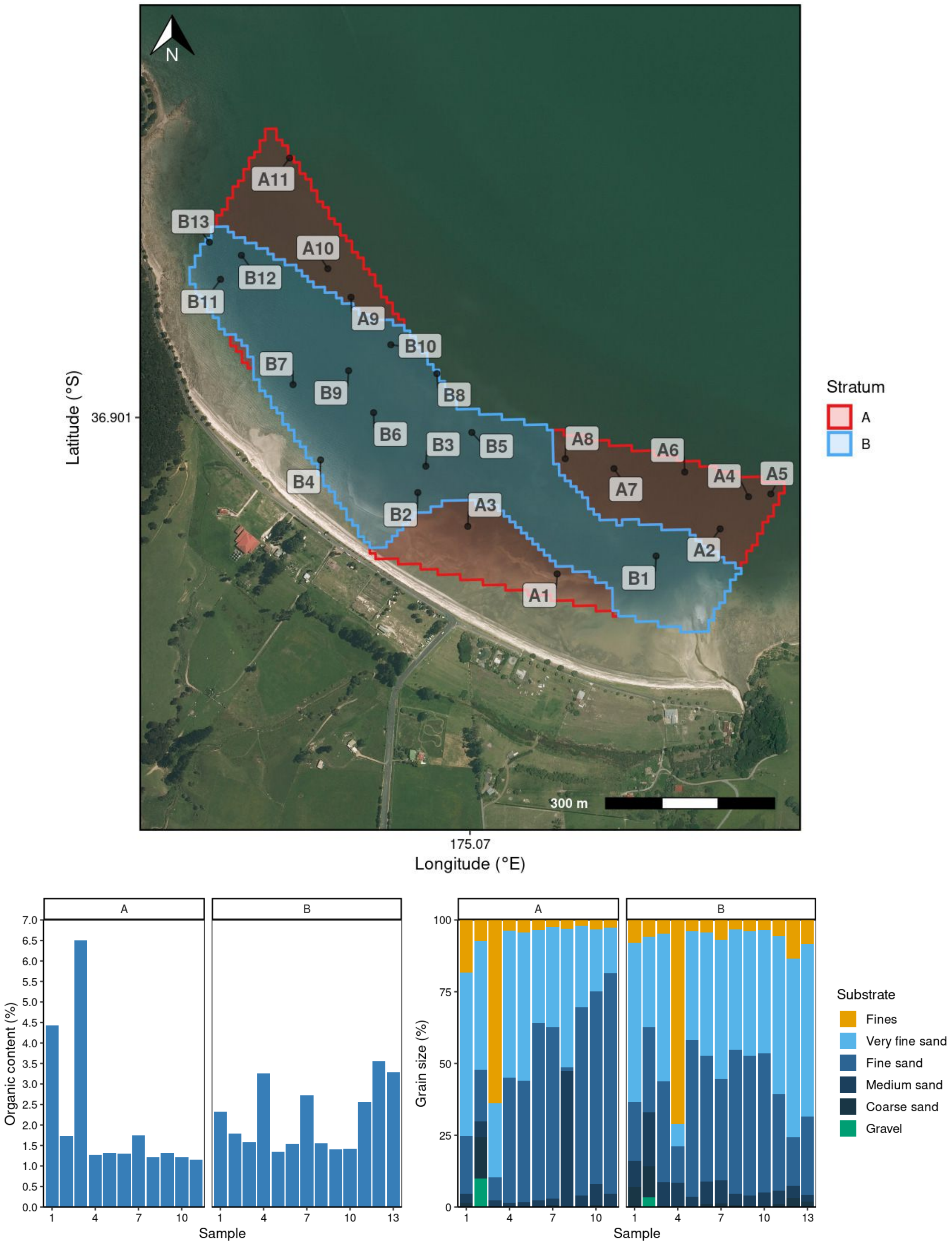


Figure 48: Sediment sample locations and characteristics at Umupuia Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.11.1 Cockles at Umupuia Beach

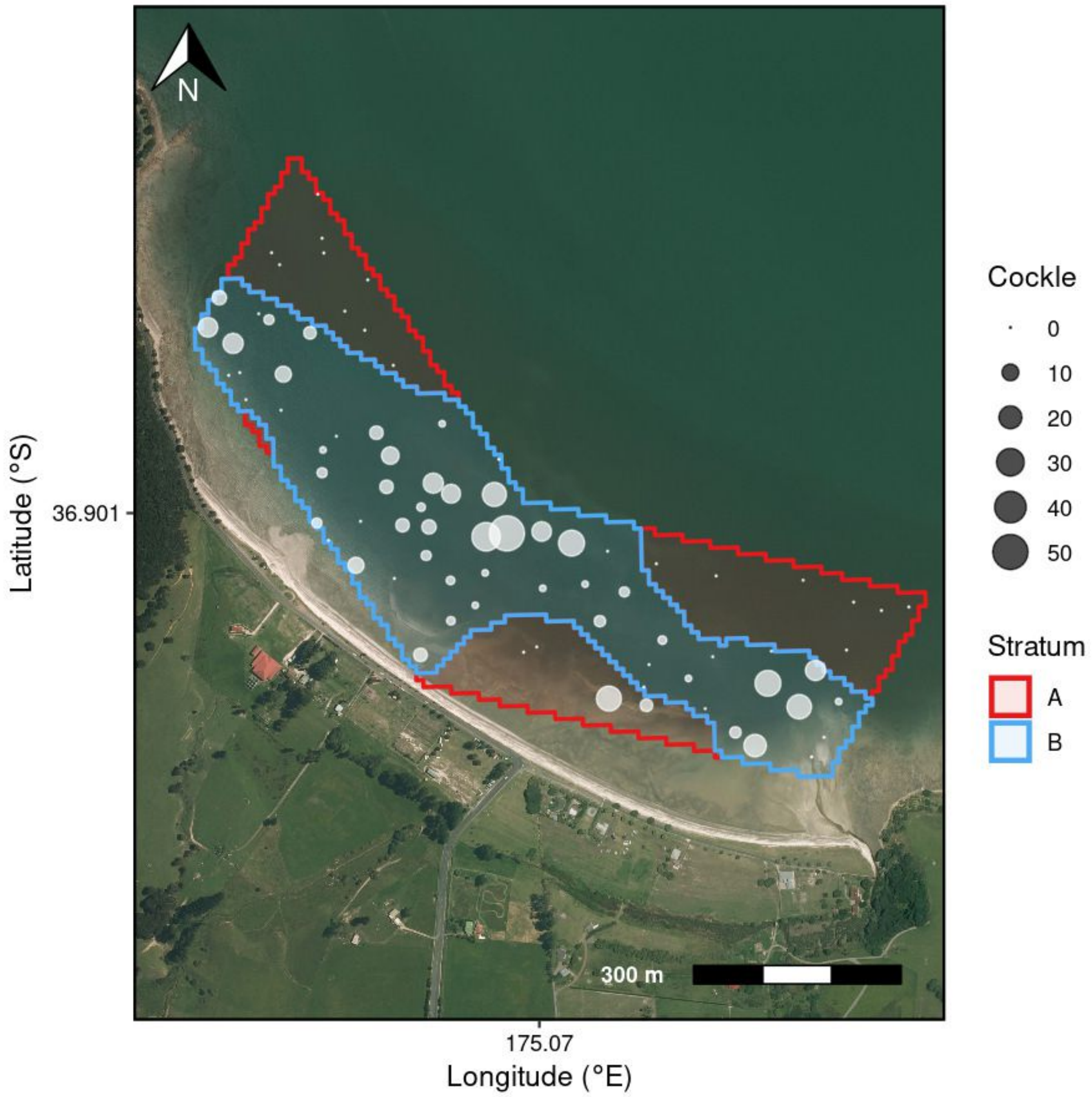


Figure 49: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2023–24. Presented are the area surveyed, 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	12.9	20	29	5.34	41	83.64
B	21.0	60	395	39.53	188	19.00

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	25.0	84.41	338	5.51	18.59	74	7.99
2000–01	36.0	177.48	493	5.50	66.98	186	8.32
2001–02	36.0	66.22	184	7.00	29.49	82	9.42
2002–03	36.0	64.43	179	5.26	24.96	69	7.87
2003–04	36.0	29.94	83	9.53	21.62	60	11.44
2004–05	36.0	41.49	115	6.95	30.72	85	7.97
2005–06	36.0	26.86	75	9.99	14.53	40	15.93
2006–07	36.0	11.59	32	13.84	5.07	14	23.91
2009–10	36.0	61.58	171	11.30	1.89	5	20.84
2010–11	36.0	103.08	286	9.96	9.32	26	17.10
2012–13	36.0	125.18	348	14.17	47.99	133	14.64
2013–14	33.9	170.35	503	16.79	44.29	131	17.80
2015–16	33.9	98.88	292	15.93	39.12	115	10.61
2017–18	33.4	92.15	276	19.27	41.70	125	22.25
2019–20	33.4	90.05	269	18.45	32.61	98	21.90
2021–22	32.7	52.05	159	17.18	23.41	72	17.12
2023–24	33.9	44.86	132	19.47	24.14	71	22.23

Table 51: Summary statistics of the length-frequency (LF) distribution of cockles at Umupuia Beach. The 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 (%)
2019–20	27.74	27	12–46	0.48	36.21
2021–22	29.02	27	13–46	0.76	44.98
2023–24	28.73	34	5–44	6.81	53.92

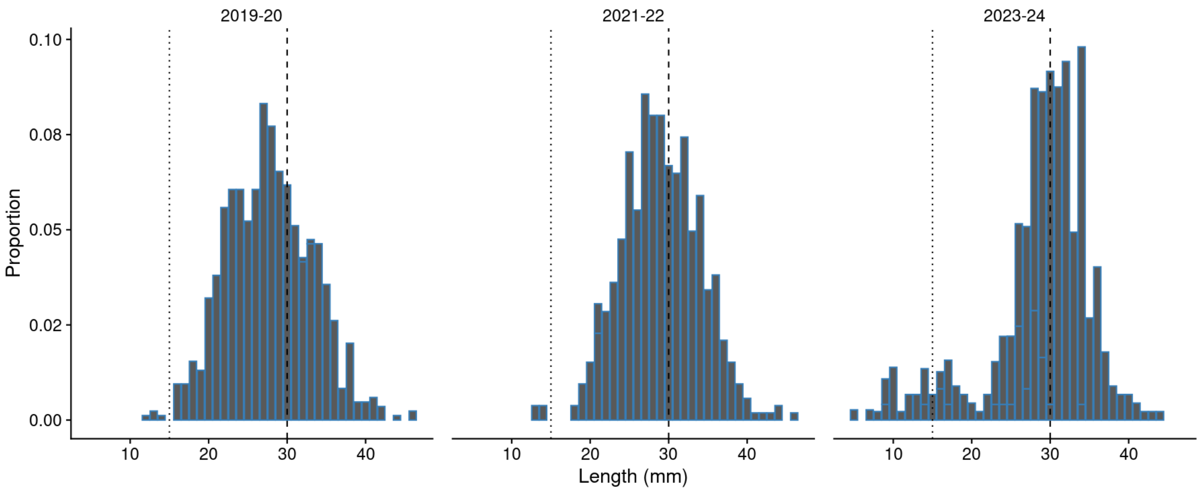


Figure 50: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

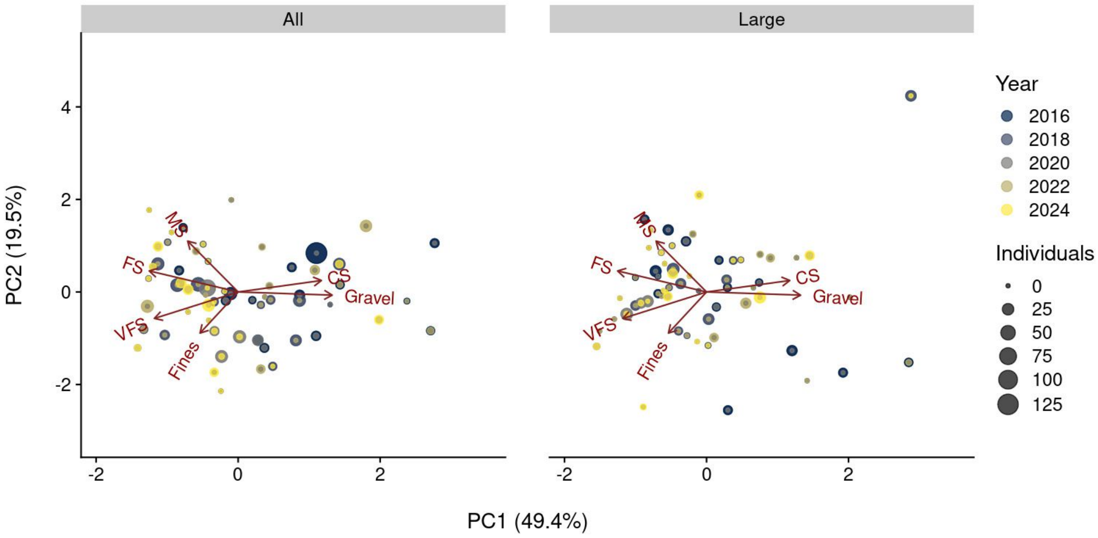


Figure 51: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Umupuia Beach. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, 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.

3.12 Whangateau Harbour

Whangateau Harbour is a large estuary in Tīkapa Moana (Hauraki Gulf), and has been closed to cockle and pipi collections since 2010 (Department of Internal Affairs 2015b). There have been 13 surveys in the harbour since 2001–02, most recently in 2021–22 before the current assessment (see Appendix A, Tables A-1, A-2). The 2023–24 sampling extent was similar across recent surveys, following an earlier expansion in 2013–14. In the current field survey, bivalves were sampled across 101 points at two separate locations that represented five strata, including one pipi stratum.

Sediment samples were generally characterised by low organic content (i.e. less than $< 1.5\%$) (Figure 52; and see details in Appendix B, Table B-1). Sediment grain size compositions varied between the two sampling areas; stratum A was mostly composed of fine sand size fractions (grain size $>$125 µm) and smaller proportions of medium sand ($>$250 µm), compared with strata B and D, where sediment consisted mostly of medium sand. Across all cockle strata, the proportion of sediment fines ($<$63 µm) was small, but made up 5% in one sample.

Cockles were present across the entire sampling extent, with the majority of the cockle population distributed throughout strata A and D (Figure 53, Table 52). Their current population estimates were a total abundance of 606.56 (CV: 10.68%) million cockles and a mean density of 545 individuals per m^2 (Table 53). These estimates represented a significant population decline from 983.06 (CV: 9.91%) million cockles in 2021–22. The decline followed consistent population increases since 2009–10, with the 2021–22 estimates reflecting the largest cockle population in the survey series.

