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Intertidal shellfish monitoring in the northern North Island region, 2022–23

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EXECUTIVE SUMMARY

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Culturally important marine species in New Zealand include cockles (*Austrovenus stutchburyi*) and pipi (*Paphies australis*), which are targeted in non-commercial fisheries throughout the country. Both species have a widespread distribution in intertidal soft sediments along New Zealand's coastline, including populations close to urban centres. Given their easy accessibility to fishing in intertidal habitats, and possible impacts from other human activities, there is a potential risk of population declines and local depletion at some sites. To support the management of cockle and pipi populations, Fisheries New Zealand commissions regular (usually annual) assessments across the wider northern North Island region. The monitoring programme commenced in the early 1990s in the Auckland area, and has since then been extended to include other sites in Fisheries Management Areas (FMAs) 1 and 9, adding Northland, Waikato, and Bay of Plenty sites to the survey series.

The current study provides population information for cockles and pipi at 13 sites included in the 2022–23 assessment. The survey sites in the current study were (in alphabetical order): Aotea Harbour, Cockle Bay, Eastern Beach, Grahams Beach, Hokianga Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Pataua Estuary, Waiotahe Estuary, Whangamatā Harbour, and Whangapoua Harbour. These sites represented a diverse range of intertidal sedimentary habitats, from open beaches to sheltered bays, estuaries, and large tidal inlets.

All of the northern sites contained cockle populations, which generally had relatively high abundance and density estimates. For all of the current estimates, the coefficient of variation (CV) was below the target percentage of 20%, except at Grahams Beach. At this beach, additional sampling effort did not lead to sufficient lowering of the CV below 20%. Cockle population sizes ranged from an estimated 4.42 million cockles at Grahams Beach (with a CV of 25.91%) to 303.16 million (CV: 11.48%) individuals at Pataua Estuary. The corresponding density estimates ranged from a low average of 17 cockles per m^2 also at Grahams Beach to 1206 cockles per m^2 (CV: 9.32%) at Whangamatā Harbour.

Across the 2022–23 sites, the cockle population size compositions were frequently dominated by medium-sized individuals (>15 mm and <30 mm shell length), whereas large individuals were scarce. This finding was similar to previous recent assessments of these sites, where cockle populations have usually been characterised by a unimodal cohort of medium-sized cockles. At the same time, their populations have been regularly augmented by an influx of recruits, and this size class contributed over 25% of the cockle population at the majority of sites in 2022–23.

Long-term fishing restrictions at Cockle Bay and Eastern Beach have restricted or prohibited the take of shellfish for a considerable period of time. Both sites were distinct from the remaining 2022–23 sites in supporting a comparatively large population of large cockles, which made up 20.6% and 27.8% of their current population, respectively. Nevertheless, total population estimates at Cockle Bay and Eastern Beach have undergone marked declines over the monitoring series, implicating factors other than fishing (e.g., habitat degradation) as impacting on the resident populations.

Eight of the 2022–23 survey sites contained pipi populations. At two of these sites, Grahams Beach and Waiotahe Estuary, the population estimates had high uncertainty; even with additional sampling effort, the CV values exceeded 20%. Most of the pipi populations were small, with abundance estimates ranging from 1.47 million pipi at Ōhiwa Harbour to 39.27 million individuals at Hokianga Harbour. Their population densities were similarly low, with the lowest density estimate of 56 pipi per m^2 at Whangamatā Harbour (not including Grahams Beach and Waiotahe Estuary) compared with the highest density estimates at Hokianga Harbour of 390 pipi per m^2.

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Similar to the current cockle populations, the majority of individuals within the pipi populations were in the medium size class (>20 mm and <50 mm shell length), and there were few or no pipi in the large size class at most sites. Notable exceptions were Pataua Estuary, Whangamatā Harbour, and Whangapoua Harbour, where large pipi made up at least 15% of the population. Recent recruitment to the pipi populations varied dependent on the site, with strong recruitment at Whangamatā Harbour and Hokianga Harbour, where the proportion of recruits was 25.05% and 31.40%, respectively; at Grahams Beach, 79.12% of the current pipi population consisted of recruits.

Sediment sampling in the cockle strata revealed that sediment at the northern sites was low in organic matter, at an average of less than 3% across sites. The grain size composition of the sediment varied, but consisted primarily of medium and fines sands (grain sizes >125 and >500 μm). The proportion of sediment fines (silt and clay; ≤63 μm grain size), which have the potential to impact on suspension-feeding cockles, exceeded an average of 10% at Aotea Harbour and Cockle Bay. In addition, individual samples at these two latter sites and at Hokianga Harbour, Eastern Beach, Kawakawa Bay (West), Ōhiwa Harbour, Whangamatā Harbour, and Waiotahe Estuary (greatly) exceeded 10%. Principal component analysis cockle abundance and sediment grain size fractions revealed no universal patterns for the association of total or large cockle abundance with particular grain size fractions.

In addition to survey-based estimates, the current study used geostatistical models to examine spatial patterns in predicted cockle densities over time. At all sites, except at Grahams Beach, the areas of high predicted cockle density were similar between the total population and large cockles, but the spatial extent was usually more restricted for the large cockle size class. At Grahams Beach, there have been no high-density areas throughout the survey series. Considering temporal patterns across the northern sites, there were no distinct shifts in predicted high-density areas over time, but there was an overall reduction in their spatial extent at Eastern Beach, Kawakawa Bay (West), Ōhiwa Harbour, Pataua Estuary, and Waiotahe Estuary. At Hokianga Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Whangamatā Harbour, and Whangapoua Harbour, high-density areas persisted throughout the time series.

1. INTRODUCTION

A number of marine invertebrate species in nearshore coastal environments can be considered "cultural keystone species" (*sensu* Garibaldi & Turner 2004) for their importance to human cultures for a variety of reasons. These species include bivalves which often support significant nearshore fisheries, including recreational and customary fishing activities (Barber et al. 2019). Important bivalve species in New Zealand include cockles/tuangi (*Austrovenus stutchburyi*) and pipi (*Paphies australis*), which are widely distributed throughout the country, and amongst the main target species in non-commercial fisheries.

Their often close proximity to urban centres makes cockle and pipi beds easily accessible, but also vulnerable to human activities such as over-fishing, pollution, and other forms of habitat degradation (e.g., sediment runoff). For the assessment of fishing impacts, there are currently no data available on the recreational and customary take of cockles and pipi, although there is some limited information reported in national surveys of recreational fishers that are conducted every five to six years (Wynne-Jones et al. 2019). In view of the lack of fishing data, regular monitoring of cockle and pipi beds targeted in recreational and customary fisheries provides population data that support the management of both species.

This monitoring includes the present study, which is part of the northern North Island survey series, commissioned by Fisheries New Zealand. The monitoring programme started in the early 1990s in the Auckland area, and was subsequently extended to include sites throughout Fisheries Management Areas 1 and 9. These areas encompass Auckland, Northland, Waikato, and Bay of Plenty. The annual population assessments survey (usually) 12 sites, spread across these regions. Since the 1999–2000 fishing year, the survey methods have remained largely consistent, providing time-series data for the northern sites included in the survey series. The survey data provide abundance and density estimates for each species, and also information about the population size structure. Since 2021–22, the data analysis has also included an exploration of geostatistical methods in addition to the survey-based estimates of population metrics.

In addition, sediment sampling started in 2013–14 and provides some information about the habitat quality across the northern sites, including sediment organic content and grain size composition. This data collection was restricted to cockles in 2015–16, because cockle beds are considered to be less ephemeral than pipi beds (which may also extend into subtidal areas). The sediment sampling was amended at the same time to support formal assessments of sediment properties and cockle population data. Since 2021–22, the analysis of sediment data has included principal component analysis to explore cockle abundance in relation to sediment grain size fractions.

Presented here are the findings from the 2022–23 survey that signifies the most recent assessment of cockle and pipi in the northern North Island monitoring series. There were 13 sites in the current assessment (in alphabetical order): Aotea Harbour, Cockle Bay, Eastern Beach, Grahams Beach, Hokianga Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Pataua Estuary, Waiotahe Estuary, Whangamatā Harbour, and Whangapoua Harbour (Figure 1).

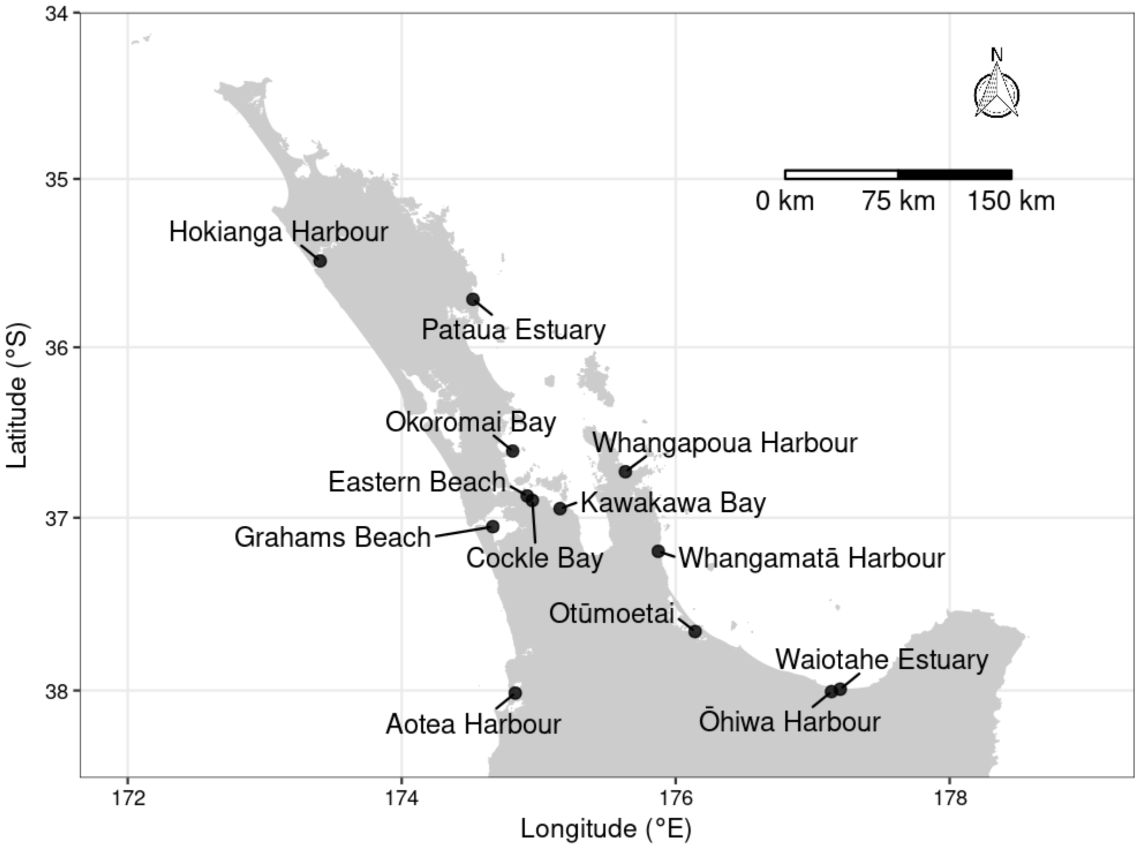


Figure 1: Sites included in the northern North Island intertidal bivalve survey in 2022–23.

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 13 northern North Island sites was conducted in February and March 2023. During this period, bivalve populations at each site were sampled during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

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

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

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

2.3 Field sampling – sediment

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

The grain size analysis was based on wet sieving to ascertain the proportion of different size classes, ranging from sediment fines (silt and clay, $\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 $\pm$ 0.0001 g).

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

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

2.4 Data analysis – bivalves

2.4.1 Survey-based population estimates

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.4.2 Model-based population estimates

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

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

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

Based on the initial 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 2022–23 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 2022–23.

3. RESULTS

3.1 Aotea Harbour

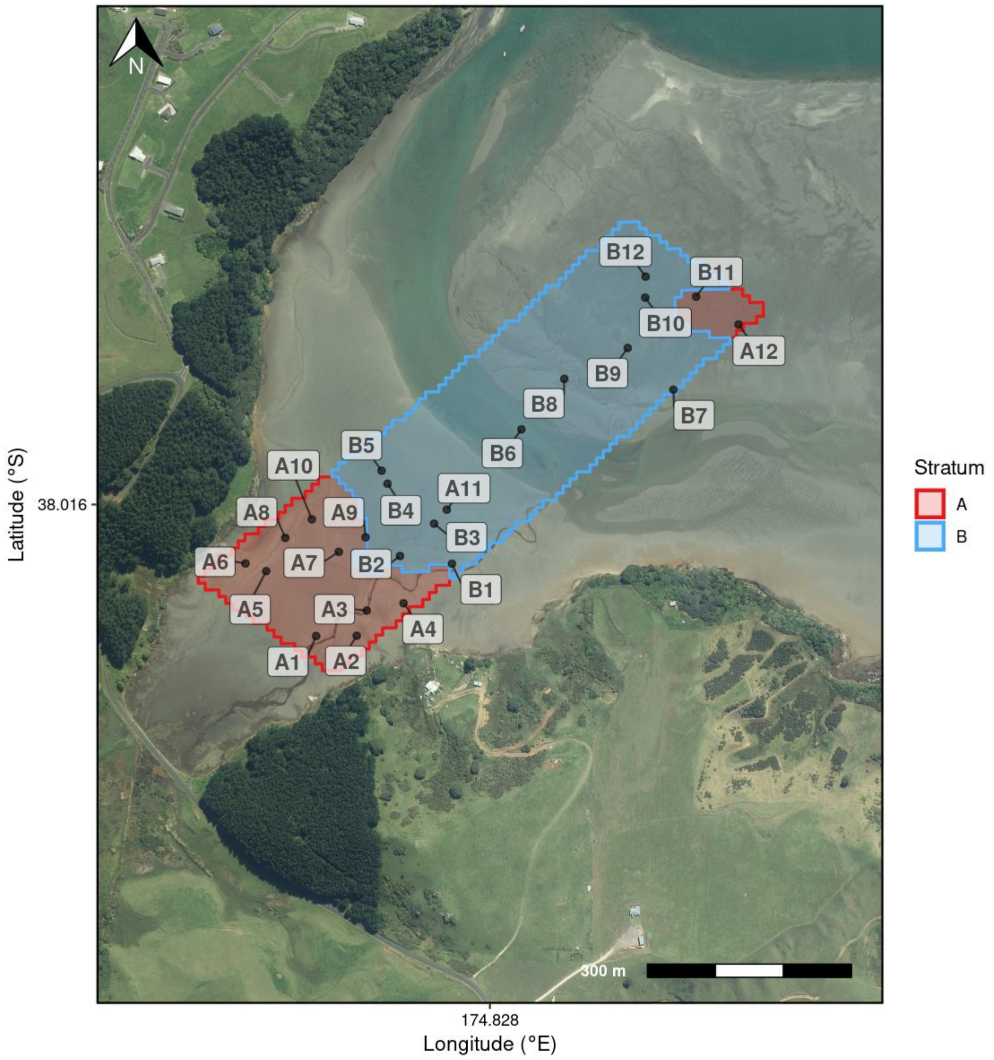
Aotea Harbour is a relatively large inlet on the Waikato west coast. It was first included in the survey series in 2005–06, and the immediately preceding survey was in 2020–21 (see Appendix A, Tables A-1, A-2). Since 2014–15, the sampling extent has been an intertidal mudflat in the southern part of the harbour, which supports a cockle bed across a tidal side channel. Within this sampling extent, the 2022–23 survey sampled cockles in a total of 90 points across two strata.