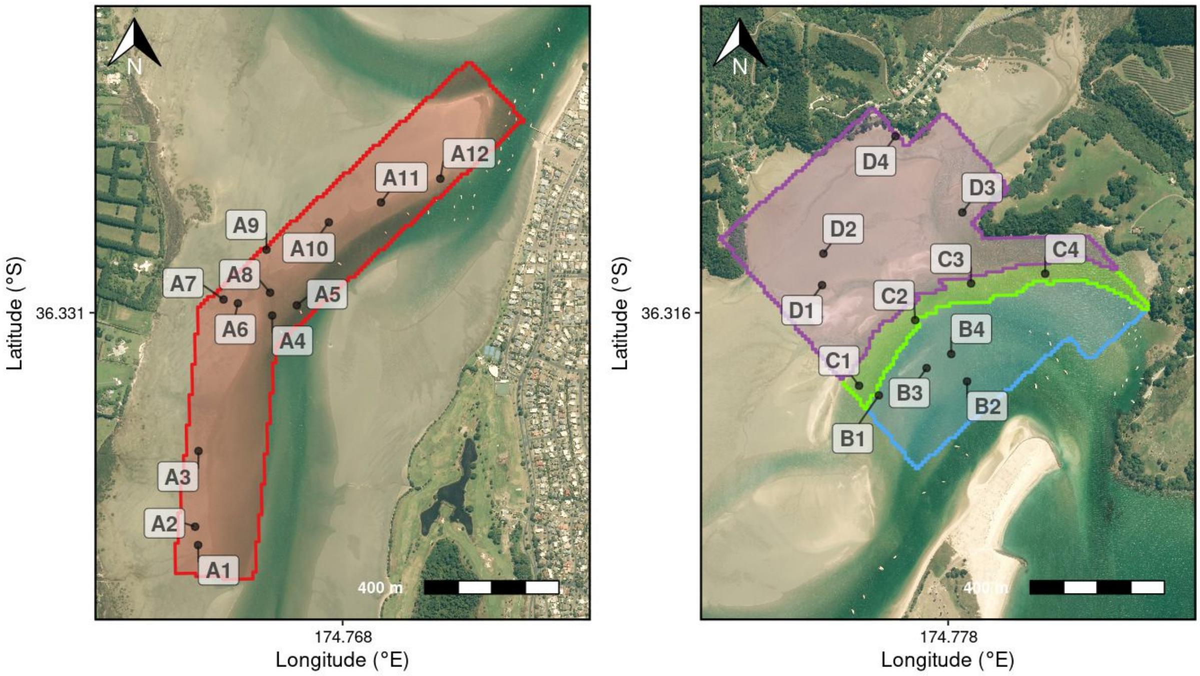
Similar to previous surveys, the total population included a relatively small number of large cockles ($>$30 mm shell length) in 2023–24; their abundance was estimated at 25.43 (CV: 41.02%) million large individuals and their average density was 23 large cockles per m^2, but the estimates had high uncertainty (i.e. CV $>$30%)

Most of current population comprised medium-sized cockles, followed by a substantial proportion (25.40%) of recruits (Table 54, Figure 54). Combined, the two size classes formed the unimodal cockle population at this site, with a similar population size composition across recent surveys. Corresponding with this pattern, mean and modal sizes remained relatively unchanged at shell lengths just above the recruit size class cut off, i.e., between 17 and 19 mm.

There was no distinct pattern in the principal component analysis for all cockles in relation to sediment grain sizes (Figure 55). Large cockle abundance was generally associated with grain sizes larger than sediment fines.

The pipi population at Whangateau Harbour was generally restricted to the pipi stratum (E), with few individuals in a localised area in stratum D (Figure 56, Table 55). The estimated population size of this species was 22.80 (CV: 48.18%) million pipi in 2023–24, and the corresponding density estimate was 20 pipi per m^2 (Table 56). The considerable uncertainty indicated by the high CV of almost 50% around these estimates was related to the small localised patch of pipi in stratum D, contributing uncertainty to the overall estimate. In comparison, for the pipi stratum alone, the CV was about 11%. Nevertheless, the current total estimates were similar to previous values (since 2017–18). Large pipi ($\geq$50 mm) were scarce at this site, with an estimated 0.09 million large individuals in this size class; their estimated density was <1 large individuals per m^2. These estimates had high uncertainty (CV: 35.55%).

The small population of large pipi meant that this size class was only a minor proportion (0.38%) of the population overall (Table 57, Figure 57). In general, medium-sized pipi determined the unimodal population size structure at Whangateau Harbour in recent surveys, but a strong influx in recruits ($\leq$20 mm) in 2023–24 led to a shift in the single cohort towards smaller sizes. As recruits made up 63.32% of the pipi population, mean and modal sizes decreased to 20.74 mm and 18 mm, respectively.



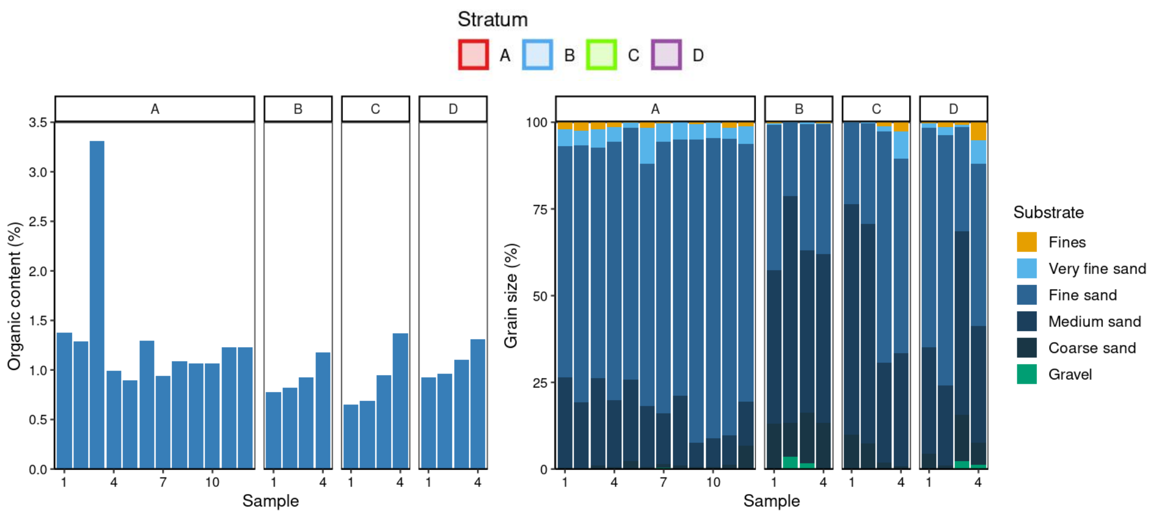


Figure 52: Sediment sample locations and characteristics at Whangateau Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.12.1 Cockles at Whangateau Harbour

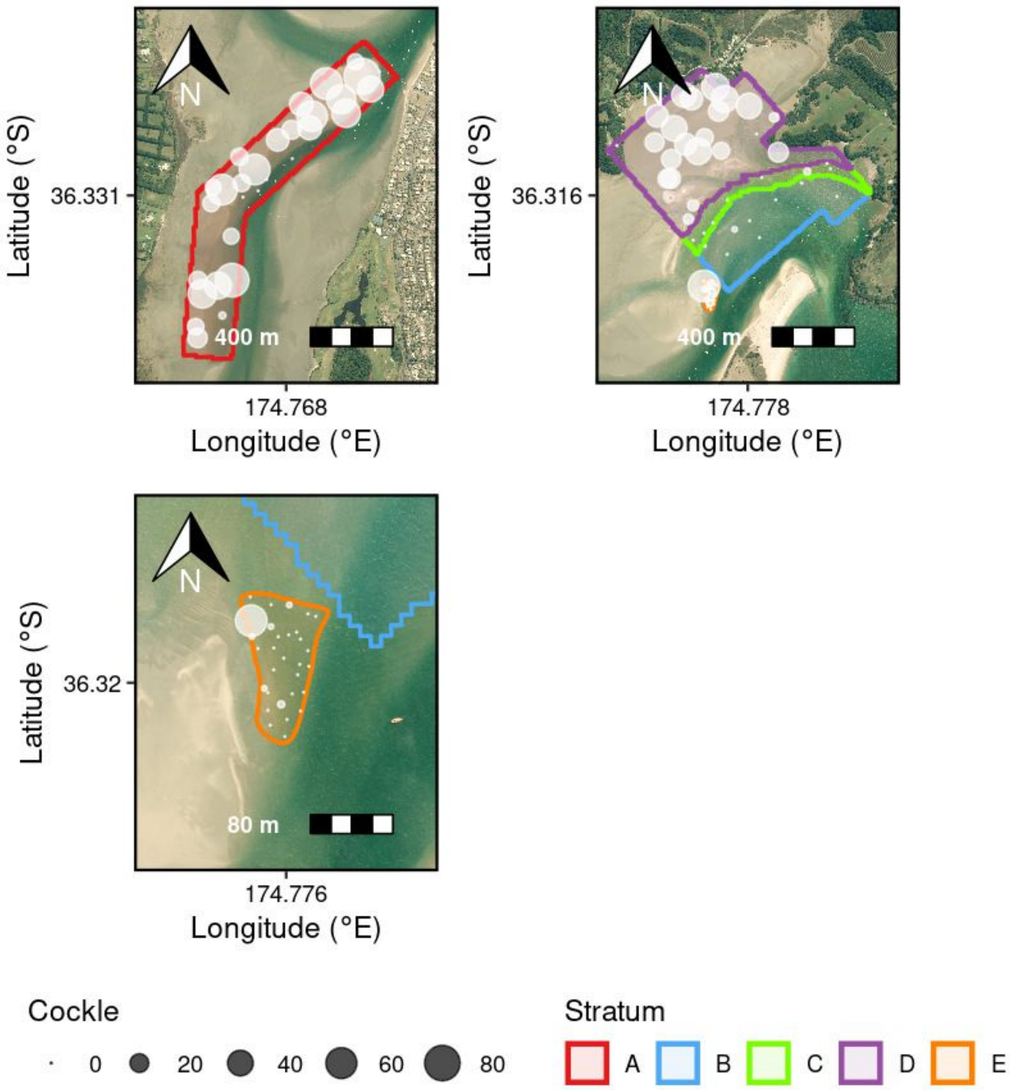


Figure 53: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	904	370.14	861	14.69
B	20.9	8	1	0.75	4	>100
C	7.1	8	2	0.51	7	>100
D	39.5	25	520	234.67	594	15.02
E	0.8	30	69	0.50	66	91.09

Table 53: Estimates of cockle abundance at Whangateau Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	253.26	395	6.51	62.36	97	16.17
2003–04	64.2	376.68	587	5.80	56.85	89	12.66
2004–05	64.2	349.04	544	8.52	59.52	93	13.12
2006–07	64.2	266.04	415	8.24	35.20	55	21.91
2009–10	64.5	230.55	357	7.16	16.16	25	25.71
2010–11	64.2	239.27	373	5.06	19.77	31	16.19
2012–13	64.2	363.72	567	5.87	30.84	48	14.67
2013–14	110.9	730.89	659	5.70	44.50	40	13.45
2015–16	110.7	742.44	671	7.02	45.43	41	18.77
2017–18	110.9	852.27	768	9.28	33.69	30	28.12
2019–20	110.9	887.67	801	10.72	32.10	29	37.02
2021–22	111.2	983.06	884	9.91	34.49	31	37.90
2023–24	111.3	606.56	545	10.68	25.43	23	41.02

Table 54: Summary statistics of the length-frequency (LF) distribution of cockles at Whangateau Harbour. The 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 (%)
2019–20	18.49	18	4–37	30.18	3.62
2021–22	18.87	17	6–40	29.04	3.51
2023–24	18.70	17	6–37	25.40	4.19

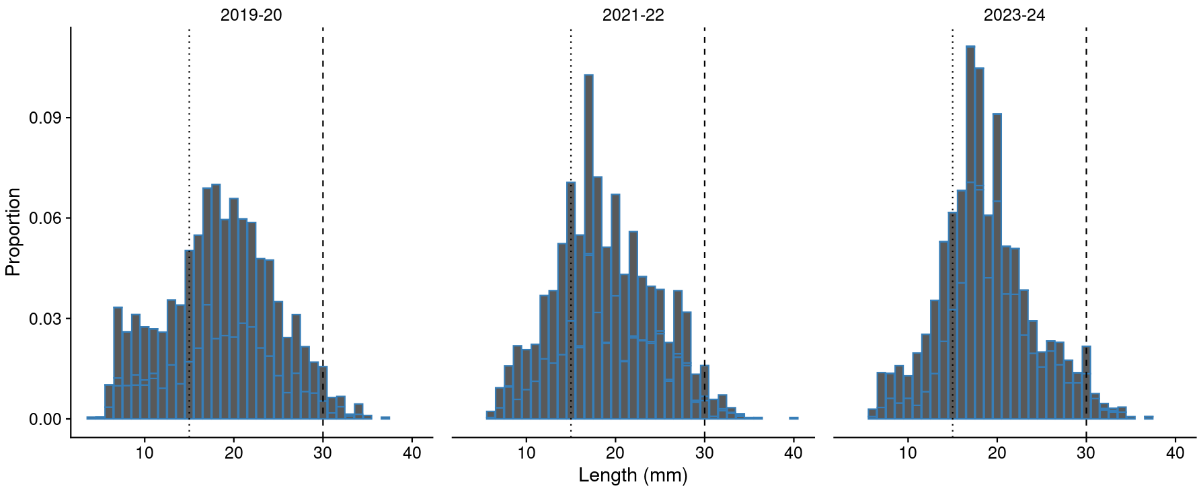


Figure 54: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

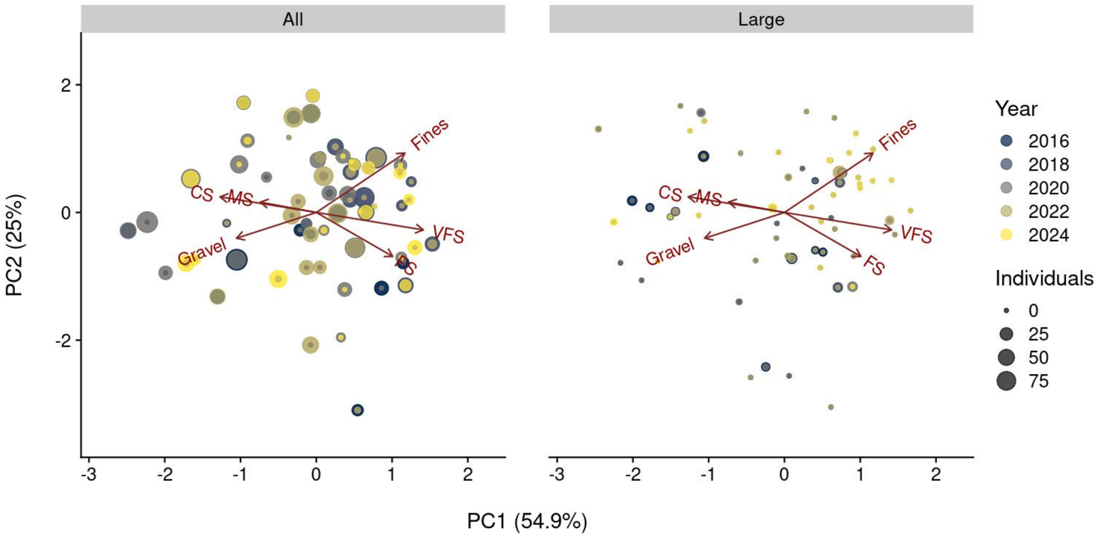


Figure 55: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Whangateau Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63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

3.12.2 Pipi at Whangateau Harbour

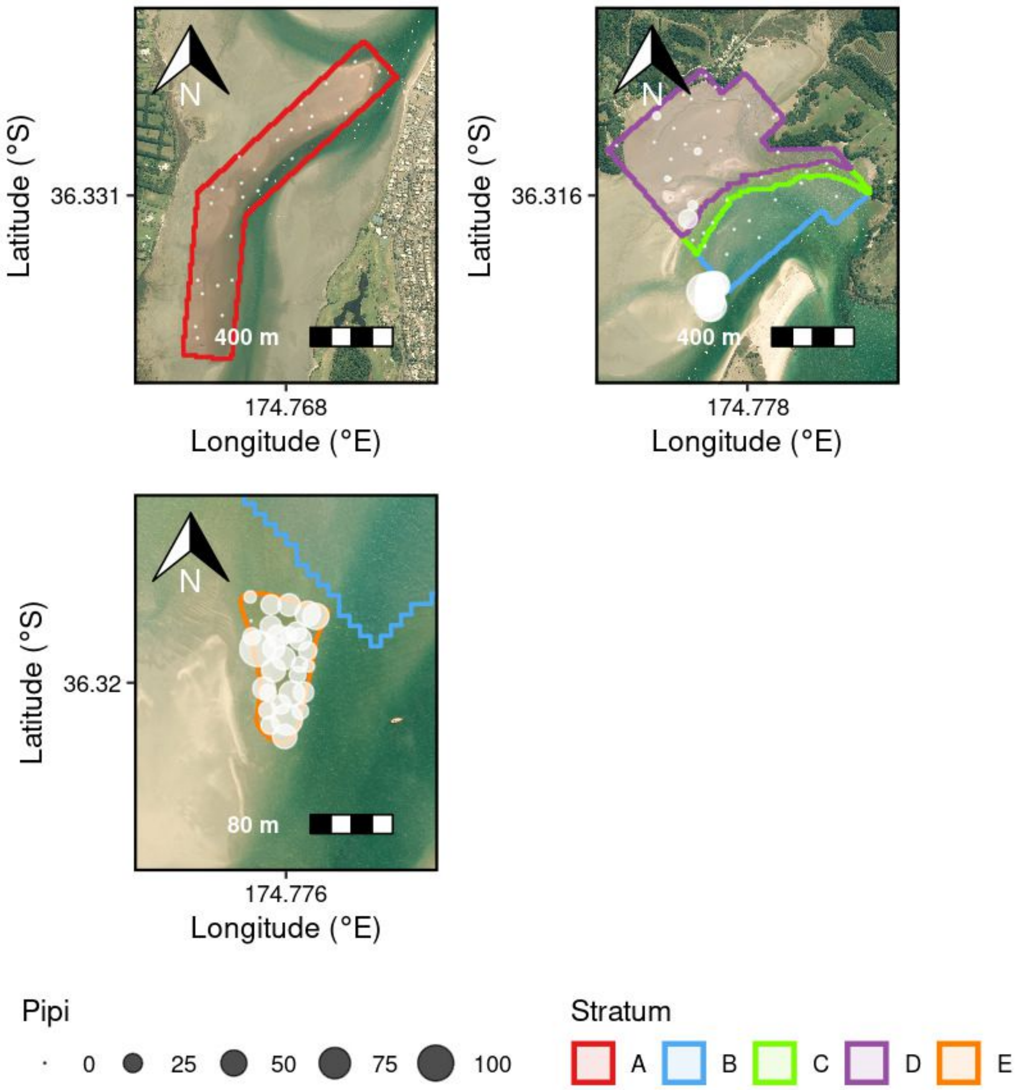


Figure 56: Map of sample strata and individual sample locations for pipi at Whangateau Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2023–24. Presented are the area surveyed, 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	0	0.00	0	
D	39.5	25	35	15.80	40	69.38
E	0.8	30	976	7.01	930	11.14

Table 56: Estimates of pipi abundance at Whangateau Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	64.2	1.83	3	31.83	0.31	<1	>100
2003–04	64.2	0.48	<1	10.18	0.42	<1	9.85
2004–05	64.2	6.85	11	22.46	0.58	<1	9.72
2006–07	64.2	10.56	16	33.78	0.05	<1	>100
2009–10	64.5	17.58	27	33.35	0.11	<1	>100
2010–11	64.2	9.31	15	17.74	1.57	2	22.52
2012–13	64.2	19.58	30	16.89	0.60	<1	42.05
2013–14	110.9	55.39	50	26.92	0.68	<1	24.04
2015–16	110.7	15.00	14	23.20	0.40	<1	9.04
2017–18	110.9	20.13	18	42.77	0.09	<1	28.79
2019–20	110.9	29.96	27	72.05	0.26	<1	22.41
2021–22	111.2	20.03	18	12.34	0.50	<1	22.32
2023–24	111.3	22.80	20	48.18	0.09	<1	35.55

Table 57: Summary statistics of the length-frequency (LF) distribution of pipi at Whangateau Harbour. The 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 (%)
2019–20	24.42	24	9–57	33.15	0.87
2021–22	29.37	34	8–58	20.32	2.51
2023–24	20.74	18	7–54	63.32	0.38

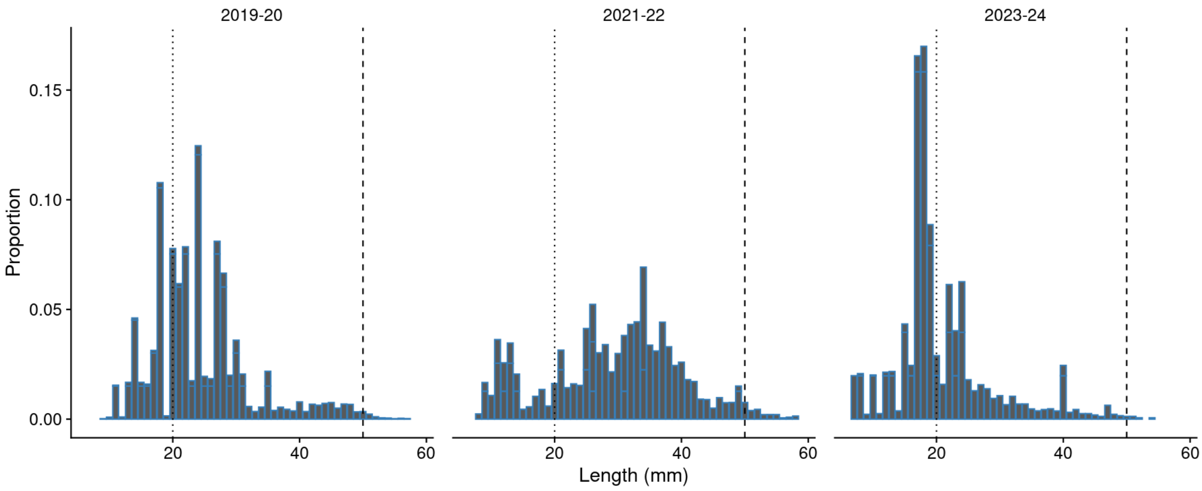


Figure 57: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

Nine of the 2023–24 survey sites contained cockle populations, representing their persistence across a range of intertidal habitats in northern North Island. The cockle sites ranged in sizes and characteristics, and included sheltered bays, relatively small, river-dominated estuaries, and large tidal inlets and harbours.

The sampling effort was sufficient to provide reliable cockle population estimates across these sites, with CV values below 20% (Table 58); however, for two sites, Little Waihi Estuary and Tairua Harbour, the sampling required a second phase to achieve this CV value.

Reflecting the diversity of the survey sites, the current estimates represented different cockle population sizes across the northern regions. Populations estimates ranged from the lowest total abundance of 27.60 (CV: 4.65%) million cockles at Bowentown Beach to 606.56 (CV: 10.68%) million cockles at Whangateau Harbour.

Some of these differences were related to the overall size of the sampling extent at each site, so that density estimates provide a more meaningful way to compare populations as these estimates are per unit area. This comparison highlighted that Bowentown Beach, the site with the lowest total cockle abundance, had the highest cockle density across all sites, with an estimated 1843 individuals per m^2 at this beach. Only two other sites in 2023–24 supported similar densities of over 1000 cockles per m^2; these sites were Raglan Harbour and Ngunguru Estuary. Total cockle densities were lower at the remaining sites, ranging from 132 cockles per m^2 at Umupuia Beach to 834 cockles per m^2 at Tairua Harbour.

Most populations included relatively small numbers of large cockles ($\geq$30 mm shell length), and these individuals were generally only a small component of the cockle populations overall. The main exception was Umupuia Beach, where the density of large cockles was estimated to be 71 (CV: 22.23%) individuals per m^2. Considering their population size in relation to total cockle abundance, large cockles made up over 50% of the total population at this beach. Other sites with densities of large cockles exceeding 20 individuals per m^2 were Mangawhai Harbour and Whangateau Harbour.

Throughout the time series, population trends were similar at most sites, with overall increases in total cockle densities over time (Figure 58). At several sites, the declines were recent, notably at Mangawhai Harbour, Ngunguru Estuary, Tairua Harbour, Te Haumi Bay, Umpuia Beach, and Whangateau Harbour. At Umupuia Beach, the recent decline was a continuation of the decreasing trend that started in 2015–16. At Te Haumi Bay and Whangateau Harbour, the decrease in cockle densities in 2023–24 was after an extended period of notable increases in total cockle densities.

Comparison of population size structures over time revealed a general pattern of unimodal populations in the combined length-frequency distributions, with some variations dependent on the survey year (Figure 59). Most populations were largely determined by medium-sized cockles, and often also a notable number of recruits, particularly in recent assessments. As the contribution of large cockles diminished over time, the populations were skewed towards small-sized individuals and recruits.

For large cockles, there was a unifying trend of declining densities over time (Figure 60). Although densities differed across sites, all sites had relatively high densities of large cockles at the start of the survey series. Subsequently, their densities declined, resulting in the low densities recorded in recent assessments. The notable exception to this trend was Umupuia Beach, where large cockle densities declined considerably in the first part of the survey series, before showing a marked increase and then another ongoing decline.

Table 58: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2023–24 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	27.60	1 843	4.65	0.18	12	18.87
Little Waihi Estuary	34.24	206	19.55	0.24	1	74.62
Mangawhai Harbour	50.38	702	10.83	2.09	29	18.32
Ngunguru Estuary	75.02	1 247	8.44	0.45	8	28.75
Raglan Harbour	111.85	1 497	7.50	1.01	14	28.09
Tairua Harbour	45.47	834	11.78	0.45	8	25.90
Te Haumi Bay	56.63	564	13.42	1.55	15	22.66
Umupuia Beach	44.86	132	19.47	24.14	71	22.23
Whangateau Harbour	606.56	545	10.68	25.43	23	41.02

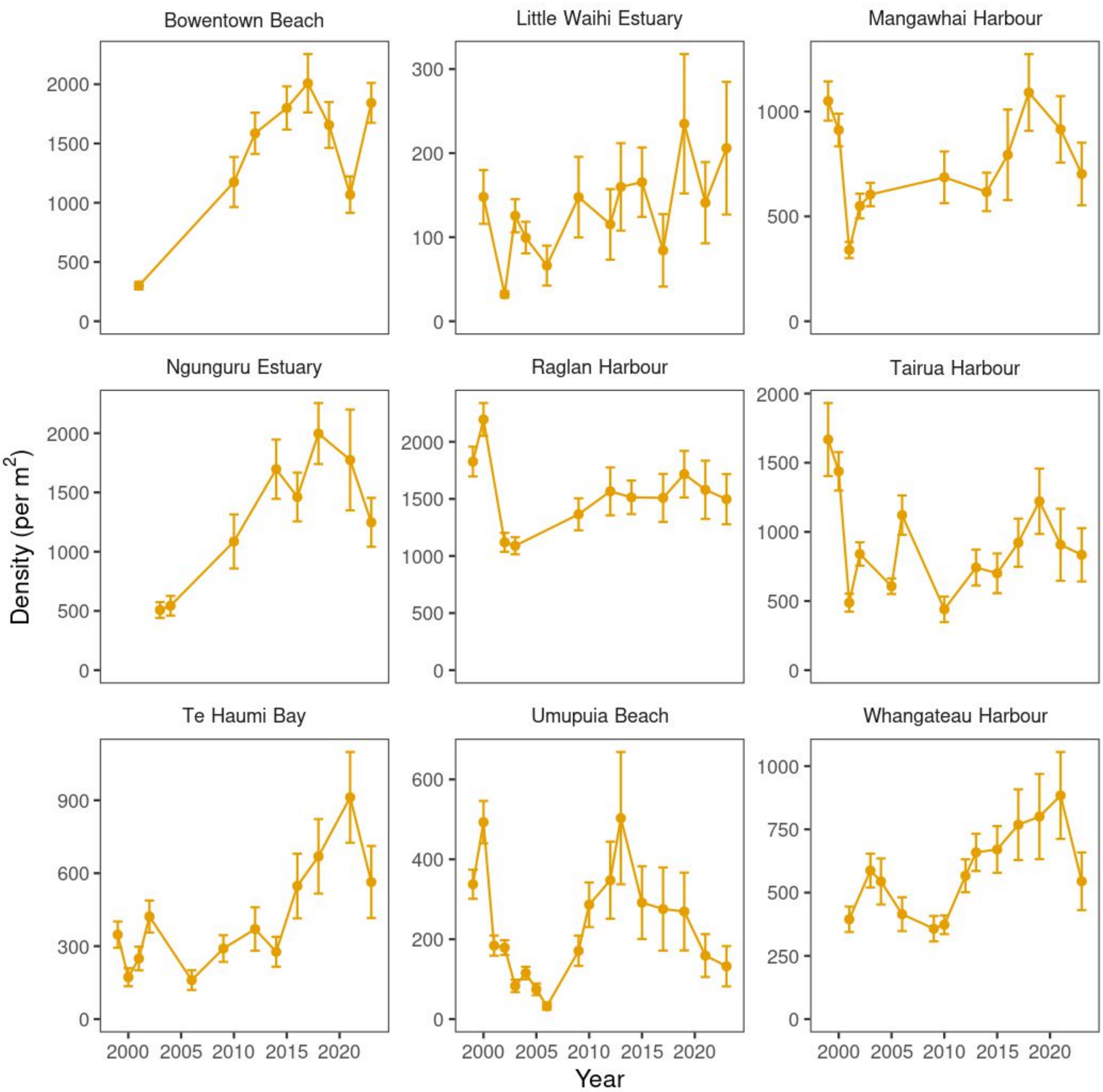


Figure 58: Estimated density of cockles for all sites included in the 2023–24 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