Sediment characteristics at this site indicated a low organic content of less than 4%, with fine sand (grain size >125 µm) forming the dominant sediment grain size fraction (Figure 2, and see details in Appendix B, Table B-1). There was a variable proportion of sediment fines (grain size ≤ 63 µm) across samples, ranging from 4 to 24%, with most samples containing more than 10% of sediment in this grain size fraction.

There were few cockles in the upper intertidal zone, and their distribution was relatively even throughout most of the remaining sampling extent (Figure 3, Table 1). Their estimated total abundance was 88.00 million (CV: 8.23%) cockles in 2022–23, and their population density was 454 cockles per m^2 (Table 2). Although these estimates were lower than the preceding estimates in 2020–21 (99.69 million (CV: 9.44%) cockles, and 514 individuals per m^2), they were consistent with a relatively stable population in recent assessments. At the same time, the population generally lacked large cockles (≥ 30 mm shell length), and their current and previous estimates (i.e., since 2014–15) had considerable uncertainty (CV $>30\%$).

In recent assessments, both the population estimates and size structure were largely determined by medium-sized cockles, with a notable contribution from recruits (≤ 15 mm shell length) (Table 3, Figure 4). The latter size class contributed a quarter of the population in recent surveys (e.g., 25.78% in 2022–23). Their influence was also evident in the population size structure: although the unimodal population was largely determined by medium-sized individuals, mean and modal sizes were around 18 to 20 mm shell length in the three most recent surveys.

Relating cockle abundance to sediment grain size fractions showed a general pattern of low total abundance associated with sediment fines (Figure 5). This pattern was consistent across surveys.



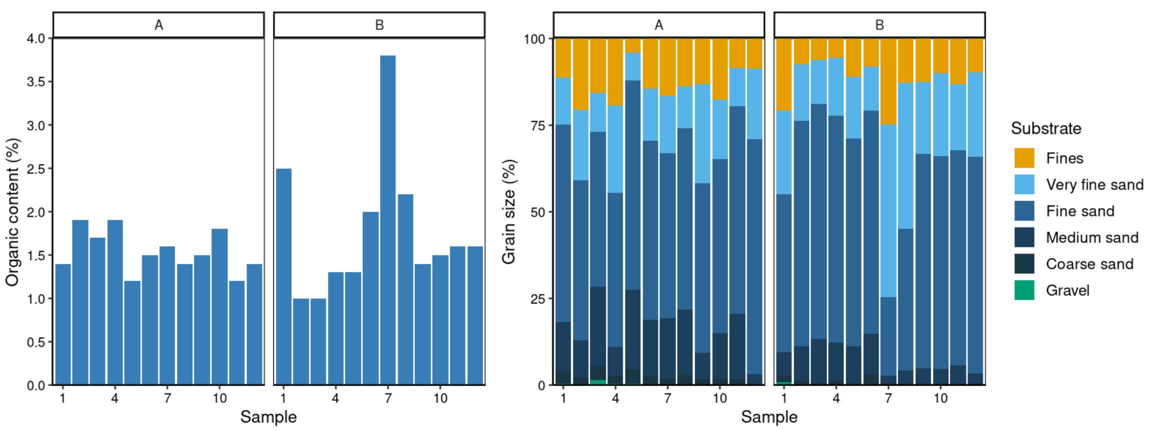


Figure 2: Sediment sample locations and characteristics at Aotea Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.1.1 Cockles at Aotea Harbour

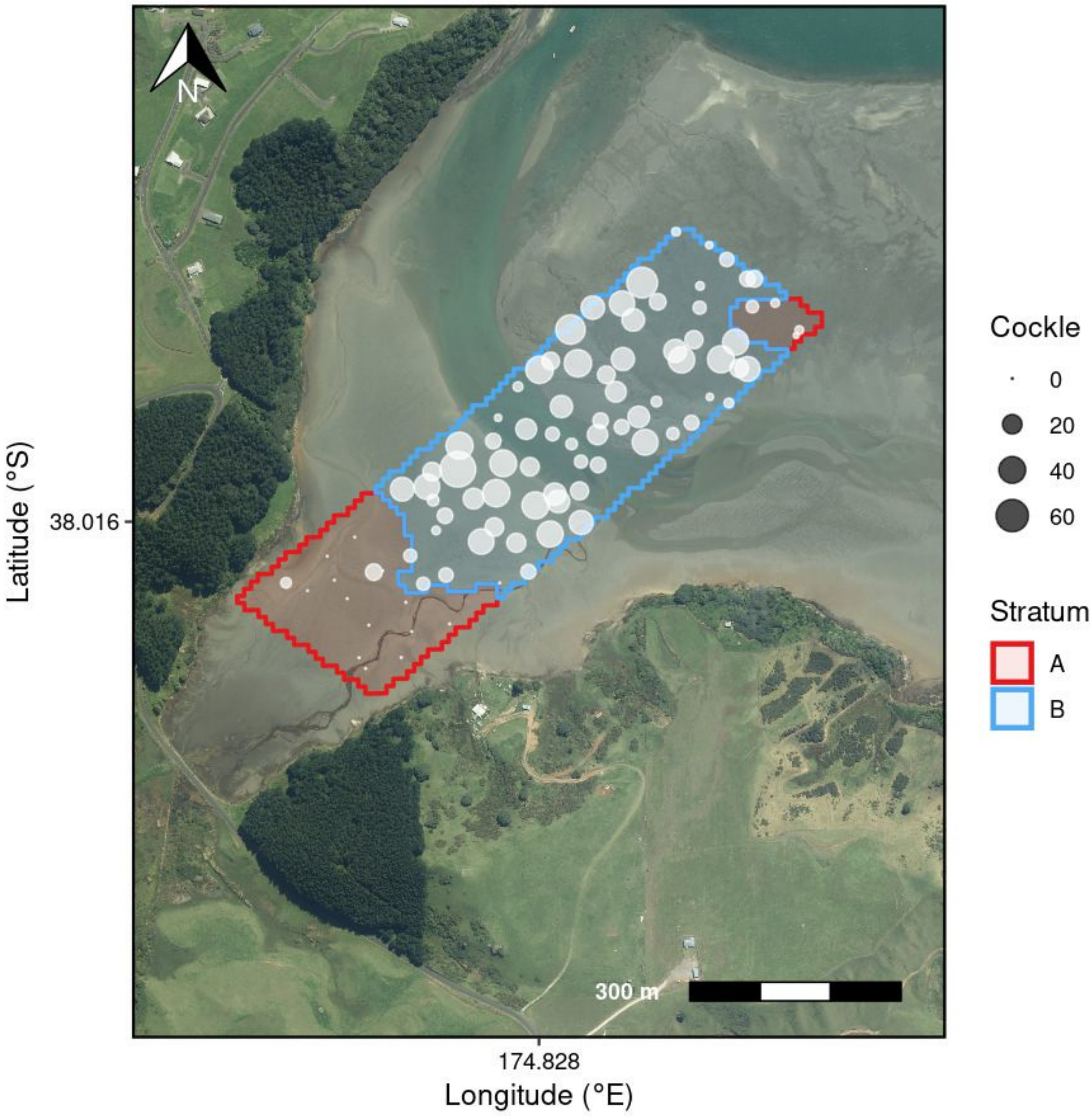


Figure 3: Map of sample strata and individual sample locations for cockles at Aotea Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 1: Estimates of cockle abundance at Aotea Harbour, by stratum, for 2022–23. 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	5.7	20	41	3.33	59	41.04
B	13.7	70	1 513	84.67	618	8.39

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2005–06	9.6	30.25	315	4.98	1.18	12	17.18
2009–10	28.1	140.78	501	10.54	3.46	12	27.88
2014–15	19.5	74.20	381	13.37	0.55	3	45.13
2016–17	19.5	76.41	393	11.05	0.00	0	
2018–19	19.5	82.34	423	11.06	0.96	5	32.86
2020–21	19.4	99.69	514	9.44	0.60	3	53.20
2022–23	19.4	88.00	454	8.23	0.56	3	38.63

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Aotea 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	18.64	20	5–34	22.44	1.17
2020–21	18.48	20	6–33	24.79	0.60
2022–23	18.26	17	5–34	25.78	0.64

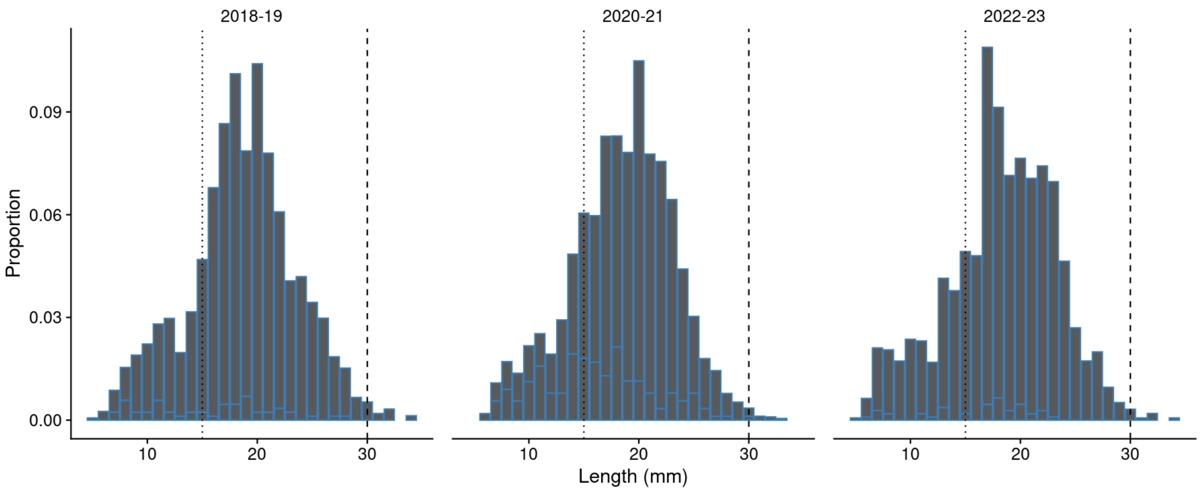


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Aotea Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

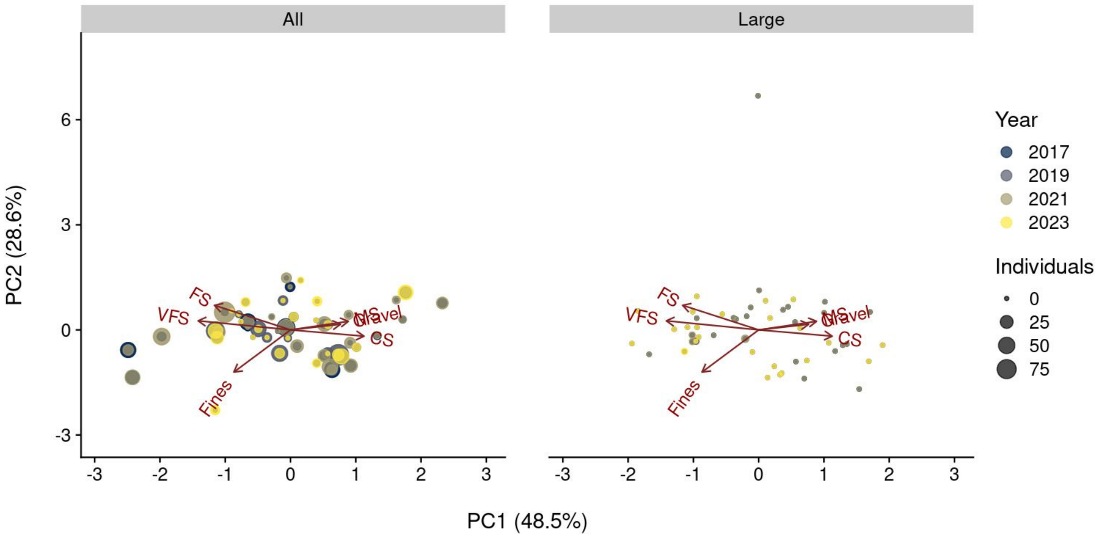


Figure 5: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Aotea Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm,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

3.2 Cockle Bay

Cockle Bay/Tūwakamana is a small beach in Hauraki Gulf, situated on Auckland's south-east coast. The take of shellfish at this beach has been restricted since 2008, first with a seasonal (summer) closure, followed by a year-round closure in 2021 (Department of Internal Affairs 2008, 2021). There have been nine surveys at this beach since 2009–10, including the present assessment (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has remained the same at this site. The current survey was based on 80 sampling points across four strata.

The sediment organic content at this beach ranged from 1.1 to 5.7% (Figure 6, and see details in Appendix B, Table B-1). Most of the sediment consisted of fine sand (grain size >125-μm), followed by very fine sand (grain size >63 μm). There was considerable variation in the proportion of sediment fines (grain size ≤63 μm), with four samples containing a considerable proportion (up to 69.4%) of sediment in this grain size fraction.

The cockle population at this beach was primarily distributed throughout the upper to mid-intertidal zone (Figure 7, Table 4). Current population estimates based on the field sampling included a total abundance of 32.28 million (CV: 16.54%) cockles, and an estimated density of 205 individuals per m^2 (Table 5). These estimates signified small decreases in abundance and density estimates since the preceding survey in 2021–22. Over the same period, there was an increase in the population of large cockles (≥30 mm shell length), from an estimated 4.99 million (CV: 15.57%) large individuals in 2021–22 to 6.65 million (CV: 45.02%) large individuals in the current survey. The corresponding increase in density over this period was from 32 large cockles per m^2 to 42 large individuals per m^2 in the current study.