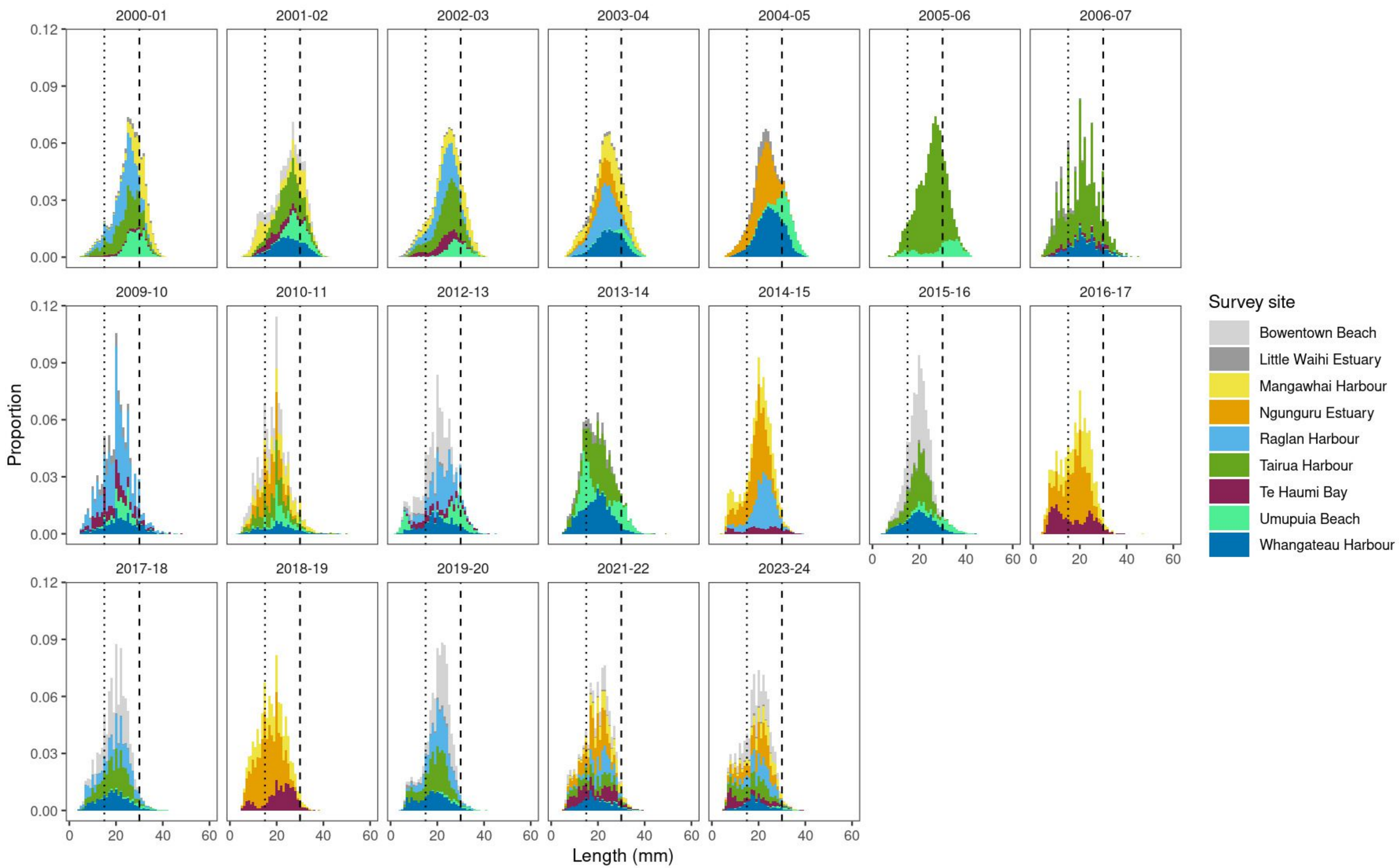


Figure 59: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2023–24 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

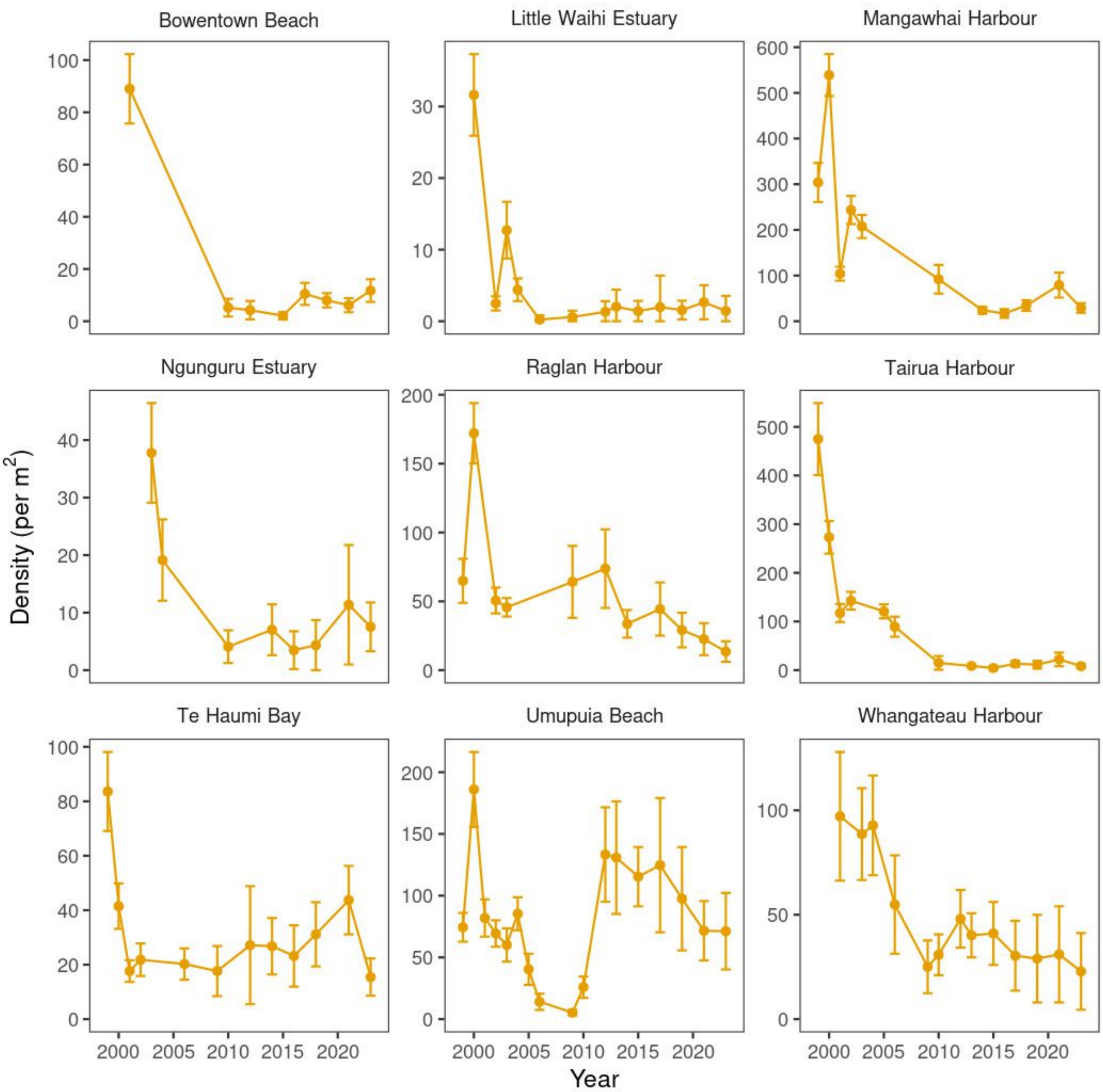


Figure 60: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all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

4.2 Pipi populations

Pipi populations were present at ten of the 2023–24 survey sites, and population estimates had associated CV values of less than 20% at eight of the sites (Table 59). At Tairua Harbour, phase-2 sampling did not lead to a sufficient reduction in the CV below the target value; at Whangateau Harbour, the CV was met for the designated pipi bed, but the patchy occurrence of pipi across cockle strata led to the high CV for the total estimate across all strata.

Pipi population sizes varied across sites, ranging from the smallest abundance estimate of 0.45 (CV: 15.66%) million pipi at Marsden Bank to 121.15 (CV: 13.48%) million individuals at Ruakākā Estuary (Table 59).

The highest density estimate was also at Ruakākā Estuary with 5857 individuals per m^2, largely caused by the significant influx of recruits. The only other site with high pipi densities was Te Mata Bay, where this species exceeded 1000 individuals per m^2. In contrast, the lowest density estimates were at Whangateau Harbour and Raglan Harbour, at 20 individuals per m^2 and 27 individuals per m^2, respectively.

Few populations contained notable numbers of large pipi ($\geq$50 mm shell length), and Te Mata Bay was the only site where the population estimates for large pipi had low uncertainty (i.e., a CV of less than 20%). At this site, over 10% of the total population consisted of individuals in this size class. Their estimated density was 1383 individuals per m^2.

Comparing pipi population trends over time documented overall increases in pipi densities at several sites, even though densities varied across sites (Figure 61). These increases were evident at Bowentown Beach, Ngunguru Estuary, Raglan Harbour, Ruakākā Estuary, and Tairua Harbour. Pipi densities also increased to some extent at Whangateau Harbour. Ruakākā Estuary supported the highest densities of pipi, particularly in recent surveys, when estimates were largely influenced by recruitment events. At Little Waihi Estuary, an initial steady increase was followed by a decrease across several surveys, before densities remained comparatively low in recent assessments. The time series also highlighted the notable decline of the pipi population at Marsden Bank, with a recent small increase in densities after the loss of the pipi population at this site.

The combined length frequencies for the pipi populations across the survey sites illustrated the loss of large individuals over time (Figure 62). Early length-frequency distributions were generally bimodal, and included survey years when the second cohort was largely determined by large pipi, such as in 2003–04 and 2004–05. Over time, the population generally changed to be dominated by the medium size class, frequently resulting in a unimodal size structure. In some of the survey years, recruits also exerted a strong influence on the length-frequency distributions at a number of sites, such as Marsden Bank in 2009–10, and Ruakākā Estuary and Te Haumi Bay in the survey years when these two sites were included in the assessments (most recently in 2021–22 and 2023–24).

Eight of the nine pipi populations assessed in the current study included large individuals at some point in the survey series (Figure 63). Density estimates for this size class generally had high uncertainty, and densities at Raglan Harbour and Whangateau Harbour were consistently low, with one or two individuals per square metre in this size class. At the other sites, there was a universal decline in large pipi densities over time, except Te Mata Bay. This site also contained the only pipi population that included high densities of large pipi (e.g., over 100 individuals per per m^2).

Table 59: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2023–24 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	0.79	53	14.46	0.00	<1	71.82
Little Waihi Estuary	108.92	655	15.50	1.14	7	39.51
Marsden Bank	0.45	120	15.66	0.00	0	
Ngunguru Estuary	23.84	396	12.56	0.40	7	24.64
Raglan Harbour	2.00	27	15.29	0.15	2	30.39
Ruakākā Estuary	121.15	5 857	13.48	0.00	0	
Tairua Harbour	41.66	764	22.26	0.22	4	24.66
Te Haumi Bay	72.11	718	14.15	0.60	6	21.43
Te Mata Bay	10.10	1 383	7.99	1.25	171	12.79
Whangateau Harbour	22.80	20	48.18	0.09	<1	35.55

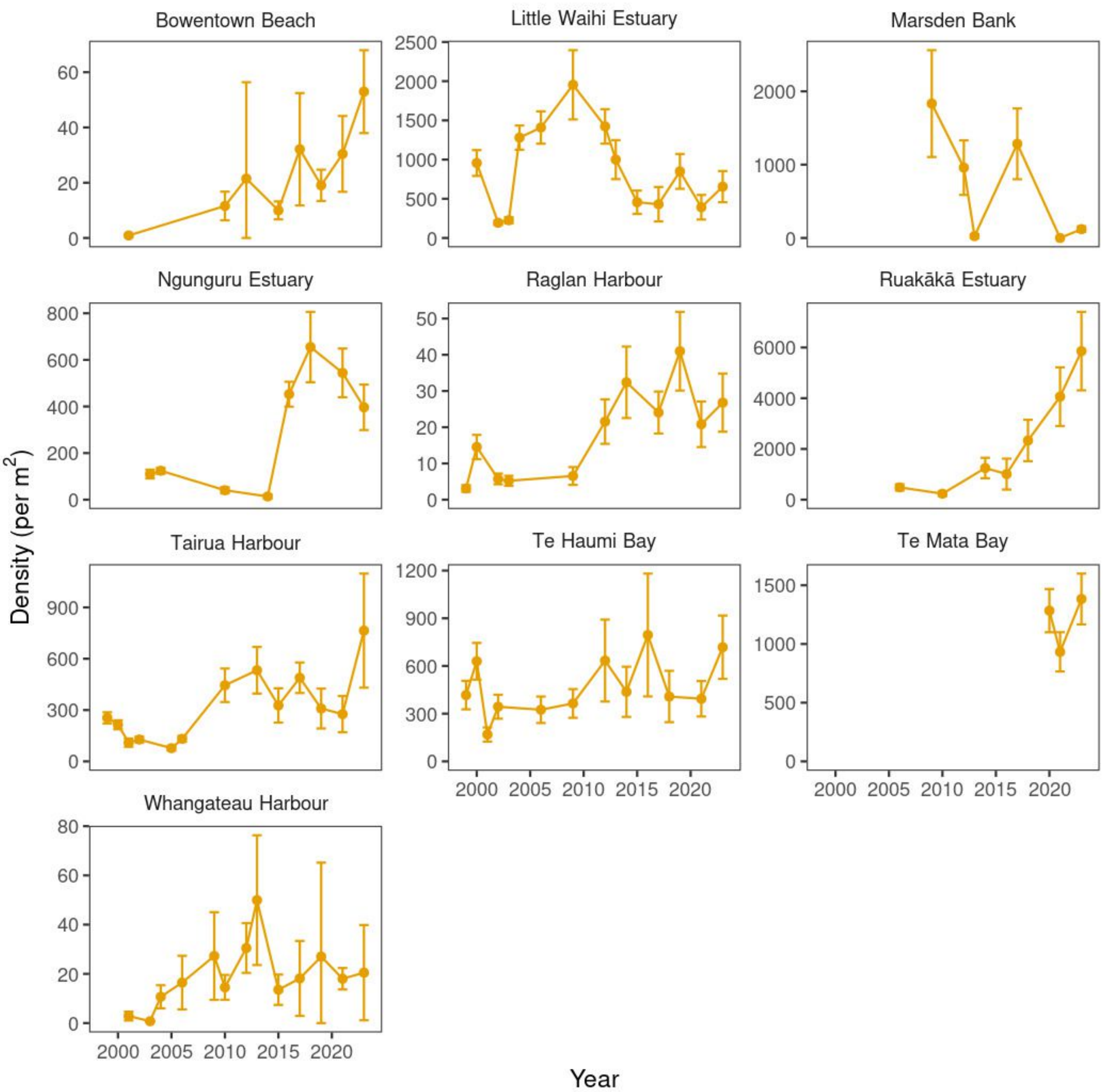


Figure 61: Estimated density of pipi for all sites included in the 2023–24 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