The increase in large cockles was also reflected in their larger proportion of 20.60% of the total population in 2022–23 compared with 14.44% in 2021–22 (Table 6). In addition, there was an increase in the proportion of recruits (≤15 mm shell length) between 2021–22 and 2022–23, from 11.13% to 24.15% of recruits in the current population. The increases in both recruits and large cockles meant that mean and modal sizes remained similar to sizes in the two preceding surveys, at shell lengths of 22.08 mm and 15 mm, respectively.

The length-frequency distributions reflected changes in population size structure, with a comparatively smaller cohort of medium-sized cockles in 2022–23, and a small second cohort of large cockles; recruits contributed to the former cohort (Figure 8). The findings highlighted that a proportion of medium-sized cockles grew to larger sizes, exceeding the 30-mm threshold of the large size class. At the same time, there was a notable recruitment event that resulted in an increase in the recruits size class.

The PCA of cockle abundance and sediment grain size indicated comparatively higher total cockle abundances associated with medium to fine sands, compared with gravel across surveys (Figure 9). These grain size fractions were distinguished by PC1, which explained 46% of the variance in 2022–23. Similarly, large cockles were mostly associated with these same sand fractions. Considering sediment fines, there were fewer cockles and fewer large cockles associated with this grain size fraction, with PC2 explaining 24.6% of the variance in the current data.

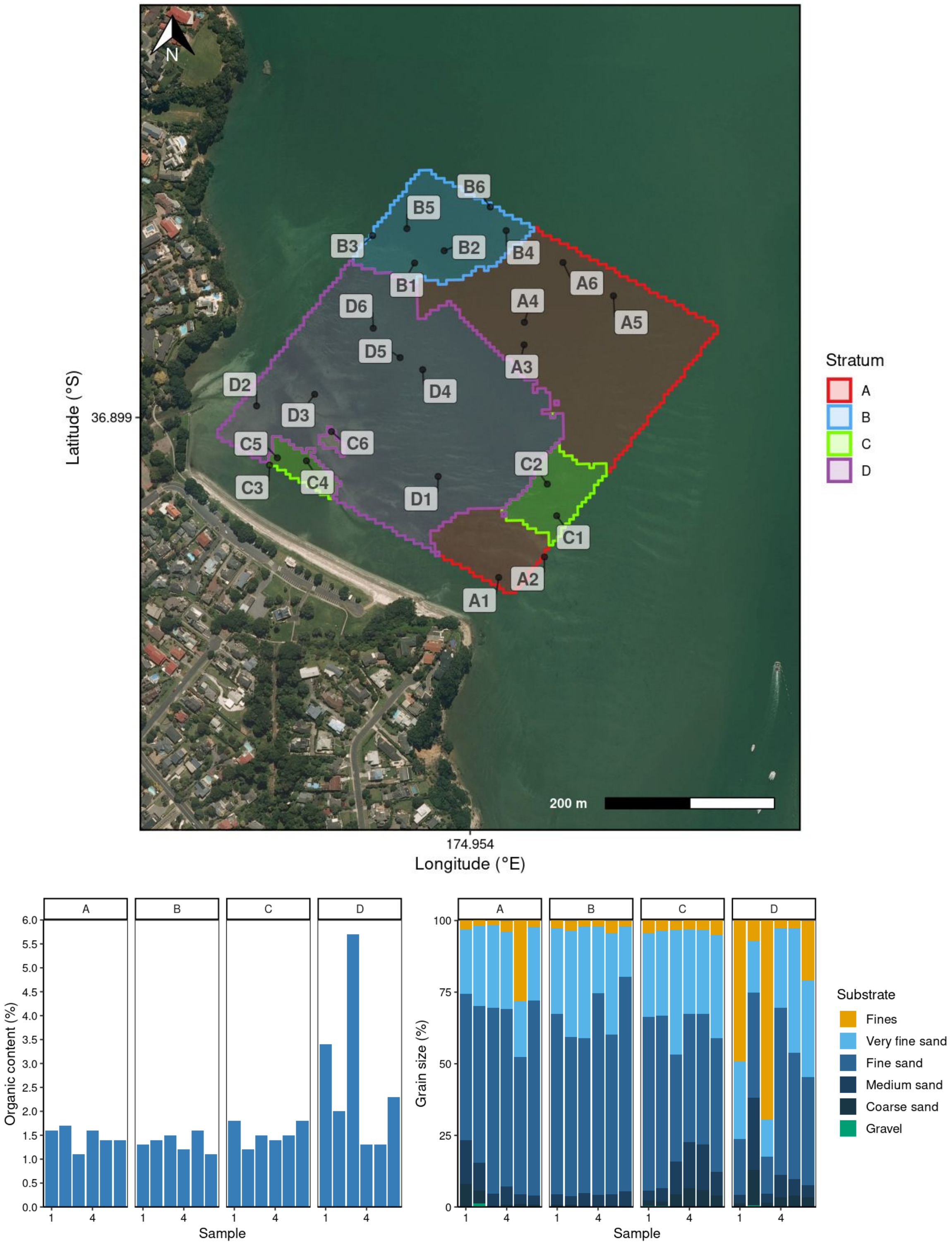


Figure 6: Sediment sample locations and characteristics at Cockle Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.2.1 Cockles at Cockle Bay

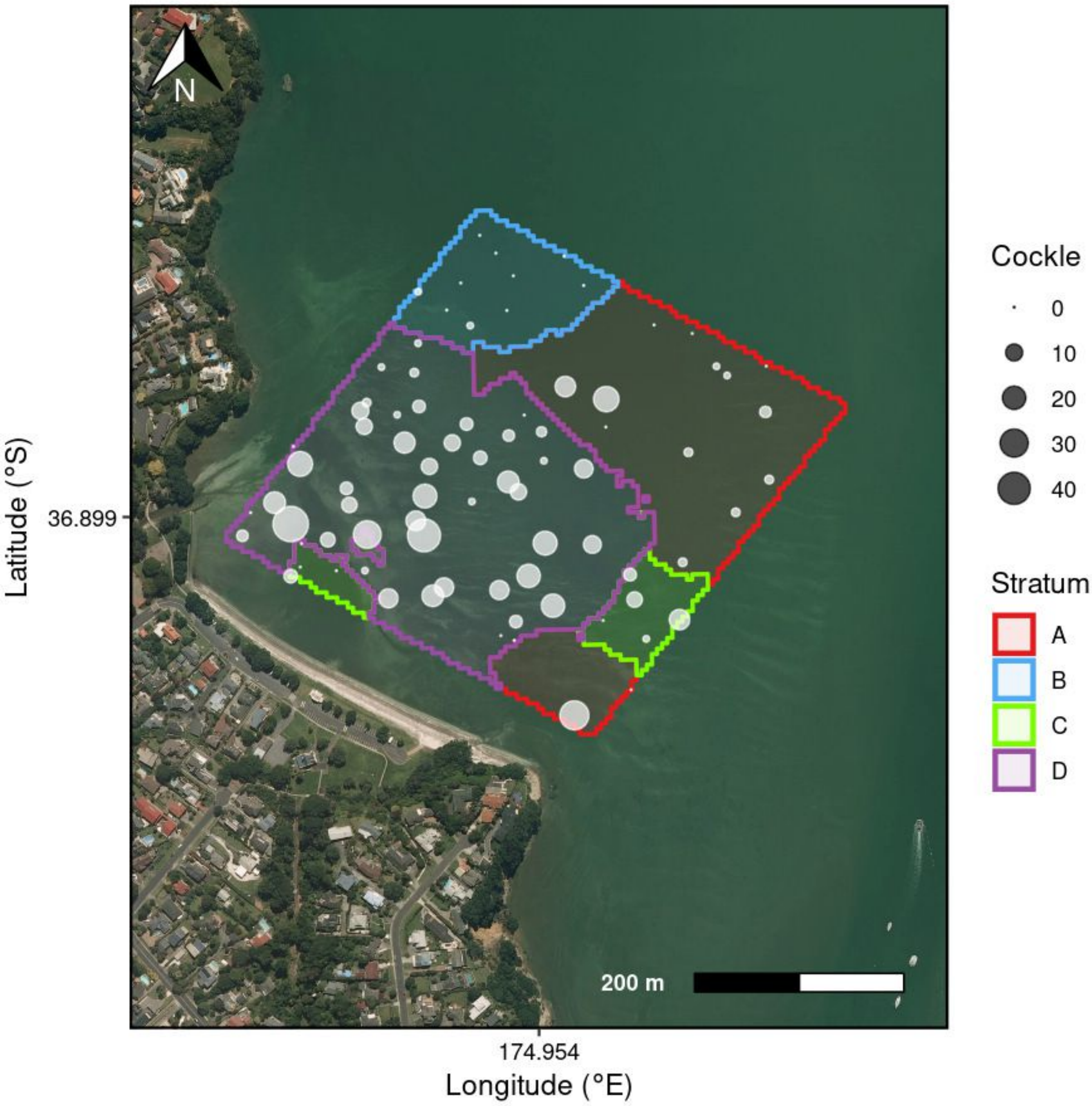


Figure 7: Map of sample strata and individual sample locations for cockles at Cockle Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 4: Estimates of cockle abundance at Cockle Bay, by stratum, for 2022–23. 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	5.6	15	85	9.05	162	45.19
B	1.7	10	2	0.10	6	66.67
C	1.0	10	64	1.86	183	46.07
D	7.5	45	447	21.26	284	15.60

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	16.0	59.54	372	5.60	6.27	39	12.48
2010–11	16.0	72.20	451	5.61	21.29	133	8.15
2012–13	16.0	54.67	342	7.51	36.46	228	8.78
2013–14	15.8	33.68	214	8.14	21.02	133	9.50
2015–16	15.8	21.46	136	8.48	15.37	98	10.77
2017–18	15.8	43.37	275	11.62	17.48	111	13.87
2019–20	15.8	44.41	282	13.84	11.75	75	15.81
2021–22	15.6	34.58	222	14.93	4.99	32	15.57
2022–23	15.8	32.28	205	16.54	6.65	42	45.02

Table 6: Summary statistics of the length-frequency (LF) distribution of cockles at Cockle 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 (%)
2019–20	23.58	18	5–47	12.27	26.46
2021–22	22.77	17	7–39	11.13	14.44
2022–23	22.08	15	6–46	24.15	20.60

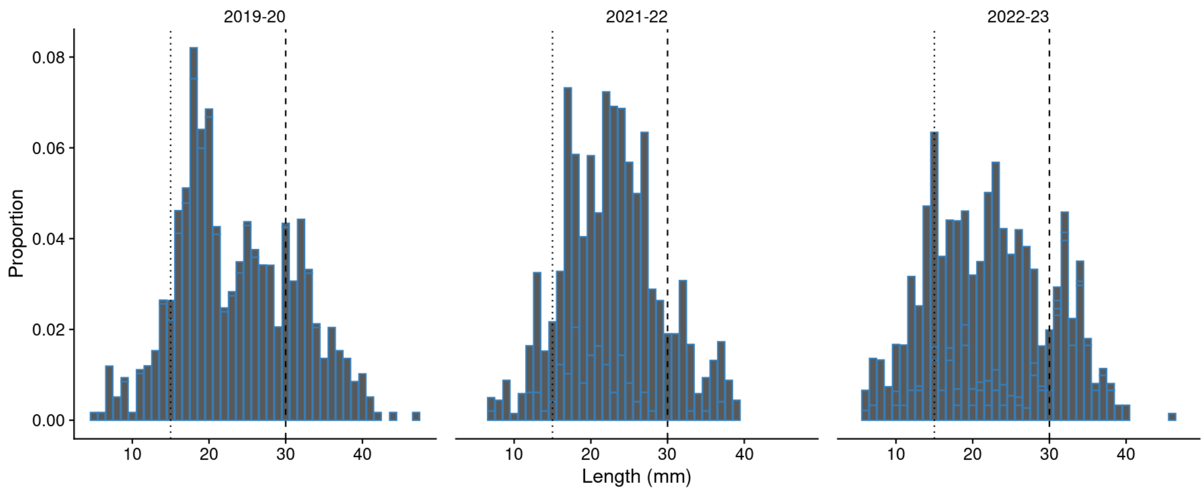


Figure 8: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

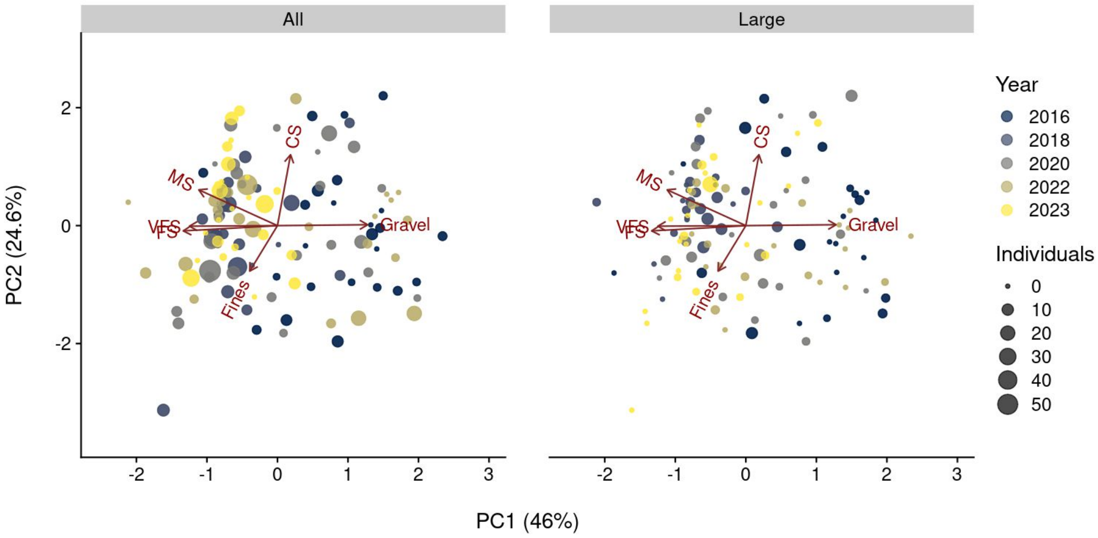


Figure 9: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Cockle Bay. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.3 Eastern Beach

Eastern Beach is in east Auckland and part of the Hauraki Gulf coastline. Shellfish collections at this beach have been prohibited since 1994 (Department of Internal Affairs 1994, 1995). There have been six bivalve surveys at Eastern Beach since 1999–2000, and the immediately preceding survey was in 2019–20 (see Appendix A, Tables A-1, A-2). The sampling extent across the beach has remained the same since 2016–17, and the current field survey included two strata and a total of 80 sampling points.

The sediment at Eastern Beach had a low organic content ($<$4%) and was characterised by fine sand (grain size $>$125 µm), followed by very fine sand (grain size $>$63 µm) (Figure 10, and see details in Appendix B, Table B-1). Most samples contained a small proportion of sediment fines (grain size $\leq$63 µm), except for two samples, where this grain size fraction made up 15.4 and 42.1% of the sediment, respectively.

The cockle distribution extended along most of the beach, but was generally patchy, with few cockles at the northern end, in stratum B (Figure 11, Table 7). The current cockle abundance and density estimates were a marked (over 50%) reduction from the preceding population estimates in 2019–20: the estimated total abundance in 2022–23 was 43.24 million (CV: 15.43%) cockles, compared with 117.16 million (CV: 12.98%) cockles in 2019–20 (Table 8). Similarly, the current density estimate was 193 cockles per m^2, compared with 519 cockles per m^2 in the preceding survey. The population of large cockles ($\geq$30 mm shell length) underwent a smaller decrease, with an abundance estimate of 12.02 million (CV: 23.77%) cockles in 2022–23, and a density estimate of 54 large cockles per m^2, declining from the preceding abundance estimate of 17.49 million (CV: 20.74%) large cockles and density estimate of 77 large cockles per m^2 in 2019–20.

This size class made up 27.80% of the population in 2022–23, indicating that the observed population decrease was predominantly caused by the decline of medium-sized cockles (Table 9). Recruits ($\leq$15 mm shell length) were a minor proportion (1.57%) of the cockle population, and recruitment at this site was also low in the two preceding surveys. The influence of large cockles was reflected in mean and modal sizes that both showed a 4-mm increase to 27 mm shell length in 2022–23. The population size structure remained unimodal, but showed a distinct shift towards large-size individuals in the three most recent surveys (Figure 12).

The PCA analysis illustrated a general pattern of higher cockle abundance associated with finer grain size fractions, excepting sediment fines (Figure 13). This pattern was also present in the PCA of large cockle abundance.

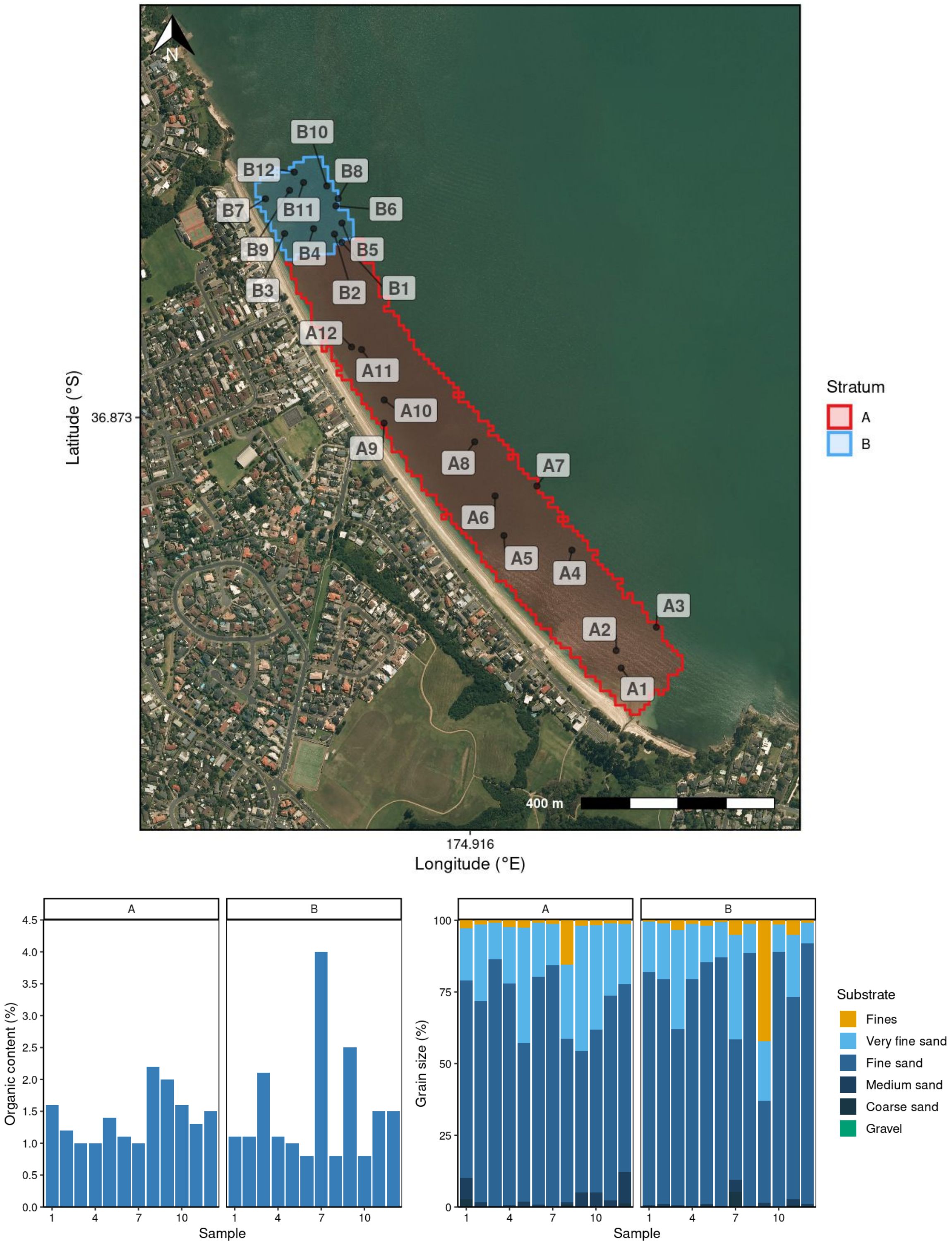


Figure 10: Sediment sample locations and characteristics at Eastern Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.3.1 Cockles at Eastern Beach

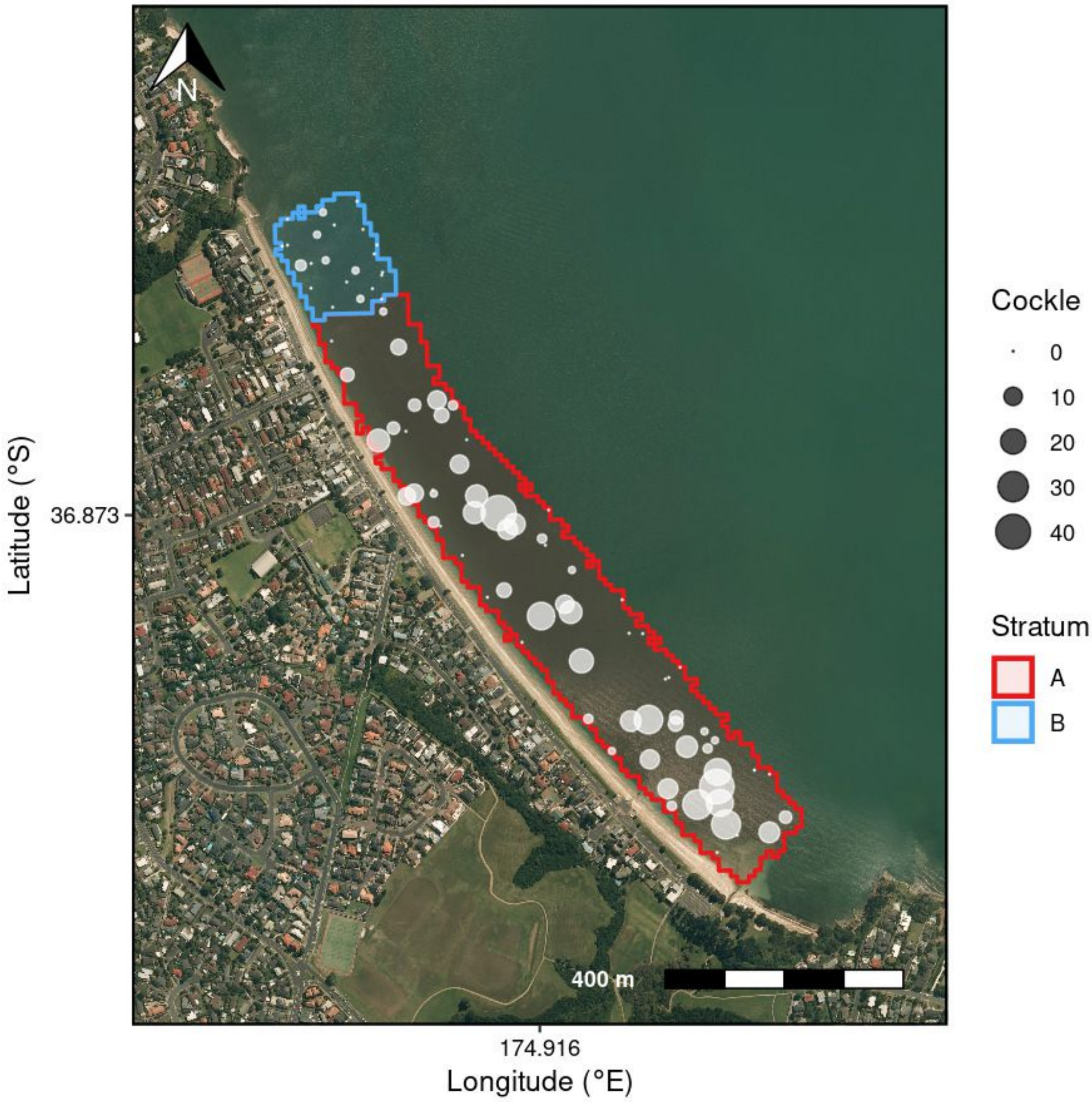


Figure 11: Map of sample strata and individual sample locations for cockles at Eastern Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 7: Estimates of cockle abundance at Eastern Beach, by stratum, for 2022–23. 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	19.6	60	461	42.96	220	15.53
B	2.8	20	7	0.28	10	47.61

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	48.0	6.39	13	17.17	0.00	0	
2001–02	43.4	13.07	30	17.58	3.00	7	29.93
2014–15	41.4	28.16	68	16.59	12.84	31	26.54
2016–17	22.6	176.91	784	13.05	15.07	67	17.38
2019–20	22.6	117.16	519	12.98	17.49	77	20.74
2022–23	22.4	43.24	193	15.43	12.02	54	23.77

Table 9: Summary statistics of the length-frequency (LF) distribution of cockles at Eastern 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 (%)
2016–17	21.54	17	8–42	7.66	8.52
2019–20	23.88	22	10–40	3.98	14.93
2022–23	27.01	27	7–38	1.57	27.80

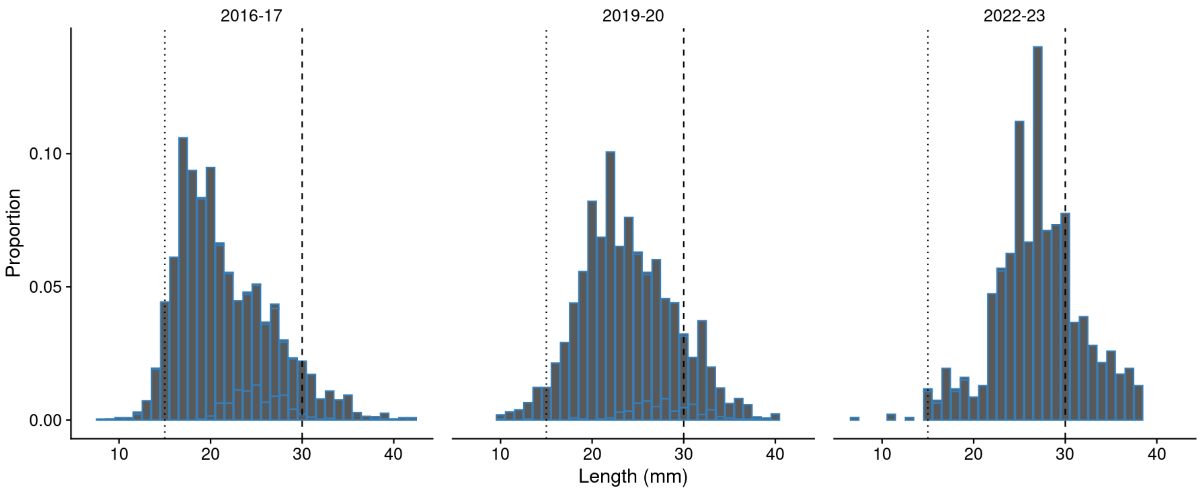


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Eastern Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

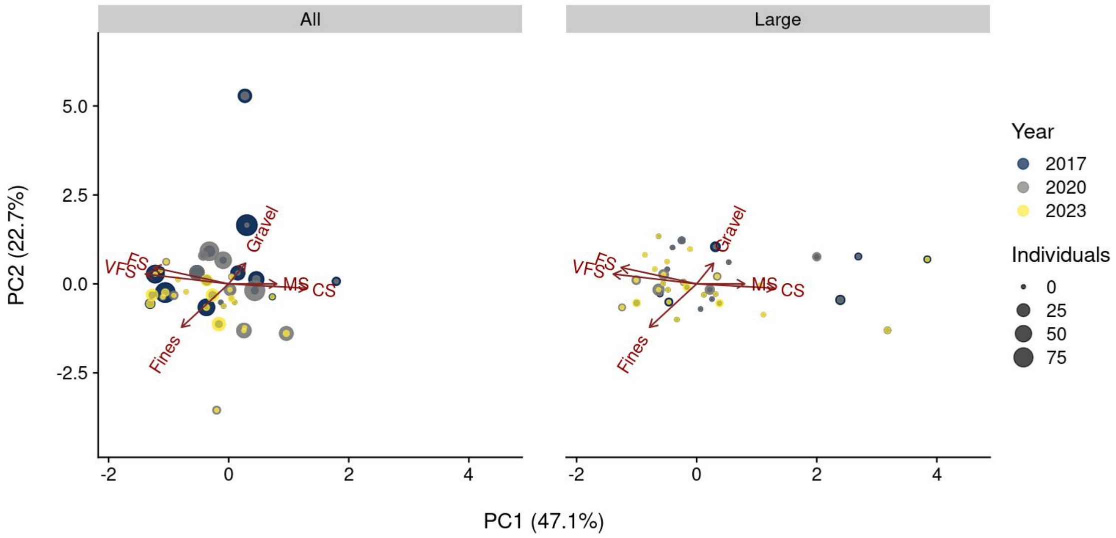


Figure 13: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Eastern Beach. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, 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.