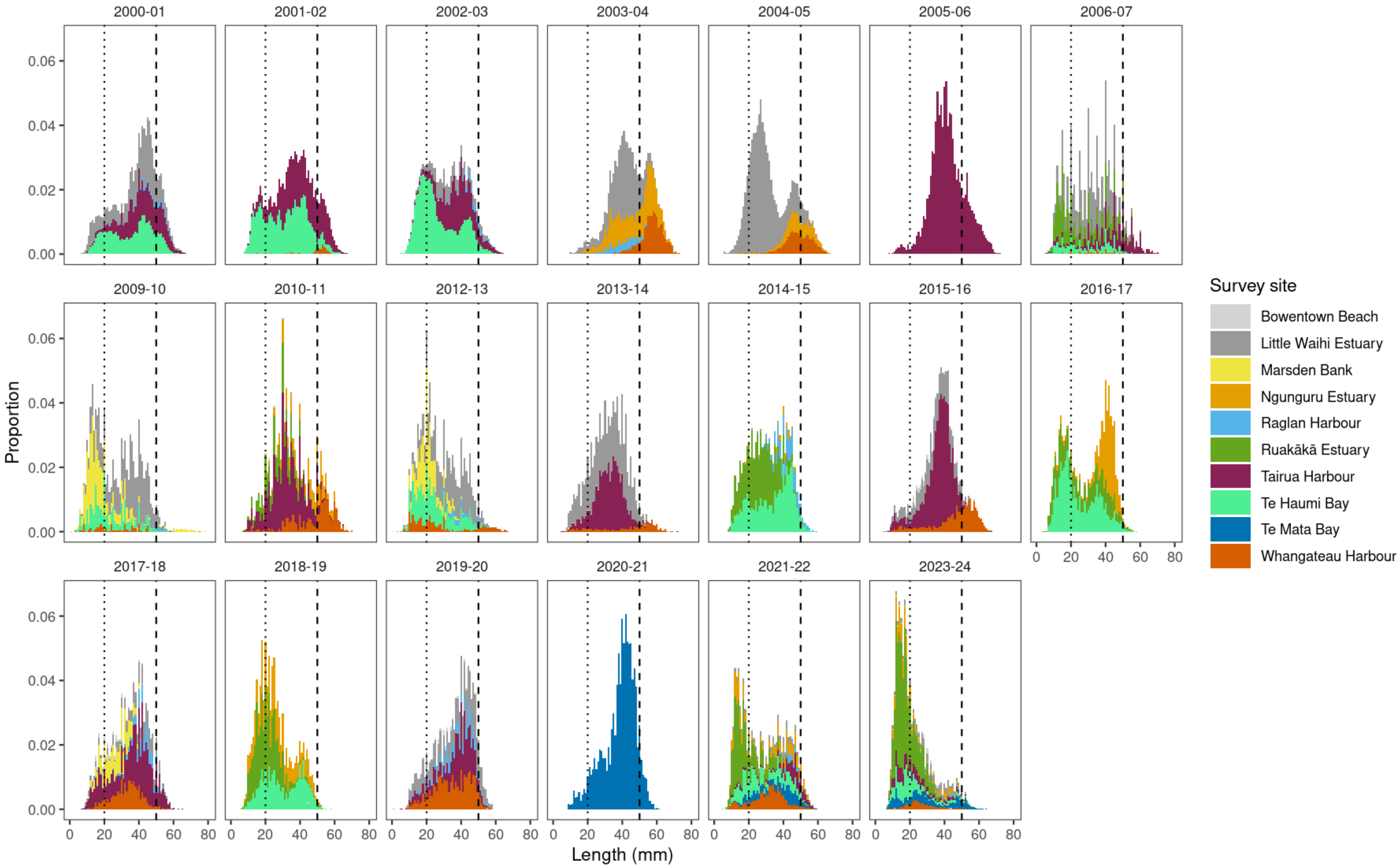


Figure 62: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2023–24 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

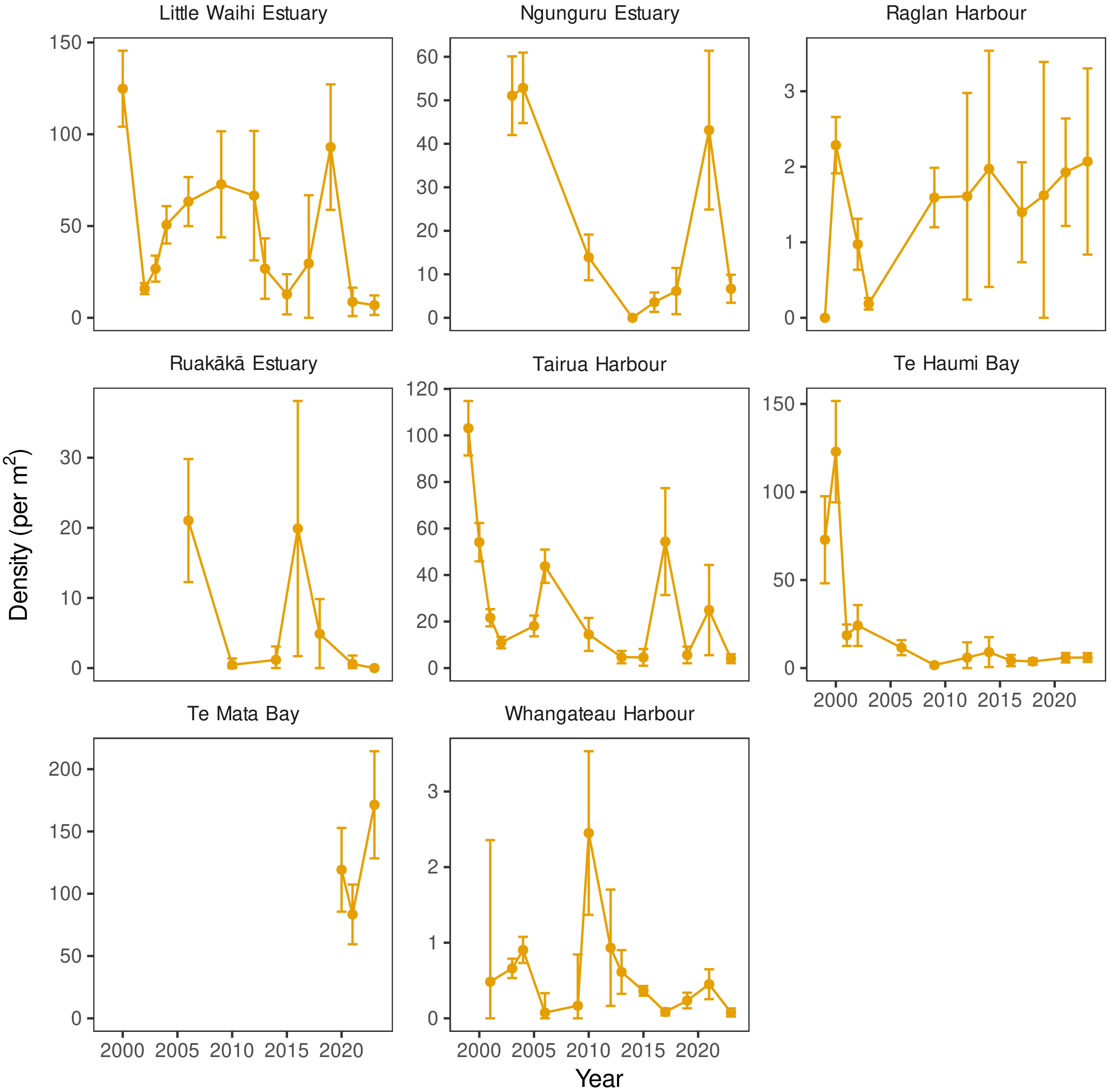


Figure 63: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites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

4.3 Sediment data

Sediment characteristics of the cockle beds at the 2023–24 survey sites included a low proportion of organic matter, with average values below 3% (Figure 64). Sediment grain size compositions across all sites were dominated by fine sand (grain size >125 µm), followed by varying proportions of medium and very fine sands (>250 and >63 µm)).

The proportion of sediment fines (<63 µm) was relatively high at a number of the 2023–24 sites, with average proportion of sediment in this grain size fractions between 8 and 10% at Ngunguru Estuary, Raglan Harbour, Tairua Harbour, Te Haumi Bay, and Umupuia Beach. Most notably was Umupuia Beach where two samples contained 64% and 71% of sediment fines, respectively. Sediment at this beach also included a high proportion of very fine sand, with the two fine size fractions on average representing over 50% of the sediment samples.

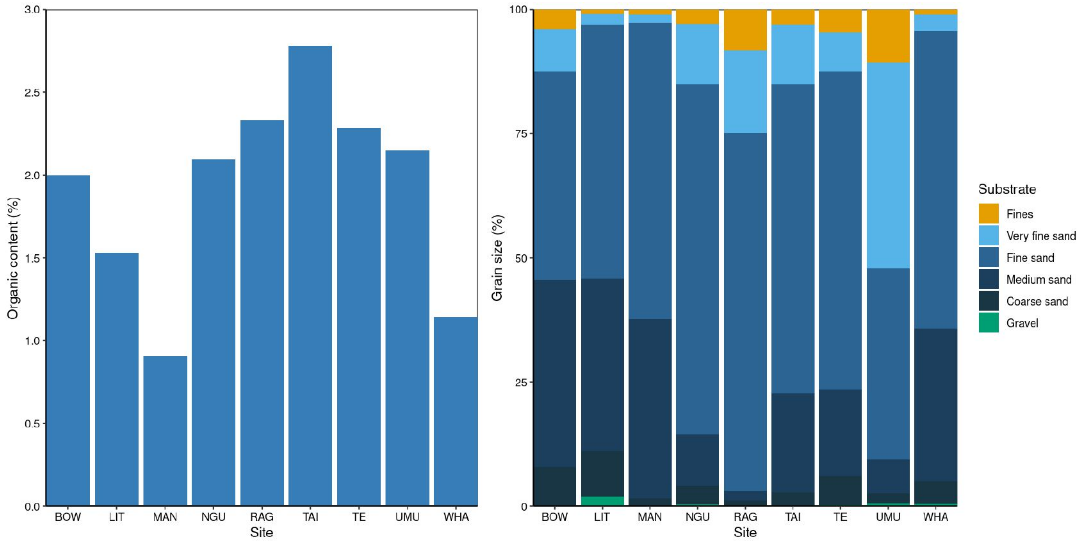


Figure 64: Sediment organic content and grain size composition (averages per site) at the 2023–24 northern survey sites with cockle strata. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand >63 µm, fine sand >125 µm, medium sand >250 µm, coarse sand >500 µm, and gravel >2000 µm. The sites were Bowentown Beach, Little Waihi Estuary, Mangawhai Harbour, Ngunguru Estuary, Raglan Harbour, Tairua Harbour, Te Haumi Bay, Umupuia Beach, and Whangateau Harbour.

4.4 Geostatistical model predictions of cockle density

In addition to providing survey-based population estimates, data from the field survey were used to examine spatio-temporal trends in predicted cockle densities at the survey sites. The geostatistical models used in this analysis allowed the identification of high-density areas within cockle strata, and assessment of changes in these "hotspots" over time (see Appendix C, Figures C-1 to C-9).

At most of the survey sites, the locations of high-density areas were comparable between the total population and large cockles, although hotspots were more restricted for the latter populations. This aspect was particularly prominent at Ngunguru Estuary and Tairua Harbour (Figures C-4 and C-6). At Tairua Harbour, and also Umupuia Beach and Te Haumi Bay, distinct high-density areas in early surveys became smaller and also less pronounced over time (Figures C-8 and C-7). In contrast, three sites were characterised by areas of high cockle densities that persisted over time, Bowentown Beach, Ngunguru Estuary and Raglan Harbour (Figures C-1, C-4, and C-5). At these sites, the high-density areas encompassed all or most of the cockle strata.

At Whangateau Harbour, there was a general lack of high-density areas of large cockles, and predicted hotspots of total cockle densities were only evident in one of the strata, stratum A (Figure C-9). Similarly, at Mangawhai Harbour, hotspots of total cockle densities were only prominent in strata A to C (Figure C-3).

5. DISCUSSION

This study represents the most recent assessment in the northern bivalve monitoring series, with survey sites in Auckland (Umupuia Beach), Waikato (west and east coasts; Raglan and Tairua harbours, Te Mata Bay), Northland (Te Haumi Bay, Ngunguru Estuary, Marsden Bank, Ruakākā Estuary, Mangawhai Harbour, Whangateau Harbour), and Bay of Plenty (Bowentown Beach, Little Waihi Estuary). All of the sites have been regularly surveyed as part of the northern monitoring programme since 1999–2000, with the sampling frequency ranging from three (Te Mata Bay) to 17 (Umupuia Beach) bivalve assessments. The regular and frequent monitoring of these sites provides time series of the bivalve populations, allowing the examination of inter-site comparisons and temporal trends.

Existing fishery closures prohibit the take of cockles and pipi at five of the sites, Marsden Bank, Ngunguru Estuary, Te Mata Bay, Umupuia Beach, and Whangateau Harbour. At all of these sites, these closures have been in place for multiple years, with the shortest closure period at Te Mata Bay (first coming into effect in July 2020; Department of Internal Affairs 2020).

Cockle populations were present at nine of the 12 northern sites, and their abundance and density estimates were relatively high; at three sites, density estimates exceeded 1200 individuals per m^2. The populations were dominated by medium-sized cockles, and the unimodal population size structures indicated the strength of this size class and persistence of cockle populations at the sites. Nevertheless, large-sized individuals remained generally scarce, and the time series documented steady declines in large individuals early in the monitoring series. The factors preventing the growth of medium-sized individuals to larger sizes are unclear, but may be related to changes in habitat characteristics or density-dependent limitations at the survey sites.

The generally stable cockle populations were augmented by regular recruitment events, and recruits frequently contributed at least 20 to 30% of all individuals to the populations at the 2023–24 sites. At Te Haumi Bay, their contribution was particularly pronounced in this assessment, with over 60% of all individuals within the recruits size class. Their influx resulted in a second strong cohort, in addition to the smaller cohort of medium-sized cockles.

Umupuia Beach has been closed to the collection of shellfish since 2008, and was the only site with relatively high densities of large individuals. In addition, this size class made up a substantial proportion of the resident cockle population, with over 50% of all individuals in this size class. These findings were consistent with earlier surveys of Umupuia Beach, which documented notable densities of large cockles (e.g., Berkenbusch et al. 2022). In recent surveys, the overall decline in the total population at this beach was largely due to decreases in medium and large-sized cockles, accompanied by little and irregular recruitment.

It is worth noting that sediment at Umupuia Beach was characterised by high proportions of sediment fines (over 60% in some samples) and very fine sand. Although it is difficult to establish a causal link between these sediment characteristics and the documented low recruitment and cockle declines, existing research highlights adverse effects of sediment fines on suspension-feeding cockles (Thrush et al. 2003, Thrush et al. 2005). For example, increasing mud content in intertidal areas of 19 North Island estuaries (including some of the present survey sites) had a negative effect on the predictions of cockle occurrence, and this species was more likely to occur in sediments with low mud content. A subsequent modelling study indicated that maximum cockle densities were associated with sediment mud content below 11%, with marked declines in cockle densities when the proportions of this sediment grain size fraction exceeded 11% (Thrush et al. 2005).

Notable declines in cockle populations were also documented at the other two cockle sites with fishery restrictions, at Ngunguru Estuary and Whangateau Harbour. At Ngunguru Estuary, the field survey detected a number of decomposing and dying cockles within the cockle strata, possibly indicating a recent mortality event at this estuary (see Appendix D, Figure D-1). At Whangateau Harbour, the cockle decline followed a steady increase in cockle populations across recent surveys. The lack of shellfish collections at these sites means that factors other than fishing impact resident cockle populations.