3.4 Grahams Beach

Grahams Beach is in the western Auckland area, close to the entrance of Manukau Harbour on Āwhitu Peninsula. Starting in 2010–11, there have been six bivalve assessments at this beach, including the current survey (see Appendix A, Tables A-1, A-2). The sampling extent has remained largely consistent throughout the monitoring series, and encompasses the intertidal area along the length of the beach. The 2022–23 sampling extent was split into three strata and contained a total of 99 points, including nine phase-2 sampling points.

The sediment at Grahams Beach contained less than 2% organics, and mostly consisted of a combination of fine, medium, and coarse sands (grain sizes $>$125 to $>$500 µm) (see details in Appendix B, Table B-1). The proportion of sediment fines (grain size $\leq$63 µm) was generally less than 1%, but exceeded 7% in one sample.

The distribution of cockles at Grahams Beach was patchy, and restricted to few areas of the intertidal sampling extent (Figure 15, Table 10). The sampling returned 55 cockles, and the corresponding population estimates of 4.42 million cockles and 17 cockles per m^2 had a high CV of 25.91% (Table 11). The current estimates signified a population reduction of over 50% since the previous survey in 2019–20. There were no large cockles ($\geq$30 mm shell length) at Grahams Beach, and this finding was consistent with previous surveys.

Considering the population size structure, most cockles in the present assessment were of medium sizes, with 24.08% of the population consisting of recruits less than 15 mm in shell length (Table 12, Figure 16). In the two preceding surveys, recruits dominated the population at this site, with over 80% of individuals in this size class. Their current reduction explained the population decline and also led to a shift in the unimodal population size structure towards the medium size class, with mean and modal sizes at 17.81 mm and 19 mm shell length, respectively.

Cockle abundance data in relation to sediment grain size fractions showed an association with very fine and fine sands, with PC1 explaining 46.9% of the variance in the current survey year (Figure 17).

Similar to the cockle population, there were few pipi at Grahams Beach, and only 53 pipi were sampled (Figure 18, Table 13). Most of these pipi were in the upper intertidal area. Their abundance and density estimates were 4.51 million pipi, and 17 individuals per m^2 (Table 14). Because of the small sample size, these population estimates had considerable uncertainty, with a CV of 32.09%. Pipi population estimates at this site had consistently high CV values throughout the survey series.

Since the start of the monitoring, there have been few or no large pipi ($\geq$50 mm shell length) in the population, which has been largely determined by recruits ($\leq$20 mm shell length) (Table 15, Figure 19). Both mean and modal sizes have been consistently below the 20-mm cut-off for this size class, with current mean and modal shell lengths of 14.53 mm and 9 mm, respectively. While strong recruitment events regularly determine the pipi population at Grahams Beach, recruits fail to grow to larger sizes or to become established over time.

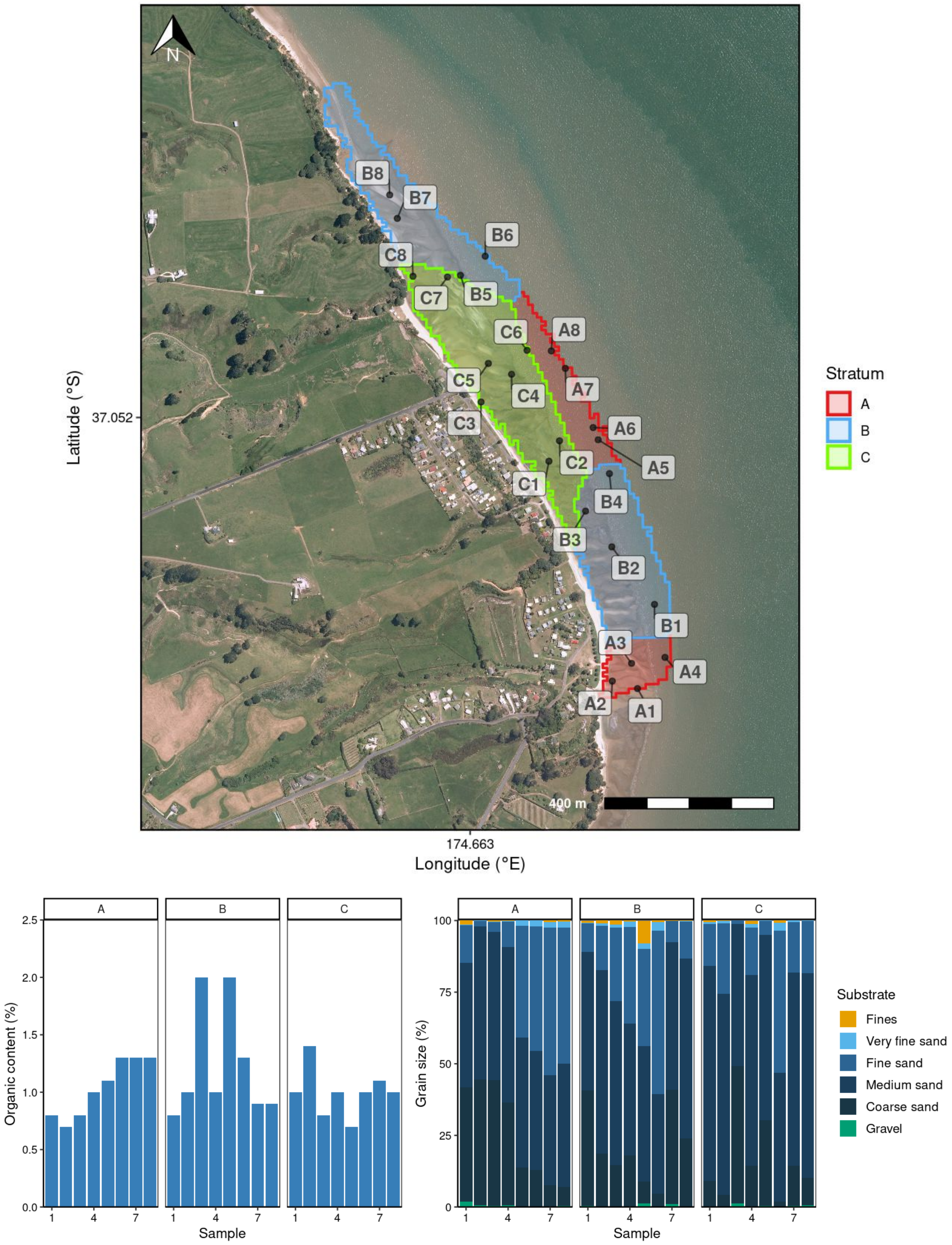


Figure 14: Sediment sample locations and characteristics at Grahams Beach. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.4.1 Cockles at Grahams Beach

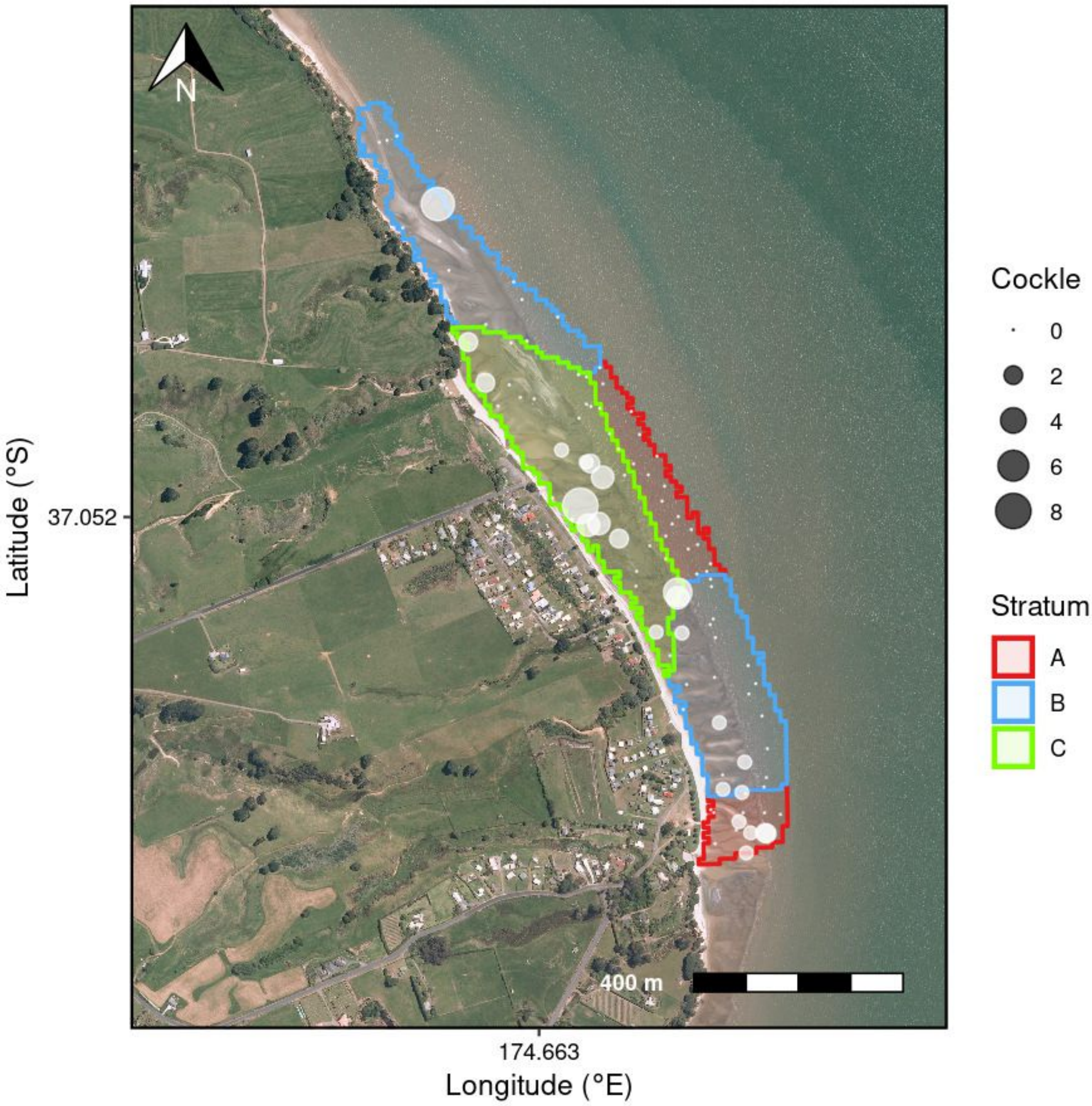


Figure 15: Map of sample strata and individual sample locations for cockles at Grahams Beach, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 10: Estimates of cockle abundance at Grahams Beach, by stratum, for 2022–23. 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	4.7	33	8	0.33	7	40.26
B	12.4	33	11	1.18	10	64.84
C	9.3	33	36	2.91	31	28.87

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2010–11	25.1	25.22	100	20.39	0.02	<1	>100
2012–13	20.1	4.23	21	21.00	0.00	0	
2013–14	26.8	4.70	18	19.10	0.12	<1	>100
2016–17	26.8	17.09	64	21.82	0.00	0	
2019–20	26.8	11.40	43	19.89	0.00	0	
2022–23	26.5	4.42	17	25.91	0.00	0	

Table 12: Summary statistics of the length-frequency (LF) distribution of cockles at Grahams 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 (%)
2016–17	11.13	9	5–25	84.33	0.00
2019–20	10.86	9	4–26	87.19	0.00
2022–23	17.81	19	7–26	24.08	0.00

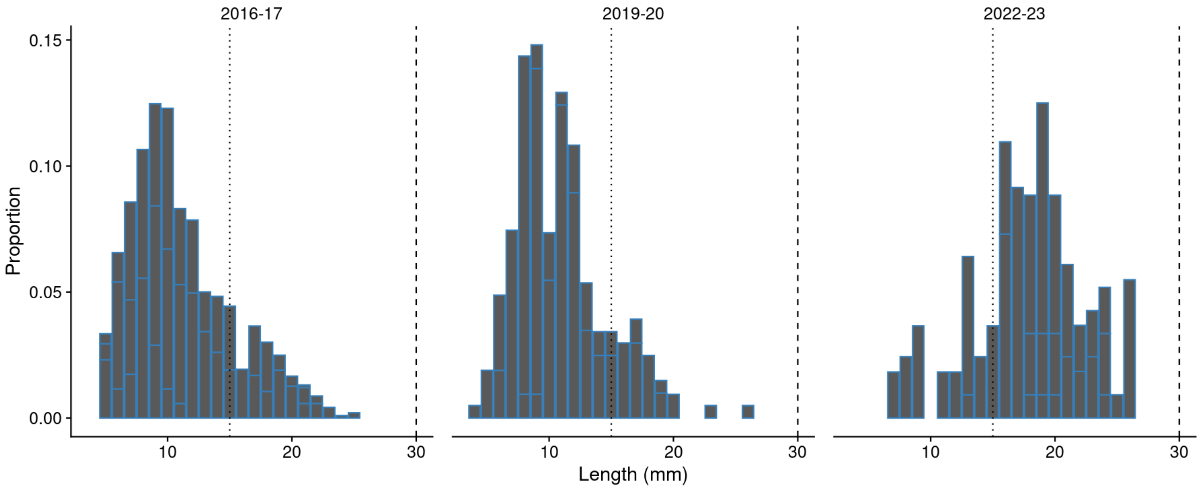


Figure 16: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

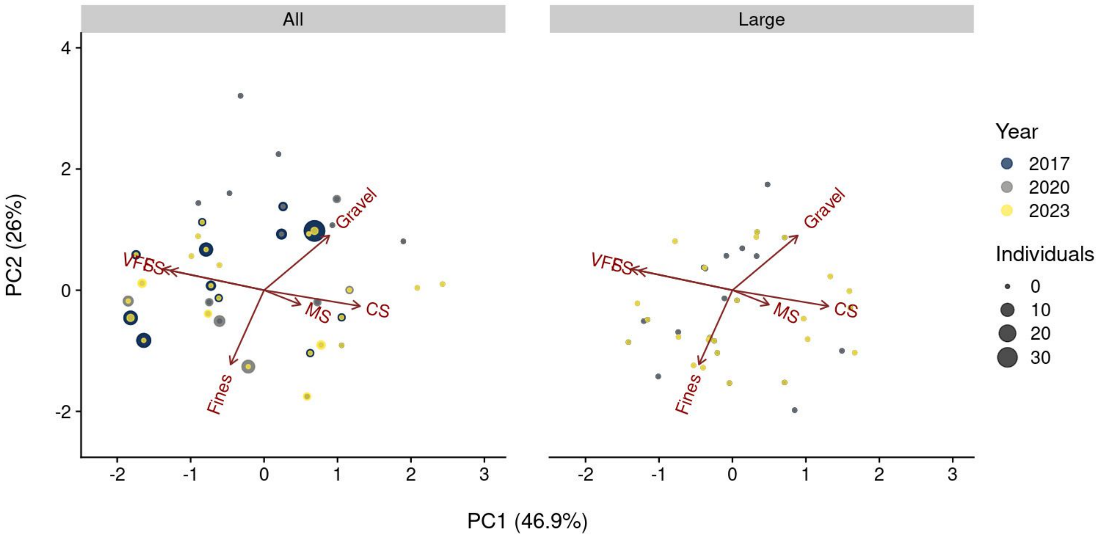


Figure 17: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Grahams Beach. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm,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

3.4.2 Pipi at Grahams Beach

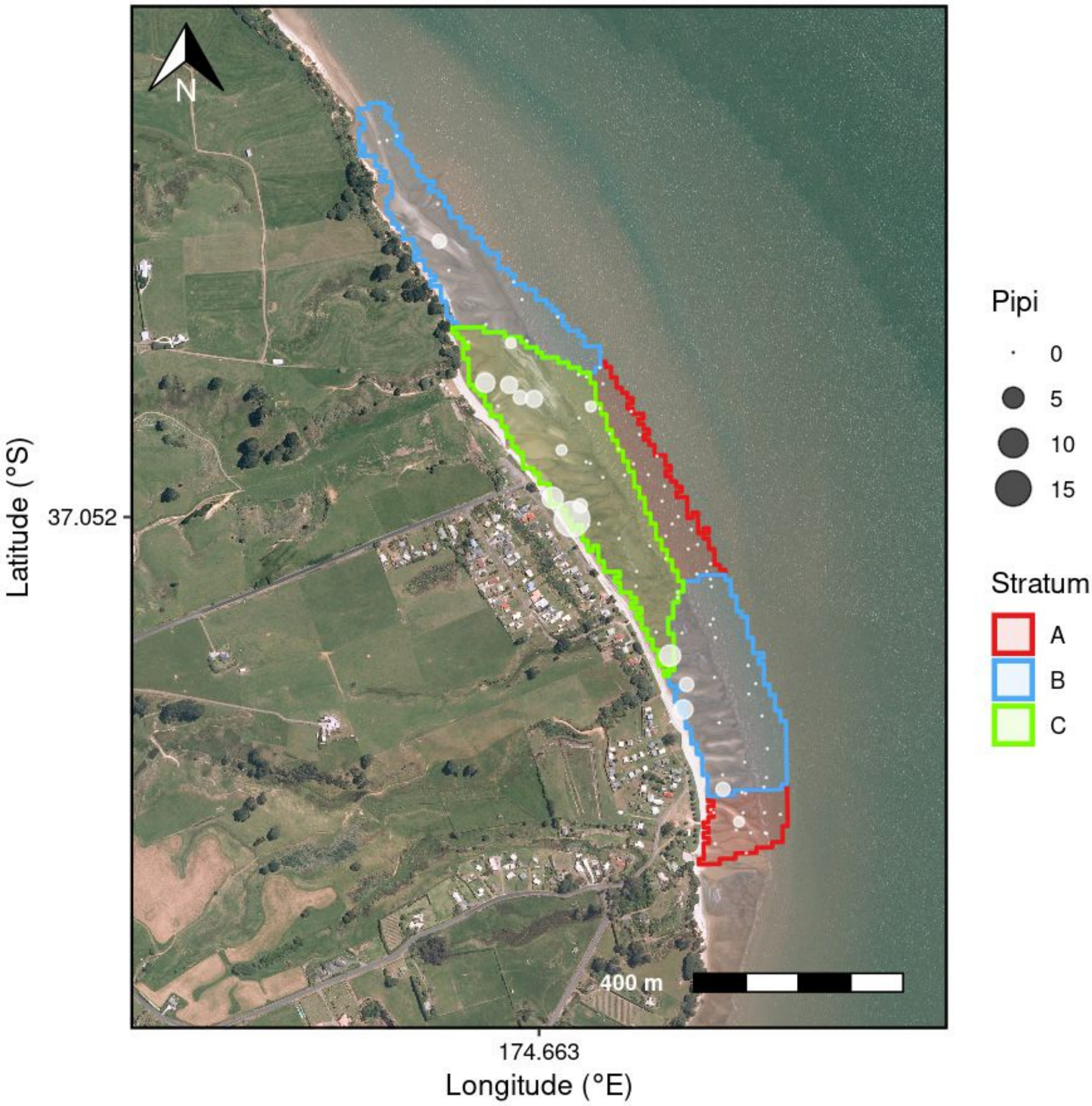


Figure 18: Map of sample strata and individual sample locations for pipi at Grahams Beach, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 13: Estimates of pipi abundance at Grahams Beach, by stratum, for 2022–23. 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	4.7	33	1	0.04	<1	>100
B	12.4	33	10	1.07	9	50.74
C	9.3	33	42	3.39	36	39.47

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2010–11	25.1	3.75	15	27.65	0.00	0	
2012–13	20.1	2.93	15	35.01	0.00	0	
2013–14	26.8	12.34	46	21.63	0.06	<1	>100
2016–17	26.8	8.77	33	25.66	0.00	0	
2019–20	26.8	4.21	16	23.21	0.34	1	48.11
2022–23	26.5	4.51	17	32.09	0.00	0	

Table 15: Summary statistics of the length-frequency (LF) distribution of pipi at Grahams 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 (%)
2016–17	13.93	8	2–48	81.21	0.00
2019–20	25.30	9	6–56	51.56	8.07
2022–23	14.53	9	6–32	79.12	0.00

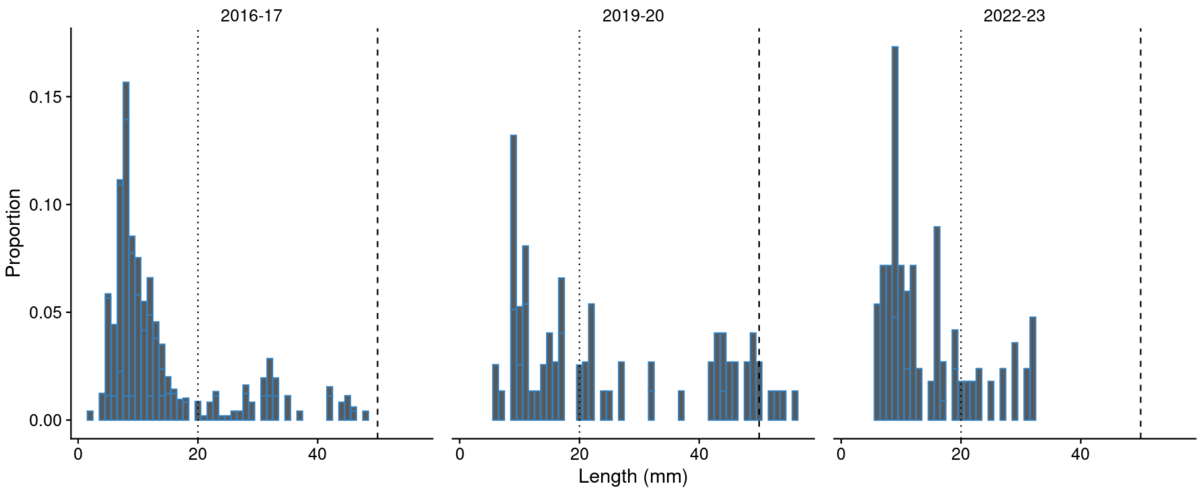


Figure 19: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Grahams Beach. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Hokianga Harbour

Hokianga Harbour is on the west coast of northern Northland. The harbour was first included in the northern survey series in 2018–19, and the current assessment was the second survey of cockles and pipi at this site (see Appendix A, Tables A-1, A-2). The sampling extent was the same in both surveys, including a cockle and a pipi bed at Pākanae, and a pipi bed at Koutou. In 2022–23, these three strata were surveyed in a total of 110 sampling points.

The sediment sampling in the cockle bed documented sediment that was low in organic content, which varied between 1.5 and 4.0% (Figure 20, and see details in Appendix B, Table B-1). Most of the sediment consisted of medium and fine sands (grain sizes >125 µm and >250 µm). The proportion of sediment fines (grain size ≤63 µm) was generally low, but exceeded 10% in four samples, with one sample containing 23.7% of sediment in this grain size fraction. At the same time, there was a notable proportion of gravel in most samples.

The cockle bed was in a small area at Pākanae, in stratum B, and individuals of this species were also sampled in the other strata (Figure 21, Table 16). Their total population estimate in 2022–23 was 27.19 million (CV: 12.89%) cockles, which was a slight increase from 25.54 million (CV: 11.88%) cockles in the previous survey (Table 17). Similarly, density estimates also showed an increase, from 254 cockles per m^2 in 2018–19 to 270 cockles per m^2 in this assessment. The population supported few large cockles (≥30 mm shell length), and their population estimates had an associated CV exceeding 50%.

Most of the Hokianga Harbour population were medium-sized cockles, while recruits (≤15 mm shell length) also contributed a marked proportion of individuals; in 2022–23, the latter size class contributed 26.33% of all individuals, and formed a distinct, albeit small, second cohort in the previously unimodal population (Table 18, Figure 22). Mean and modal sizes were just above the 15-mm cut-off for the recruits size class at around 17 mm shell length, further highlighting the influence of the recruits size class.

The PCA of cockle abundance and sediment grain size composition did not reveal a distinct pattern: total cockle abundance was associated with all sediment grain size fractions except gravel (Figure 23).

Pipi in Hokianga Harbour were also distributed across all strata, but were most prevalent in stratum A (at Pākanae) and stratum C (at Koutou) (Figure 24, Table 19). The current population estimates for this species indicated a marked (over 50%) decrease in the population, with the current estimates including a total of 39.27 million (CV: 14.37%) pipi, and an estimate mean density of 390 pipi per m^2 (Table 20). The preceding estimates in 2018–19 were 87.39 million (CV: 10.87%) pipi, occurring at a mean density of 868 pipi per m^2. There were no large pipi (≥50 mm shell length) at Hokianga Harbour in either survey.

The size composition of the pipi population at this site was determined by medium-sized pipi and also by recruits (≤20 mm shell length) (Table 21, Figure 25). The latter size class made up over 30% of the current population, which was consistent with findings in the previous survey. Within the medium size class, some of the pipi grew to larger sizes, leading to a change from a unimodal to a bimodal population in 2022–23. This change was also reflected in a slight (1 to 2 mm) increase in mean and modal sizes to 25.06 mm and 24 mm shell length in the current assessment.

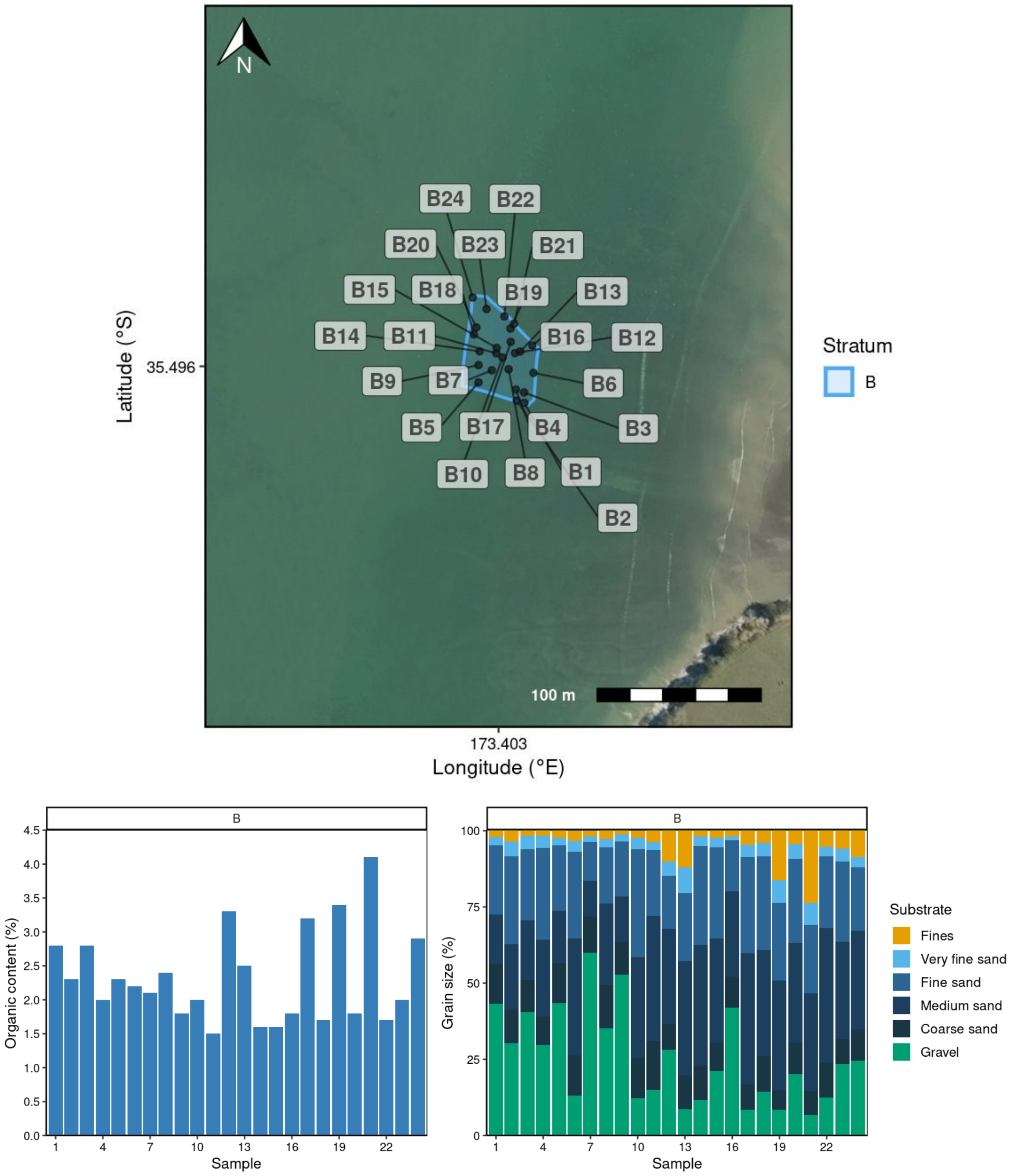


Figure 20: Sediment sample locations and characteristics at Hokianga Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.5.1 Cockles at Hokianga Harbour