Ten of the 2023–24 survey sites supported pipi populations, which occurred at relatively high abundances and densities across all regions. Pipi densities exceeded 300 individuals per m^2 at six of the sites, with particular high densities at Te Mata Bay (over 1000 individuals per m^2) and Ruakākā Estuary (over 5000 individuals per m^2). Te Mata Bay was the only site that also supported notable densities of large pipi, where the estimated average density of this size class was over 170 individuals per m^2.

The high estimates recorded for the pipi populations in this study were in part caused by significant recruitment events, particularly at Northland sites. The influx of high numbers of small pipi largely influenced population estimates and size structures, masking trends in the established parts of the pipi populations, such as declines in medium-sized individuals. For example, at Ruakākā Estuary, the exceptionally high population density in this survey was caused by recently-settled recruits, with almost 75% of the current population consisting of individuals in this size class. Given the susceptibility of recruits (and small-sized individuals) to impacts such as predation and flooding, it is likely that only a small proportion of recruits become established within these populations.

In this context, recruits at Ruakākā Estuary are vulnerable to further habitat changes, affecting the course of the estuary channel and estuarine sedimentation. Significant changes to the main channel were observed between the two most recent surveys, resulting in shallow water depths and reduced flow in parts of the channel. Pipi previously inhabiting this channel area (see Berkenbusch et al. 2022) were no longer present in 2023–24. In addition, a previously dead-ended side channel was open to the coast in the current field survey, making it available to pipi recruits. It is unclear if these changes were related to North Island flooding events in January 2023 or Cyclone Gabrielle the following month, but substantial changes to the main channel in this estuary have been reported previously (e.g., in 2007 and 2010; Pawley & Ford 2007, Pawley 2012). In 2010, dead and decaying pipi were reported in stagnant pools of water that were in the previous course of the channel (Pawley 2012). Similarly, further marked habitat changes such as through storm events or high sediment loads, may have an impact on the high number of pipi recruits recorded in the present survey.

At Marsden Bank, the signs of population recovery were directly linked to the settlement of recruits, with the 2023–24 population consisting almost entirely (90%) of this size class. Surveys by Te Patuharakeke Te Iwi Trust Board document a similar prevalence and patchy occurrence of small-sized individuals at this site (Shirkey 2019). These findings document that recruits settle at Marsden Bank, but fail to become established. A recent investigation of Northland pipi populations, including die-offs in this region, was aimed at establishing a "health" baseline for this species (Howells et al. 2024). Further research into factors contributing to mass mortalities, population declines, and the lack of population recovery is required to elucidate some of the observed patterns in resident pipi populations, and where relevant in cockle populations across northern New Zealand.

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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	2023	2024
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 1999–2000, including the present survey in 2023–24. 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
	2022–23	6 Feb	19.40	AKI2021-01
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
	2023–24	26 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
	2022–23	11 Feb	15.77	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
	2022–23	9 Mar	22.39	AKI2021-01
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
	2022–23	8 Mar	26.46	AKI2021-01
Hokianga Harbour	2018–19	20 Feb	10.07	AKI2018-01
	2022–23	10 Feb–11 Feb	10.07	AKI2021-01
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
	2022–23	10 Mar	60.89	AKI2021-01
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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
	2021–22	19 Feb–20 Feb	16.63	AKI2021-01
	2023–24	27 Feb–28 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
	2023–24	10 Feb–16 Feb	7.17	AKI2021-01
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
	2023–24	14 Feb	0.37	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
	2023–24	11 Feb–14 Feb	6.01	AKI2021-01
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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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
	2022–23	15 Mar–16 Mar	1.87	AKI2021-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01
	2015–16	11 Jan	19.84	AKI2015-01
	2017–18	6 Feb	19.83	AKI2017-01
	2020–21	27 Feb	19.83	AKI2018-01
	2022–23	7 Feb	19.83	AKI2021-01
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
	2022–23	14 Mar	4.44	AKI2021-01
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
	2022–23	8 Feb–9 Feb	28.18	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
	2023–24	22 Feb–22 Feb	7.47	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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2023–24	13 Feb–13 Feb	2.07	AKI2021-01
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
	2023–24	25 Feb	5.45	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
	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
	2023–24	12 Feb	10.04	AKI2021-01
Te Mata Bay	2020–21	14 Feb–20 Feb	0.97	AKI2018-01
	2021–22	24 Feb–26 Feb	0.68	AKI2021-01
	2023–24	23 Feb–24 Feb	0.73	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
	2023–24	9 Feb	33.90	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

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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
	2022–23	16 Mar–17 Mar	11.98	AKI2021-01
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
	2022–23	11 Mar	8.09	AKI2021-01
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
	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
	2022–23	12 Mar–13 Mar	5.07	AKI2021-01
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
	2023–24	15 Feb–16 Feb	111.32	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 2023–24 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	-37.45758	175.97398	1.8	3.1	4.8	31.6	42.4	18.2	0.0
	A	2	-37.45732	175.97385	1.9	4.7	4.3	25.7	47.0	18.1	0.3
	A	3	-37.45682	175.97340	2.7	6.6	9.9	55.0	24.9	3.6	0.0
	A	4	-37.45665	175.97323	2.3	5.9	6.8	32.5	43.9	10.9	0.0
	A	5	-37.45665	175.97330	1.7	3.5	4.2	28.9	49.7	13.6	0.0
	A	6	-37.45655	175.97301	1.4	3.5	3.6	35.6	44.0	13.3	0.0
	A	7	-37.45640	175.97306	1.6	3.2	6.7	38.3	42.1	9.6	0.0
	A	8	-37.45634	175.97295	1.4	4.0	5.2	36.9	41.9	11.9	0.0
	B	1	-37.45671	175.97219	1.8	3.8	11.5	45.9	33.4	5.4	0.0
	B	2	-37.45668	175.97194	2.6	4.8	12.7	41.2	34.2	7.2	0.0
	B	3	-37.45668	175.97211	2.4	4.3	12.3	43.3	34.3	5.8	0.0
	B	4	-37.45664	175.97200	2.0	3.8	14.3	48.1	28.5	5.3	0.0
	B	5	-37.45653	175.97188	2.1	3.9	14.4	49.0	29.0	3.7	0.0
	B	6	-37.45643	175.97154	1.6	2.0	10.3	42.0	38.0	7.7	0.0
	B	7	-37.45632	175.97123	2.7	4.8	10.2	37.1	38.9	8.6	0.4
	B	8	-37.45627	175.97116	2.7	4.1	7.8	34.7	45.9	7.6	0.0
	C	1	-37.45619	175.97098	3.3	6.9	8.3	35.2	42.5	7.1	0.0
	C	2	-37.45591	175.97092	2.4	4.4	10.8	43.3	37.3	4.2	0.0
	C	3	-37.45568	175.97148	1.6	2.4	11.5	47.3	34.8	3.9	0.0
	C	4	-37.45545	175.97191	1.9	4.1	9.9	57.1	25.8	3.0	0.0
	C	5	-37.45544	175.97248	2.0	5.5	10.2	55.0	25.4	4.0	0.0
	C	6	-37.45543	175.97197	1.4	0.6	5.3	48.5	40.5	5.1	0.0
	C	7	-37.45536	175.97207	1.3	1.7	3.0	41.4	49.2	4.7	0.0
	C	8	-37.45536	175.97246	1.2	2.3	9.1	51.3	31.3	6.0	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
Little Waihi Estuary	A	1	-37.76386	176.48074	1.4	2.5	4.1	51.5	32.7	9.2	0.0
	A	2	-37.76347	176.48028	1.3	0.5	2.8	37.7	28.1	12.8	18.0
	A	3	-37.76301	176.48107	2.4	1.3	3.6	64.9	27.7	2.5	0.0
	A	4	-37.76206	176.48201	1.2	1.3	1.5	44.5	47.3	4.8	0.6
	A	5	-37.76138	176.48033	1.1	2.5	3.4	39.4	23.8	16.3	14.6
	A	6	-37.76133	176.48253	1.5	2.0	4.5	47.5	31.6	14.2	0.1
	A	7	-37.76123	176.48254	2.4	1.5	3.5	49.0	32.1	13.4	0.5
	A	8	-37.76073	176.48229	2.0	2.3	4.6	56.3	29.2	7.4	0.3
	A	9	-37.76011	176.48155	3.5	4.1	6.6	67.9	19.7	1.7	0.0
	A	10	-37.76004	176.48139	2.0	0.3	2.3	75.2	20.9	1.4	0.0
	A	11	-37.75990	176.48064	1.7	0.0	0.8	62.3	35.9	1.0	0.0
	A	12	-37.75915	176.48162	0.9	0.8	2.9	53.2	31.8	8.2	3.1
	B	1	-37.75951	176.48022	1.3	0.7	1.0	52.0	38.4	7.4	0.6
	B	2	-37.75938	176.47947	1.5	2.0	1.7	46.1	34.6	13.9	1.6
	B	3	-37.75910	176.48037	1.6	0.0	0.3	29.8	50.8	18.9	0.1
	B	4	-37.75899	176.48019	1.2	0.3	0.5	48.1	41.9	8.9	0.2
	B	5	-37.75872	176.48025	1.4	0.0	1.4	56.5	38.2	3.3	0.6
	B	6	-37.75857	176.47867	1.9	0.6	1.2	11.1	56.4	29.8	0.9
	B	7	-37.75830	176.47937	1.1	0.0	0.5	69.7	28.8	1.0	0.0
	B	8	-37.75823	176.47881	1.3	0.0	1.1	52.0	39.7	6.9	0.2
	B	9	-37.75822	176.47909	1.7	0.0	0.5	46.3	37.5	12.4	3.4
	B	10	-37.75816	176.48004	0.5	0.0	0.5	43.8	50.7	5.0	0.0
	B	11	-37.75705	176.47808	0.2	0.0	0.6	36.2	44.6	17.1	1.5
	B	12	-37.75695	176.47903	1.5	0.3	2.8	84.2	12.3	0.4	0.0
Mangawhai Harbour	A	1	-36.08517	174.59045	1.4	2.9	1.9	64.0	29.8	1.2	0.3
	A	2	-36.08483	174.59015	0.6	0.9	0.5	45.2	51.0	2.3	0.0
	A	3	-36.08465	174.59036	0.6	0.2	0.6	40.9	53.8	4.1	0.5
	A	4	-36.08450	174.59037	0.7	1.0	0.4	28.8	62.9	6.9	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
	A	5	-36.08447	174.59077	0.9	1.2	1.2	47.8	46.3	3.4	0.0
	A	6	-36.08425	174.59108	1.0	0.7	1.8	83.9	13.1	0.5	0.0
	B	1	-36.08723	174.59012	0.6	0.5	0.9	50.0	47.8	0.9	0.0
	B	2	-36.08706	174.59013	0.8	1.2	1.4	54.3	42.7	0.4	0.0
	B	3	-36.08694	174.59019	0.8	0.7	1.1	64.8	32.8	0.6	0.0
	B	4	-36.08691	174.59039	0.9	0.3	1.4	55.4	40.1	2.8	0.0
	B	5	-36.08667	174.59023	0.8	0.9	0.8	75.0	23.0	0.3	0.0
	B	6	-36.08584	174.59039	0.8	0.7	1.6	64.9	32.0	0.8	0.0
	B	7	-36.08575	174.59091	2.6	0.0	2.5	77.1	18.4	2.0	0.0
	C	1	-36.08862	174.59021	0.6	1.0	0.9	47.3	50.2	0.6	0.0
	C	2	-36.08840	174.59018	0.7	1.1	1.0	49.5	47.6	0.7	0.0
	C	3	-36.08823	174.59026	0.6	0.0	0.7	46.2	52.2	0.9	0.0
	C	4	-36.08777	174.59029	0.6	0.4	1.4	46.0	50.6	1.3	0.4
	C	5	-36.08766	174.59029	0.6	0.4	0.6	43.4	54.8	0.9	0.0
	D	1	-36.09901	174.59237	0.9	0.2	2.6	67.1	29.1	1.0	0.0
	D	2	-36.09881	174.59258	0.8	1.3	2.8	67.7	26.9	1.2	0.0
	D	3	-36.09867	174.59203	1.2	2.0	6.1	80.1	10.8	1.0	0.0
	D	4	-36.09771	174.59196	0.9	1.8	1.1	70.9	25.8	0.4	0.0
	D	5	-36.09699	174.59152	1.2	2.7	2.9	81.4	12.5	0.5	0.0
	D	6	-36.09642	174.59180	1.0	2.1	2.3	81.5	13.5	0.6	0.0
Ngunguru Estuary	A	1	-35.63510	174.50091	1.8	1.7	13.9	75.6	6.8	2.0	0.0
	A	2	-35.63446	174.50110	2.1	3.1	13.0	70.2	10.0	3.6	0.0
	A	3	-35.63403	174.50150	1.7	0.8	8.5	68.0	16.2	6.5	0.0
	A	4	-35.63367	174.50171	1.7	1.3	9.2	67.1	15.1	7.2	0.0
	A	5	-35.63343	174.50185	1.8	0.5	7.1	62.5	18.5	10.6	0.7
	A	6	-35.63329	174.50211	3.2	0.8	8.4	42.0	30.8	15.6	2.3
	A	7	-35.63297	174.50225	2.1	4.1	12.1	57.1	17.5	9.1	0.0
	A	8	-35.63276	174.50239	2.0	1.9	16.5	59.0	9.3	9.1	4.2

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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	1	-35.63764	174.50421	1.3	2.3	6.6	76.5	12.4	2.2	0.0
	B	2	-35.63690	174.50442	1.1	1.2	7.6	73.8	14.9	2.5	0.0
	B	3	-35.63654	174.50453	1.2	1.6	8.8	79.8	8.1	1.7	0.0
	B	4	-35.63642	174.50467	4.1	8.8	8.8	75.9	5.8	0.8	0.0
	B	5	-35.63637	174.50456	1.1	0.6	8.8	79.8	8.9	1.9	0.0
	B	6	-35.63615	174.50472	1.3	0.8	9.1	76.4	10.7	3.0	0.0
	B	7	-35.63576	174.50483	1.5	1.0	6.7	67.6	18.4	6.3	0.0
	B	8	-35.63542	174.50496	1.5	1.7	10.1	65.6	19.8	2.8	0.0
	C	1	-35.63710	174.50242	2.8	8.8	19.9	69.4	1.0	1.0	0.0
	C	2	-35.63694	174.50204	2.3	6.7	17.9	73.4	1.1	0.9	0.0
	C	3	-35.63661	174.50167	1.4	1.7	14.7	78.2	2.7	2.6	0.1
	C	4	-35.63592	174.50188	2.3	2.9	16.8	77.3	2.4	0.5	0.0
	C	5	-35.63551	174.50218	2.6	4.7	22.4	70.8	1.8	0.2	0.0
	C	6	-35.63546	174.50284	2.6	4.9	21.9	71.2	1.8	0.2	0.0
	C	7	-35.63534	174.50245	4.5	5.9	10.2	78.5	4.8	0.5	0.0
	C	8	-35.63522	174.50229	2.2	3.7	10.2	77.8	7.4	0.9	0.0
Raglan Harbour	A	1	-37.80510	174.86611	2.1	8.2	16.2	74.0	1.0	0.7	0.0
	A	2	-37.80465	174.86673	2.8	10.8	22.9	64.1	1.3	1.0	0.0
	A	3	-37.80439	174.86567	2.3	5.3	17.5	72.4	2.6	1.7	0.6
	A	4	-37.80401	174.86601	2.2	6.8	14.9	74.9	2.6	0.7	0.0
	A	5	-37.80400	174.86713	2.4	8.7	24.2	66.0	0.7	0.4	0.0
	A	6	-37.80387	174.86745	3.5	17.0	33.6	46.6	1.5	1.3	0.0
	A	7	-37.80387	174.86735	3.5	15.8	30.0	52.9	0.7	0.6	0.0
	A	8	-37.80379	174.86693	2.5	12.6	12.8	70.6	3.4	0.6	0.0
	A	9	-37.80316	174.86763	2.5	12.1	20.6	47.9	7.5	9.8	2.1
	A	10	-37.80314	174.86668	3.5	15.9	11.0	63.3	8.3	1.5	0.0
	A	11	-37.80284	174.86726	3.0	14.8	17.0	66.3	1.4	0.5	0.0
	A	12	-37.80258	174.86779	4.1	24.3	26.2	44.4	2.2	2.7	0.2

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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	1	-37.79646	174.86933	1.7	3.2	14.0	82.2	0.5	0.1	0.0
	B	2	-37.79635	174.86906	1.6	3.1	10.1	84.8	2.0	0.1	0.0
	B	3	-37.79625	174.86953	1.4	1.2	11.6	86.8	0.3	0.1	0.0
	B	4	-37.79605	174.86975	1.4	2.3	10.4	86.9	0.4	0.0	0.0
	B	5	-37.79599	174.87127	1.6	6.3	20.0	67.4	5.2	1.0	0.0
	B	6	-37.79589	174.87012	1.8	3.1	10.7	85.0	1.1	0.1	0.0
	B	7	-37.79585	174.87042	1.8	3.4	11.9	84.2	0.4	0.1	0.0
	B	8	-37.79581	174.87080	2.0	5.1	11.6	82.3	0.6	0.3	0.0
	B	9	-37.79572	174.87036	1.6	2.7	12.1	84.1	0.5	0.6	0.0
	B	10	-37.79552	174.87104	2.4	3.7	9.1	86.5	0.6	0.1	0.0
	B	11	-37.79544	174.87144	2.2	4.1	16.0	77.9	1.4	0.6	0.0
	B	12	-37.79543	174.87187	2.1	7.8	16.8	73.3	1.4	0.7	0.0
Tairua Harbour	A	1	-37.00761	175.85276	2.0	1.3	7.3	65.0	22.4	3.9	0.0
	A	2	-37.00742	175.85289	2.5	3.0	8.7	71.9	14.1	2.3	0.0
	A	3	-37.00672	175.85385	2.4	1.3	5.1	70.4	20.4	2.8	0.0
	A	4	-37.00642	175.85312	3.1	5.1	18.0	67.0	8.9	1.0	0.0
	A	5	-37.00619	175.85425	2.3	1.6	4.8	75.9	16.4	1.3	0.0
	A	6	-37.00580	175.85398	3.7	2.1	13.7	61.6	16.2	5.8	0.6
	A	7	-37.00488	175.85501	1.3	0.3	2.4	48.7	44.1	4.6	0.0
	B	1	-37.00737	175.85254	2.2	1.8	12.0	63.0	21.3	1.9	0.0
	B	2	-37.00632	175.85452	1.8	0.0	1.2	66.4	30.4	2.0	0.0
	B	3	-37.00607	175.85509	1.6	0.0	1.2	64.9	28.3	4.9	0.7
	B	4	-37.00606	175.85485	1.9	0.0	2.4	75.0	21.1	1.5	0.0
	B	5	-37.00602	175.85472	2.0	0.5	2.8	71.3	24.0	1.5	0.0
	B	6	-37.00593	175.85481	2.4	1.8	4.4	72.7	19.0	2.0	0.0
	B	7	-37.00580	175.85459	1.8	1.7	5.9	45.0	35.3	11.6	0.5
	B	8	-37.00530	175.85545	3.0	4.5	6.1	59.3	27.0	3.1	0.0
	B	9	-37.00523	175.85548	2.1	0.5	4.9	58.2	31.5	4.7	0.1

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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	-37.00709	175.85229	3.4	4.8	21.4	58.0	14.5	1.2	0.0
	C	2	-37.00705	175.85258	4.2	7.2	25.2	61.4	5.5	0.6	0.0
	C	3	-37.00697	175.85266	4.4	6.5	23.4	64.6	4.9	0.7	0.0
	C	4	-37.00690	175.85260	4.9	8.9	29.8	55.9	4.9	0.5	0.0
	C	5	-37.00682	175.85241	3.9	7.3	27.4	57.8	6.8	0.7	0.0
	C	6	-37.00674	175.85240	4.1	8.5	32.1	51.1	7.5	0.9	0.0
	C	7	-37.00649	175.85265	4.2	5.4	25.4	64.3	4.5	0.5	0.0
	C	8	-37.00557	175.85588	1.6	1.5	1.0	41.3	52.8	3.4	0.0
Te Haumi Bay	A	1	-35.29689	174.09956	2.2	1.4	2.0	42.2	48.3	6.1	0.0
	A	2	-35.29664	174.09955	2.6	3.8	2.1	38.3	47.4	8.4	0.0
	A	3	-35.29624	174.09977	2.9	8.1	2.8	55.0	27.5	6.6	0.0
	A	4	-35.29576	174.09984	2.5	5.7	2.4	47.3	20.1	23.3	1.1
	A	5	-35.29560	174.10106	2.7	8.5	0.6	16.8	39.2	33.4	1.6
	A	6	-35.29539	174.09986	2.1	3.9	4.3	65.2	22.3	4.2	0.0
	A	7	-35.29522	174.10025	2.2	5.3	3.5	64.4	23.3	3.4	0.1
	A	8	-35.29491	174.09902	2.3	8.2	15.4	54.6	12.3	8.6	1.0
	B	1	-35.29540	174.10047	1.9	2.3	4.6	69.6	16.0	7.2	0.3
	B	2	-35.29523	174.09931	2.3	6.6	5.0	56.9	28.6	3.0	0.0
	B	3	-35.29500	174.10129	2.0	4.2	4.7	74.1	14.5	2.5	0.0
	B	4	-35.29499	174.10023	2.3	4.2	4.6	70.8	18.6	1.8	0.0
	B	5	-35.29487	174.10084	1.8	3.2	4.6	72.7	17.1	2.4	0.0
	B	6	-35.29453	174.10121	1.8	3.3	6.6	75.7	10.3	4.1	0.0
	B	7	-35.29437	174.09962	2.3	5.2	15.3	66.3	9.7	3.4	0.1
	B	8	-35.29417	174.10011	1.9	2.8	13.5	71.7	8.7	3.3	0.0
	C	1	-35.29498	174.10221	2.3	5.2	8.4	72.5	9.6	4.3	0.0
	C	2	-35.29467	174.10189	2.0	3.2	8.9	79.9	6.7	1.3	0.0
	C	3	-35.29424	174.10110	2.3	5.5	10.7	65.2	11.8	6.6	0.1
	C	4	-35.29416	174.10187	2.3	2.9	7.9	82.6	5.9	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	5	-35.29414	174.10126	2.4	4.6	11.8	70.9	9.0	3.8	0.0
	C	6	-35.29408	174.10181	2.2	3.2	18.5	74.9	2.9	0.5	0.0
	C	7	-35.29406	174.10078	3.5	5.0	13.9	76.8	3.4	0.8	0.0
	C	8	-35.29389	174.10141	2.1	3.3	18.4	72.5	4.6	1.3	0.0
Umupuia Beach	A	1	-36.90360	175.07134	4.4	18.4	56.9	20.2	3.1	1.4	0.0
	A	2	-36.90288	175.07459	1.7	7.2	45.0	17.9	5.5	14.4	9.9
	A	3	-36.90284	175.06956	6.5	63.8	25.9	8.0	2.3	0.1	0.0
	A	4	-36.90237	175.07516	1.3	3.6	51.3	43.5	1.5	0.0	0.0
	A	5	-36.90232	175.07561	1.3	4.3	51.7	42.3	1.6	0.0	0.0
	A	6	-36.90197	175.07389	1.3	3.5	32.5	61.8	2.2	0.1	0.0
	A	7	-36.90192	175.07247	1.8	2.4	35.0	59.7	2.4	0.5	0.0
	A	8	-36.90176	175.07150	1.2	3.2	48.1	1.3	47.3	0.0	0.0
	A	9	-36.89918	175.06723	1.3	2.1	28.4	65.6	3.9	0.1	0.0
	A	10	-36.89872	175.06676	1.2	3.2	21.7	67.1	7.5	0.5	0.0
	A	11	-36.89696	175.06600	1.2	2.7	15.8	76.9	4.6	0.1	0.0
	B	1	-36.90331	175.07332	2.3	7.9	55.6	20.5	8.9	6.8	0.3
	B	2	-36.90230	175.06856	1.8	5.9	31.5	29.5	19.0	10.7	3.4
	B	3	-36.90188	175.06872	1.6	4.7	51.4	35.3	8.2	0.4	0.0
	B	4	-36.90178	175.06662	3.3	71.0	7.9	12.6	8.0	0.4	0.0
	B	5	-36.90134	175.06964	1.4	3.8	38.0	54.6	3.3	0.2	0.0
	B	6	-36.90102	175.06768	1.5	4.4	43.0	43.7	7.8	1.1	0.0
	B	7	-36.90058	175.06607	2.7	6.9	48.5	35.2	8.1	1.2	0.0
	B	8	-36.90040	175.06894	1.6	3.2	42.1	50.2	4.0	0.6	0.0
	B	9	-36.90035	175.06718	1.4	3.9	43.4	48.6	3.8	0.3	0.0
	B	10	-36.89994	175.06802	1.4	3.5	42.9	48.5	4.6	0.5	0.0
	B	11	-36.89889	175.06462	2.6	5.6	55.1	33.6	4.7	1.1	0.0
	B	12	-36.89851	175.06504	3.6	13.5	62.1	17.1	4.3	3.1	0.0
	B	13	-36.89830	175.06440	3.3	8.3	60.2	27.2	2.4	1.9	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
Whangateau Harbour	A	1	-36.33693	174.76319	1.4	2.1	4.9	66.6	26.1	0.4	0.0
	A	2	-36.33644	174.76309	1.3	2.4	4.3	74.2	19.0	0.2	0.0
	A	3	-36.33441	174.76321	3.3	1.9	5.4	66.3	25.2	1.1	0.0
	A	4	-36.33077	174.76566	1.0	1.3	4.2	74.6	19.3	0.6	0.0
	A	5	-36.33050	174.76648	0.9	0.2	1.4	72.6	23.5	2.3	0.0
	A	6	-36.33045	174.76452	1.3	1.7	10.2	70.0	17.4	0.7	0.0
	A	7	-36.33034	174.76404	0.9	0.2	5.4	78.2	14.8	1.0	0.4
	A	8	-36.33016	174.76559	1.1	0.0	4.9	73.9	20.1	1.0	0.0
	A	9	-36.32901	174.76546	1.1	0.5	4.4	87.5	7.1	0.5	0.0
	A	10	-36.32827	174.76754	1.1	0.2	4.4	86.5	8.2	0.7	0.0
	A	11	-36.32774	174.76927	1.2	1.6	3.3	85.4	8.5	1.2	0.0
	A	12	-36.32711	174.77125	1.2	1.2	5.0	74.3	12.7	6.8	0.0
	B	1	-36.31772	174.77569	0.8	0.3	0.4	42.0	44.2	12.9	0.2
	B	2	-36.31734	174.77863	0.8	0.0	0.1	21.2	65.4	9.7	3.6
	B	3	-36.31698	174.77728	0.9	0.0	0.5	36.5	46.7	14.7	1.7
	B	4	-36.31661	174.77810	1.2	0.2	0.4	37.4	48.7	13.3	0.0
	C	1	-36.31746	174.77504	0.6	0.0	0.1	23.5	66.6	9.8	0.0
	C	2	-36.31570	174.77690	0.7	0.0	0.4	29.0	63.3	7.3	0.0
	C	3	-36.31471	174.77876	0.9	1.1	1.6	66.6	28.7	1.9	0.0
	C	4	-36.31445	174.78123	1.4	2.7	7.8	56.1	32.6	0.8	0.0
	D	1	-36.31476	174.77381	0.9	0.2	1.3	63.4	30.7	4.4	0.0
	D	2	-36.31391	174.77385	1.0	1.3	2.5	72.1	23.1	1.1	0.0
	D	3	-36.31281	174.77847	1.1	0.7	0.8	30.0	52.9	13.4	2.3
	D	4	-36.31077	174.77625	1.3	5.2	6.7	46.9	33.6	6.3	1.3

APPENDIX C: Geostatistical model predictions

C.1 Bowentown Beach

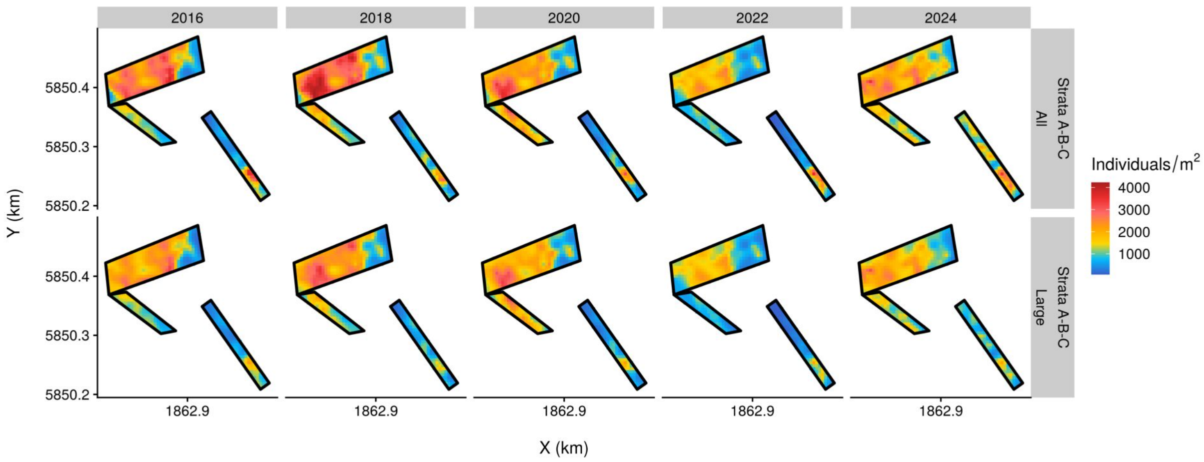

Figure C-1: Predicted cockle densities from the spatio-temporal model for Bowentown Beach. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.2 Little Waihi Estuary