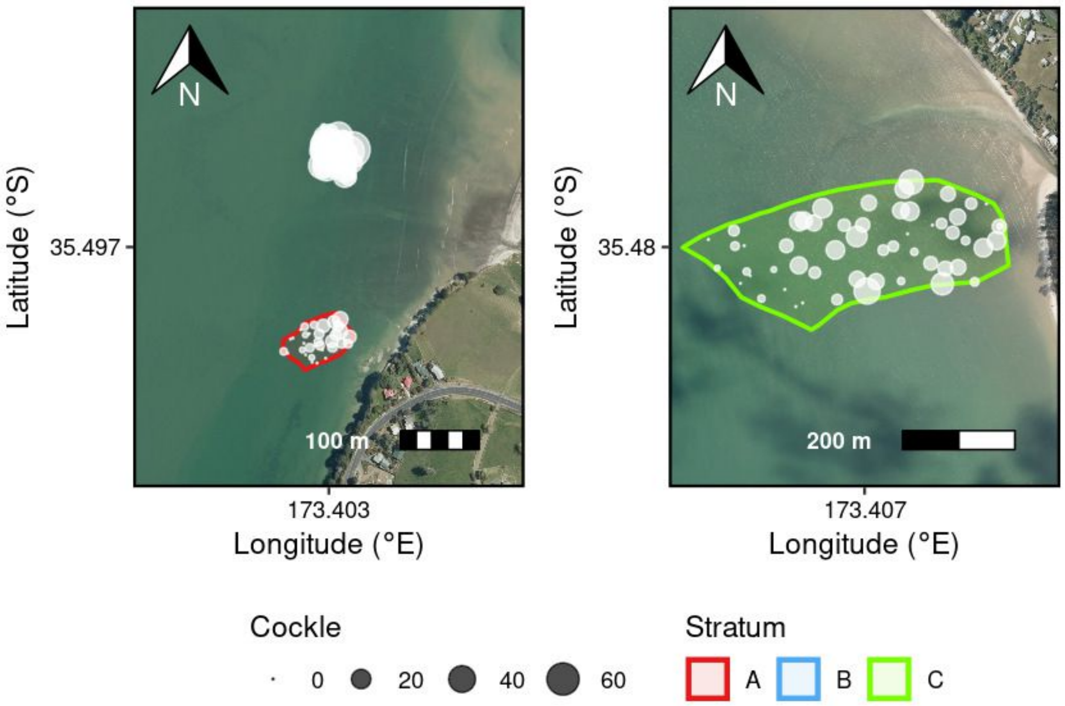


Figure 21: Map of sample strata and individual sample locations for cockles at Hokianga Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 16: Estimates of cockle abundance at Hokianga Harbour, by stratum, for 2022–23. 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	0.4	30	90	0.34	86	20.72
B	0.2	30	820	1.65	781	10.34
C	9.5	50	466	25.21	266	13.88

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

Year	Extent (ha)	Population estimate			Population $\geq$ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2018–19	10.1	25.54	254	11.88	0.32	3	49.47
2022–23	10.1	27.19	270	12.89	0.12	1	51.31

Table 18: Summary statistics of the length-frequency (LF) distribution of cockles at Hokianga 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	18.13	18	5–34	34.06	1.25
2022–23	17.82	17	4–33	26.33	0.45

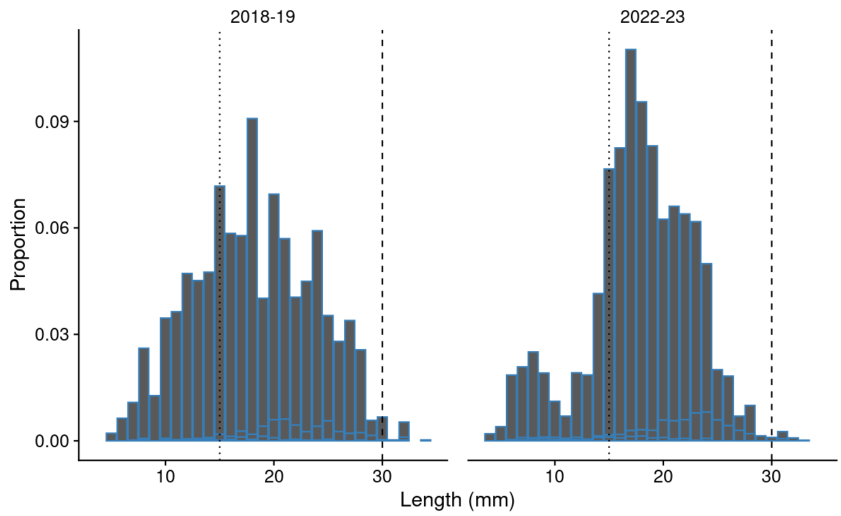


Figure 22: Weighted length-frequency (LF) distribution of cockles for the present survey at Hokianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

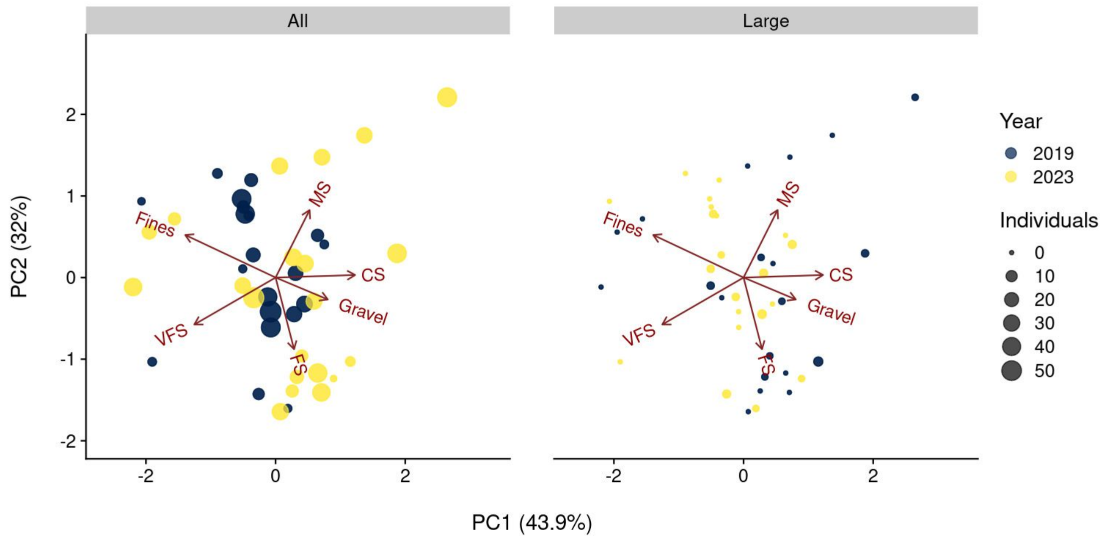


Figure 23: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Hokianga Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.5.2 Pipi at Hokianga Harbour

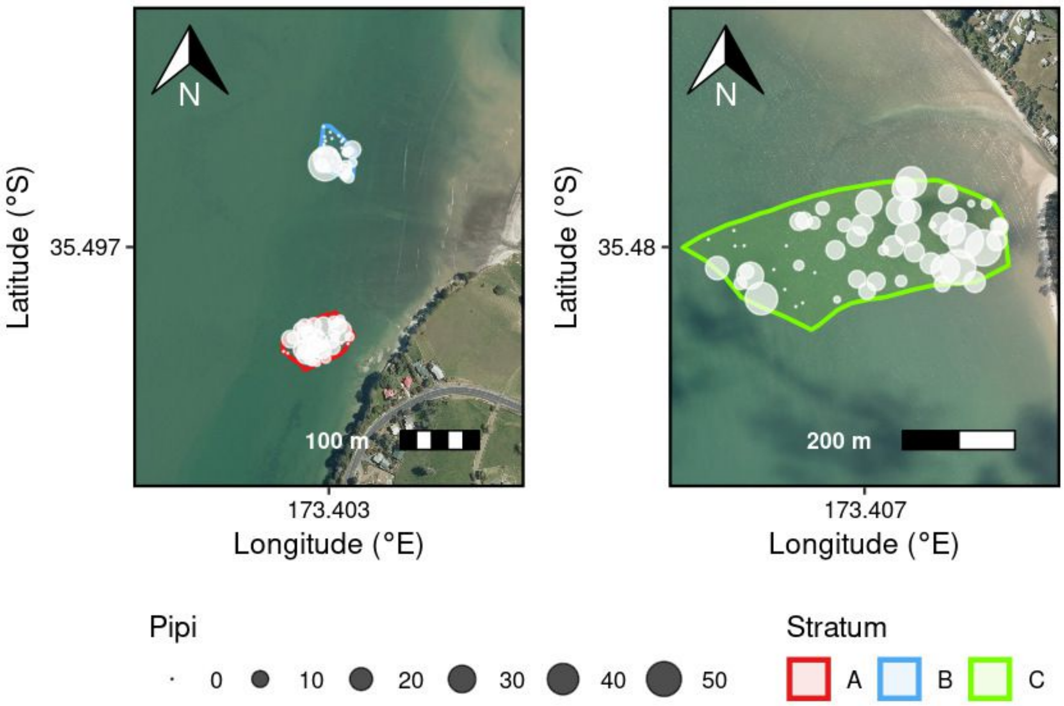


Figure 24: Map of sample strata and individual sample locations for pipi at Hokianga Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 19: Estimates of pipi abundance at Hokianga Harbour, by stratum, for 2022–23. 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	30	203	0.76	193	15.49
B	0.2	30	107	0.22	102	48.37
C	9.5	50	708	38.30	405	14.73

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2018–19	10.1	87.39	868	10.87	0.00	<1	>100
2022–23	10.1	39.27	390	14.37	0.00	<1	>100

Table 21: Summary statistics of the length-frequency (LF) distribution of pipi at Hokianga 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 (%)
2018–19	24.09	22	7–54	36.17	0.00
2022–23	25.06	24	7–51	31.40	0.01

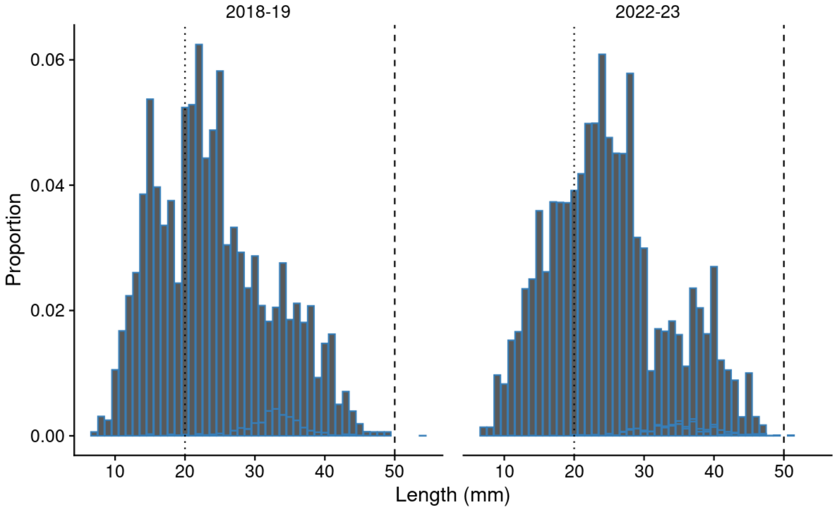


Figure 25: Weighted length-frequency (LF) distribution of pipi for the present survey at Hokianga Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Kawakawa Bay (West)

Kawakawa Bay (West) is a extensive intertidal bay in south-eastern Auckland. The current assessment was the seventh survey of this site, with the first assessment in 2004–05 (see Appendix A, Tables A-1, A-2). The field survey encompasses the entire bay, and the sampling extent has been unchanged throughout the survey series. Because there is no pipi bed in this bay, the sampling only includes cockles. The current survey had a sampling effort of 105 points across three strata.

The sediment at Kawakawa Bay (West) had a low organic content (less than 3.5%), but varied markedly in its grain size composition (Figure 26, and see details in Appendix B, Table B-1). Most samples were primarily very fine sand (grain size >63 µm), but the proportions of other grain size fractions depended on the sample, particularly for gravel (grain size >2000 µm). This grain size fraction varied from 0 (or small percentages) to 67.5%. All samples contained sediment fines (grain size ≤63 µm), with up to 22.5% of sediment in this grain size fraction.

Cockles were absent in the northern part of Kawakawa Bay (West), in stratum C and part of stratum A (Figure 27, Table 22). Their current population estimates were a total abundance of 156.07 million (CV: 14.29%) cockles, and a mean density of 256 individuals per m^2 (Table 23). These estimates represented the smallest cockle population since 2016–17, and a 25% decrease in total cockle abundance since the preceding survey in 2020–21. Consistent with previous assessments, the current population included only a small population of large cockles (≥30 mm shell length), and their current abundance was estimated at 15.33 million (CV: 36.15%) individuals, while their estimated mean density was 25 individuals per m^2. In contrast to the total population estimates, these abundance and density estimates for large cockles signified increases from the two preceding surveys.

The increase in the large cockle population was also evident in their growing contribution to the total population (Table 24). Although their proportion remained small, it increased from 5.43% in 2020–21 to 9.82% in 2022–23 (Table 24). Nevertheless, recruits (≤15 mm shell length) made up 48.26% of the current population, and also had a marked influence on the population in the two preceding surveys. This size class and medium-sized cockles represented a unimodal population structure previously, but the growth of medium-sized cockles to larger sizes and into the large size class led to a bimodal population in 2022–23.