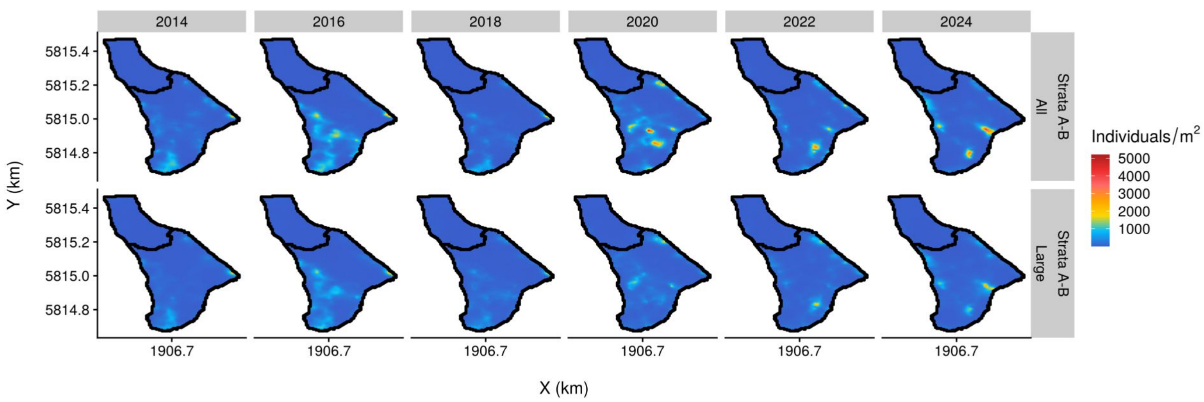

Figure C-2: Predicted cockle densities from the spatio-temporal model for Little Waihi Estuary. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.3 Mangawhai Harbour

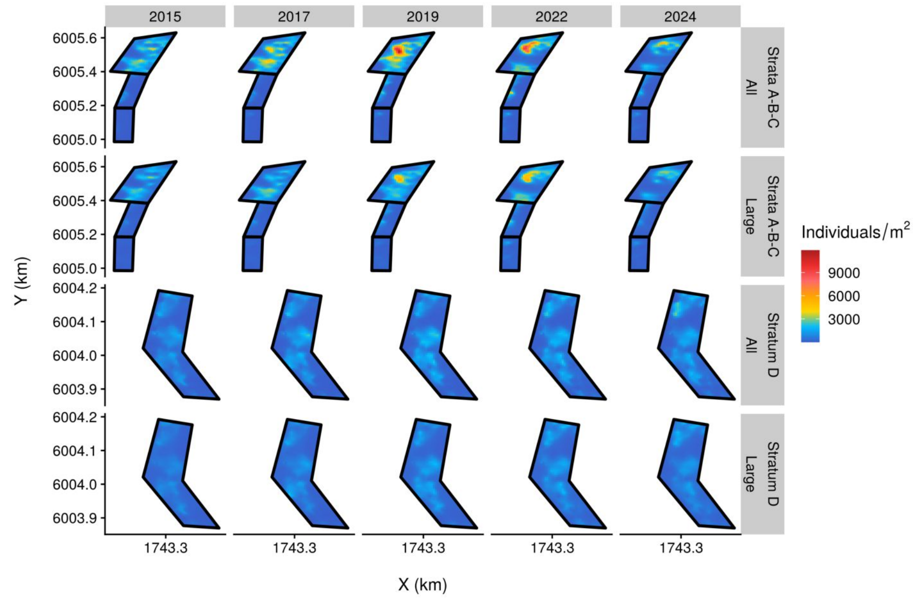

Figure C-3: Predicted cockle densities from the spatio-temporal model for Mangawhai Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.4 Ngunguru Estuary

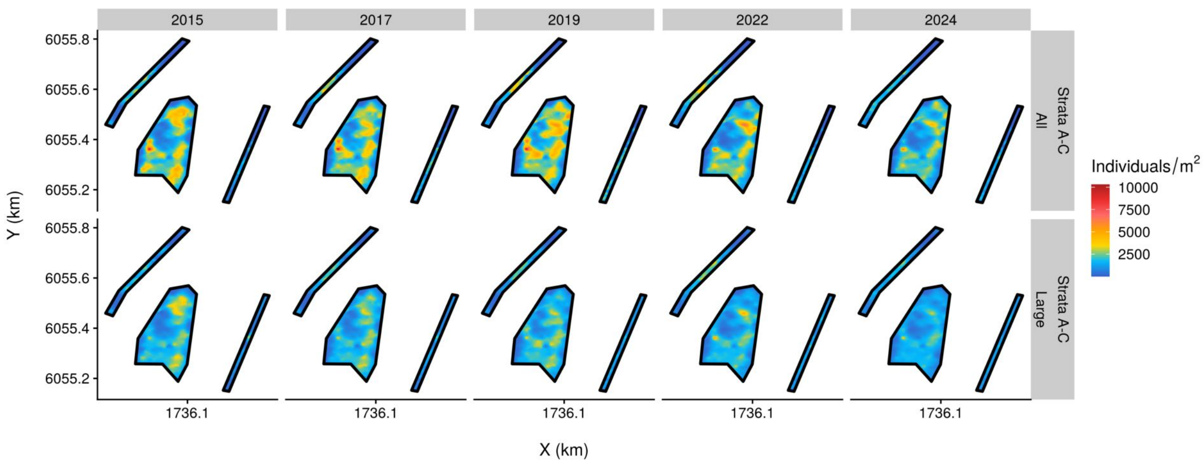

Figure C-4: Predicted cockle densities from the spatio-temporal model for Ngunguru Estuary. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.5 Raglan Harbour

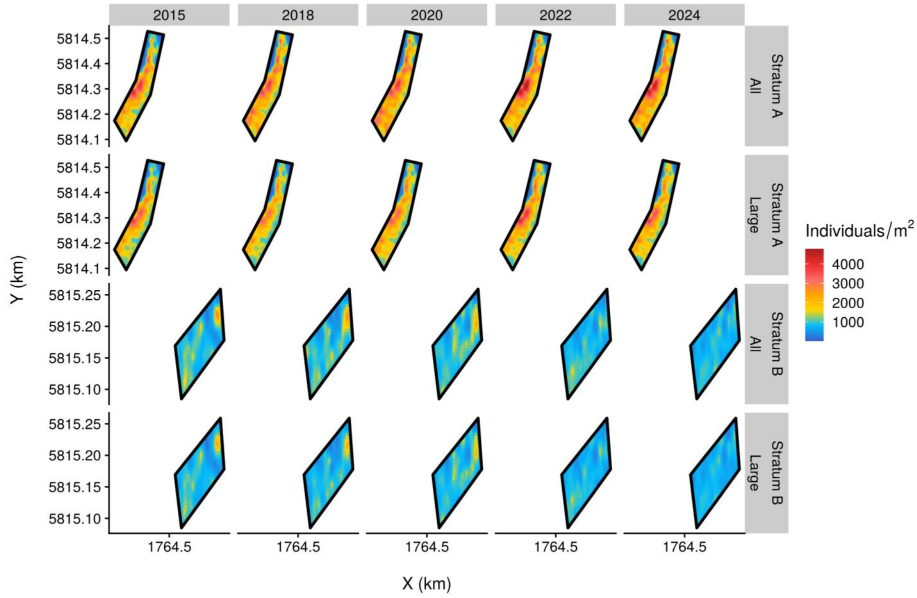

Figure C-5: Predicted cockle densities from the spatio-temporal model for Raglan Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.6 Tairua Harbour

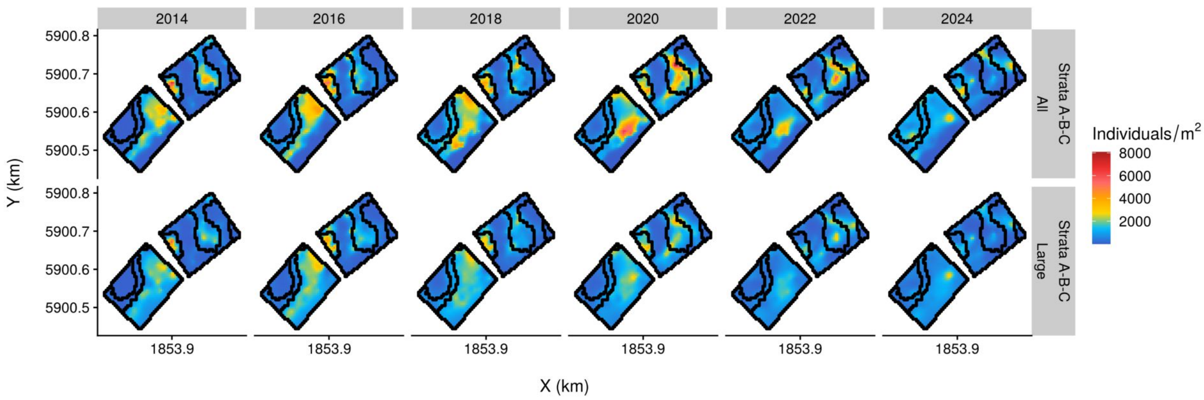

Figure C-6: Predicted cockle densities from the spatio-temporal model for Tairua Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.7 Te Haumi Bay

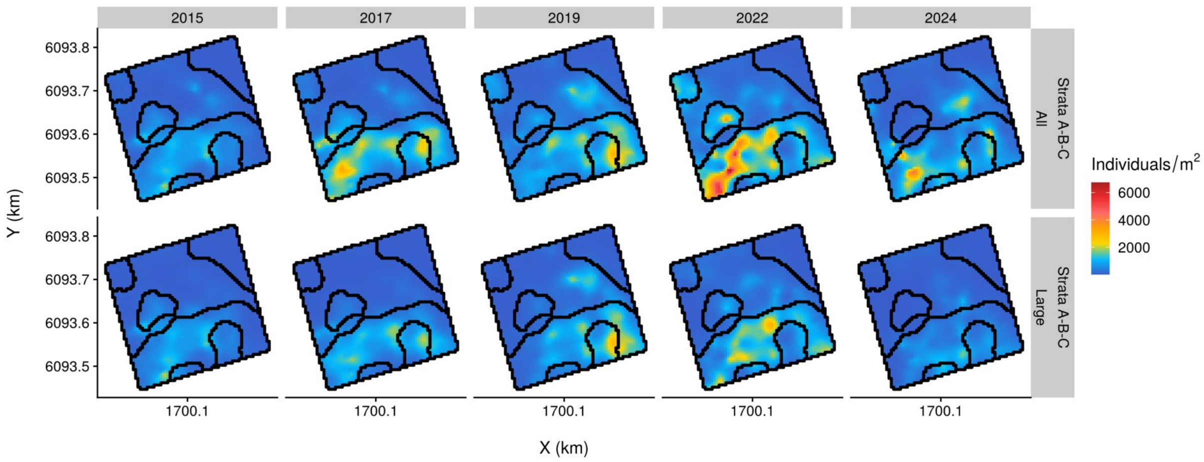

Figure C-7: Predicted cockle densities from the spatio-temporal model for Te Haumi Bay. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.8 Umupuia Beach

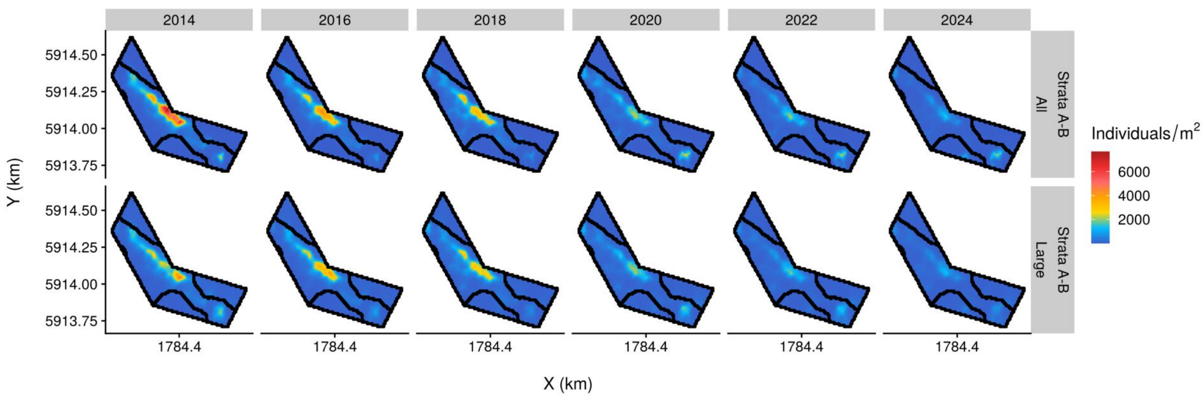

Figure C-8: Predicted cockle densities from the spatio-temporal model for Umupuia Beach. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

C.9 Whangateau Harbour

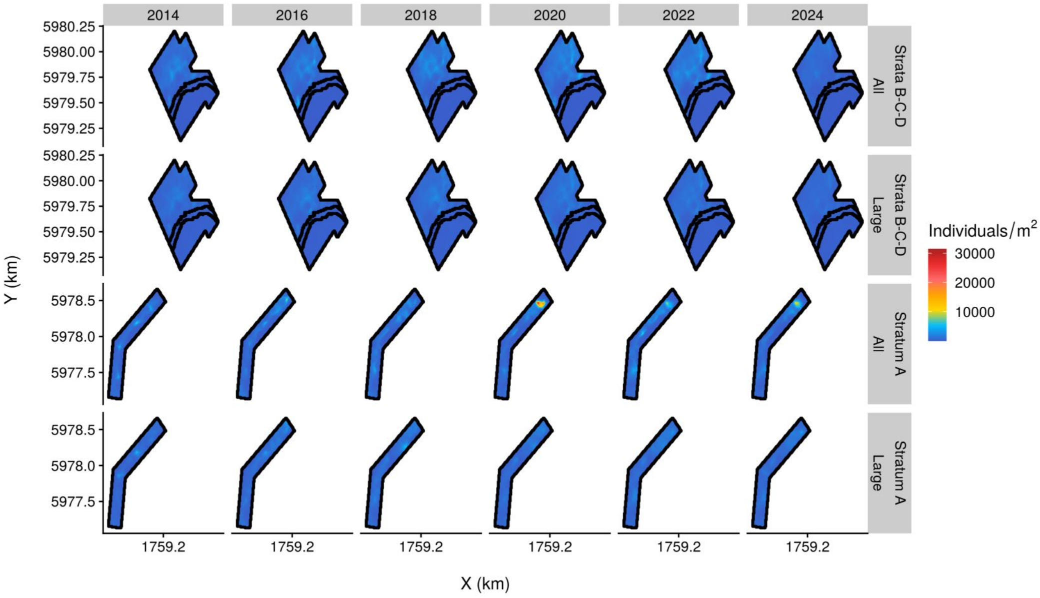

Figure C-9: Predicted cockle densities from the spatio-temporal model for Whangateau Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2024 refers to the 2023–24 fishing year.

APPENDIX D: Supplementary images

D.1 Cockle mortality at Ngunguru Estuary

Figure D-1: Recently-dead, decomposing cockle (top centre) amongst live cockles sampled at Ngunguru Estuary in 2023–24. Mesh size: 5 mm.

D.2 Satellite images of Ruakākā Estuary

Figure D-2: Satellite images of Ruakākā Estuary (Northland), illustrating changes in the course of the main channel between 2022 (left) and 2024 (right). Images from Copernicus Sentinel, retrieved from Copernicus Browser (data access 13 May 2024), processed by the European Space Agency.