Relating cockle abundance to sediment characteristics showed that PC1 separated coarse from fine grain size fractions and explained 58.8% of the variance in 2022–23 (Figure 29). Total cockle abundance in this survey was mostly associated with fine sand and gravel, and to some extent also with sediment fines.

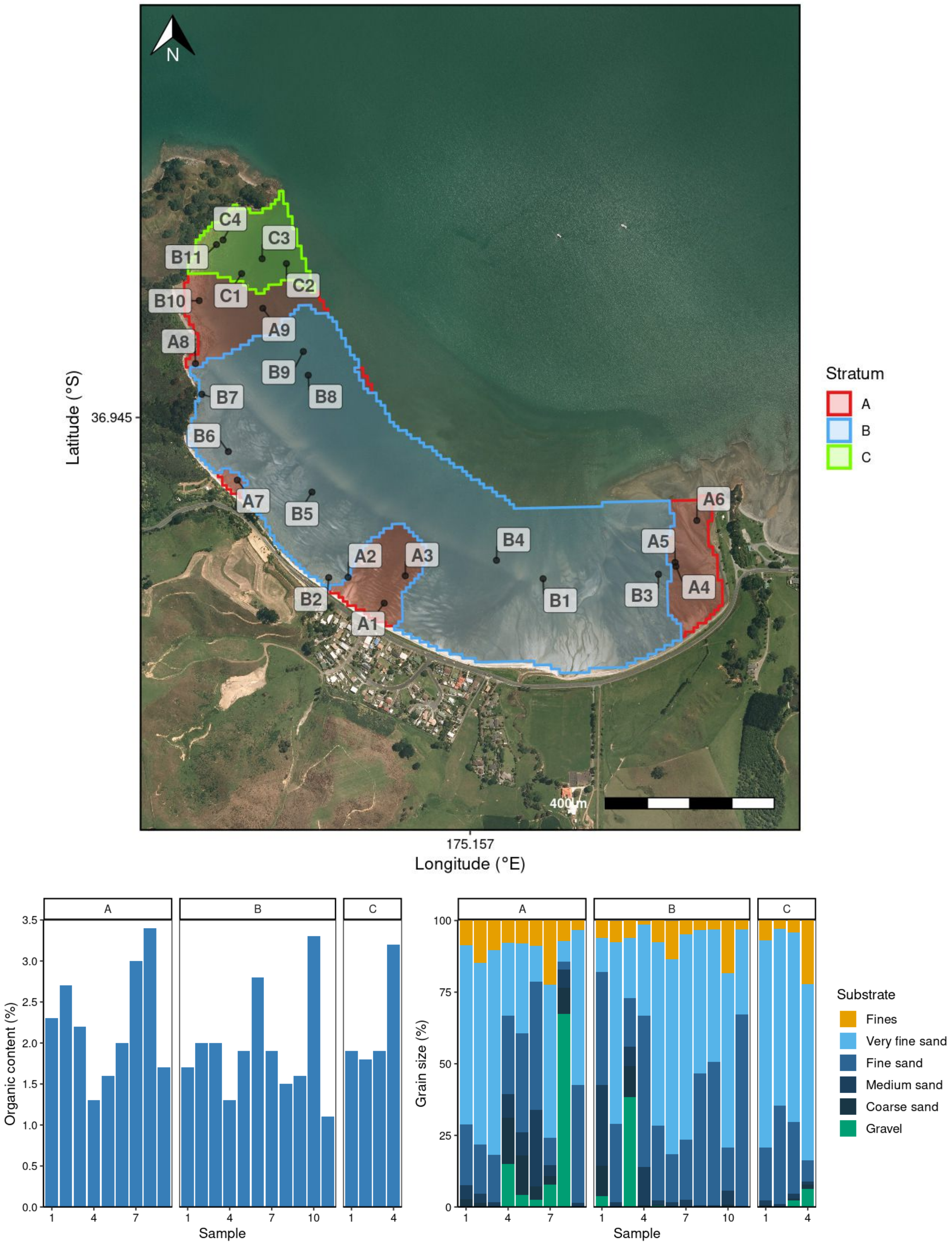


Figure 26: Sediment sample locations and characteristics at Kawakawa Bay (West). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.6.1 Cockles at Kawakawa Bay (West)

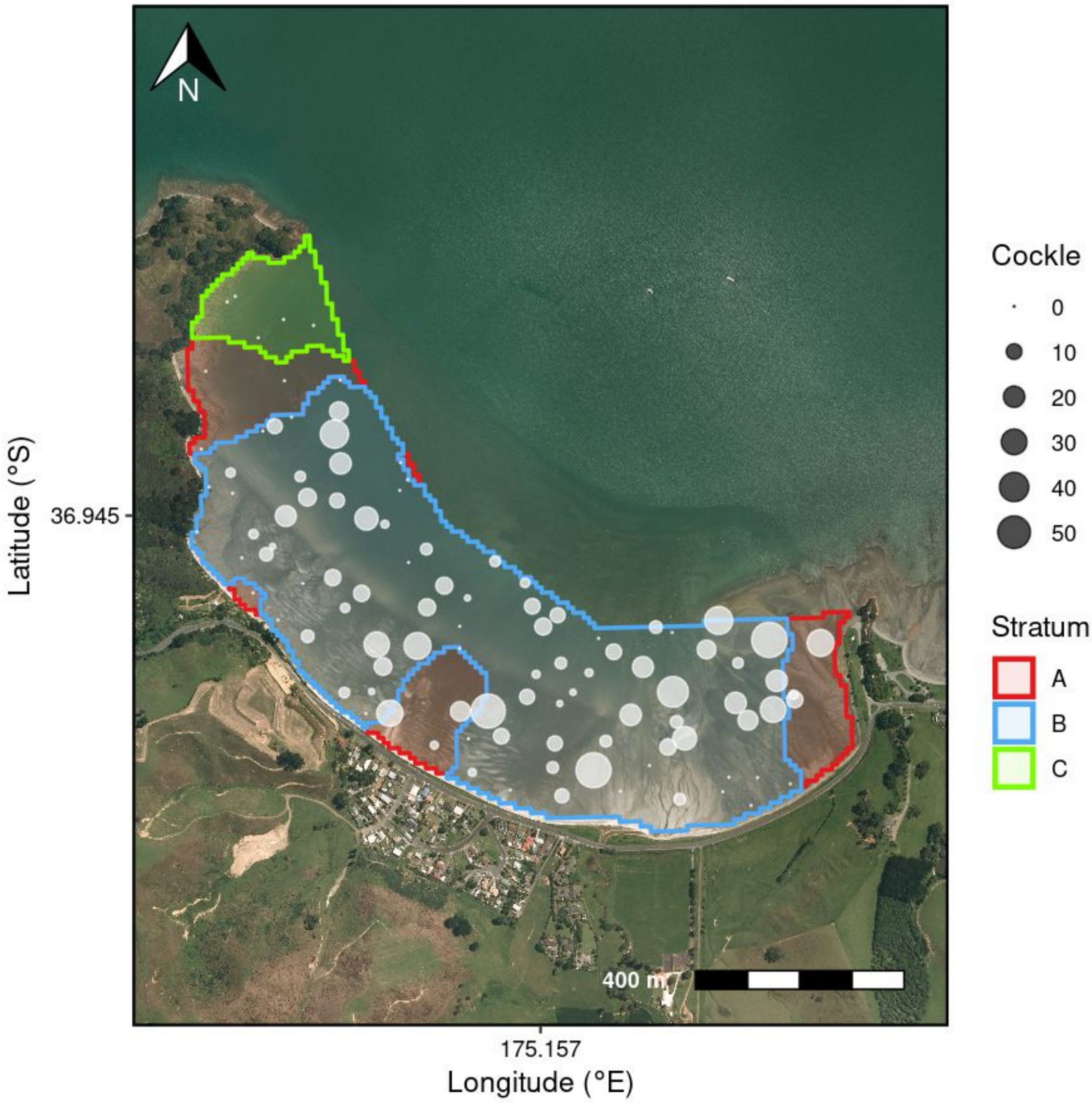


Figure 27: Map of sample strata and individual sample locations for cockles at Kawakawa Bay (West), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 22: Estimates of cockle abundance at Kawakawa Bay, by stratum, for 2022–23. 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	10.8	10	97	29.85	277	42.54
B	46.0	90	864	126.22	274	14.52
C	4.1	5	0	0.00	0	

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2004–05	60.4	87.68	145	9.19	13.28	22	17.55
2006–07	62.9	86.39	137	10.54	21.23	34	22.75
2014–15	60.9	74.44	122	9.69	19.80	33	15.80
2016–17	60.9	261.21	429	13.84	18.33	30	36.42
2018–19	60.9	222.41	365	17.52	9.34	15	28.81
2020–21	60.9	200.93	330	12.01	10.91	18	27.20
2022–23	60.9	156.07	256	14.29	15.33	25	36.15

Table 24: Summary statistics of the length-frequency (LF) distribution of cockles at Kawakawa 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	18.40	17	6–41	33.33	4.20
2020–21	18.01	15	5–40	40.80	5.43
2022–23	17.46	12	4–40	48.26	9.82

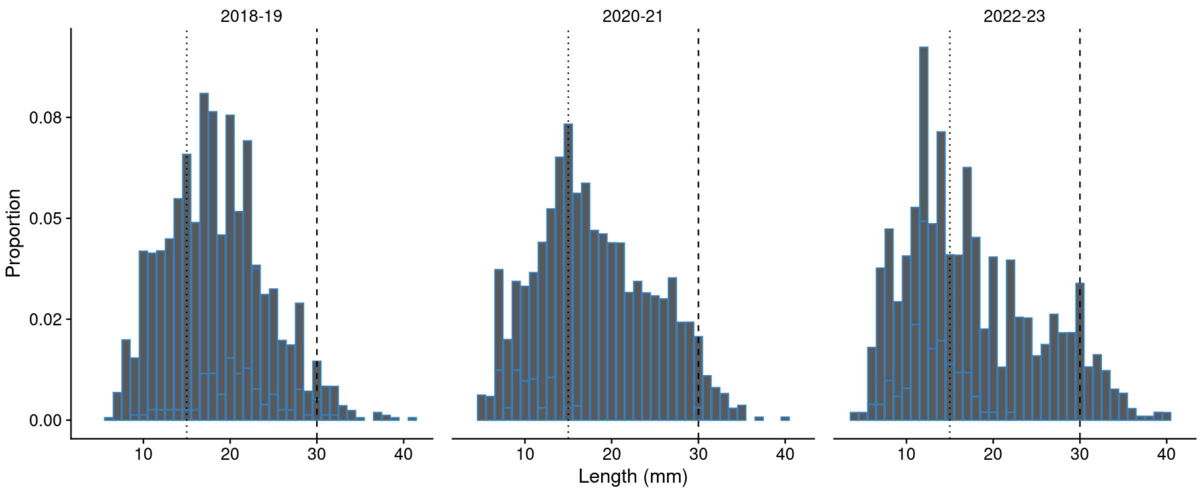


Figure 28: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Kawakawa Bay (West). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

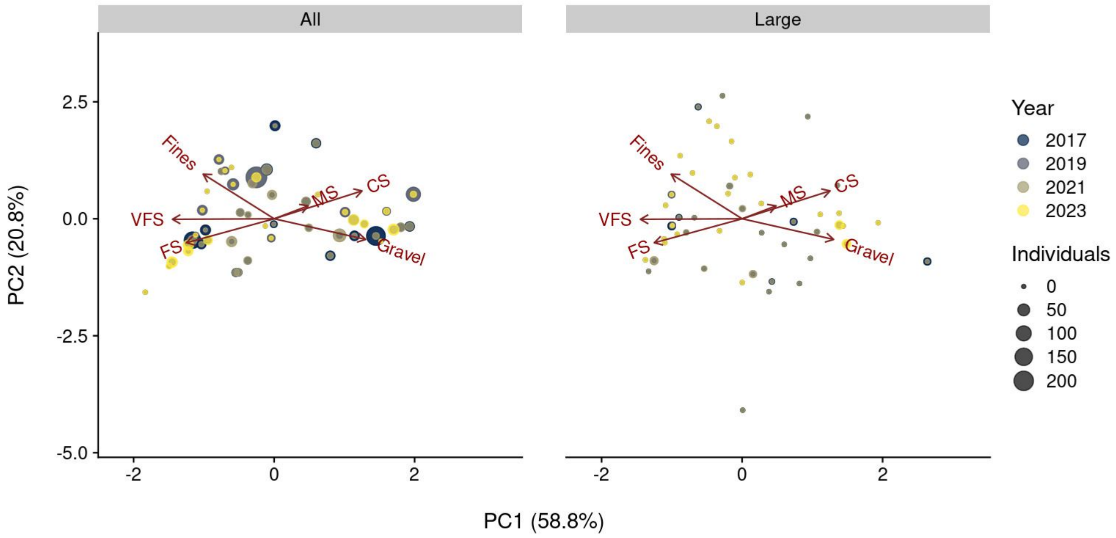


Figure 29: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Kawakawa Bay (West). Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.7 Ōhiwa Harbour

Ōhiwa Harbour is in eastern Bay of Plenty. It was included in the northern monitoring series in 2001–02 and has been surveyed eight times since then (see Appendix A, Tables A-1, A-2).). Throughout the survey series, changes to the sampling extent have been primarily caused by changes in the pipi beds. These changes included the addition of a pipi bed in 2020–21, which was inaccessible in the current field survey owing to substantial sand movement prior to the field survey. The 2022–23 survey included four disjunct strata, and the overall survey effort was a total of 155 sampling points.

The sediment in the two cockle strata contained a small amount of organic matter, which was generally less than 3% (Figure 30, and see details in Appendix B, Table B-1). The prevalent grain size fraction was fine sand (grain size >125 µm), which constituted the bulk of the sediment, followed by a small proportion of very fine sand (grain size >63 µm). Although the proportion of sediment fines (≤ 63 µm) was relatively low, this grain size fraction exceeded 10% in four of the samples.

The cockle population was spread across strata A, B, and D, with only one individual in stratum C (Figure 31, Table 25). Total cockle abundance was estimated at 5.04 million (CV: 14.23%) cockles, and their density at 269 cockles per m^2 (Table 26). These estimates indicated a considerable (over 50%) population decline since the preceding survey in 2020–21. Similar to the total population, there was also a notable decrease in large cockles (≥ 30 mm shell length), but current estimates had a high CV of 58.31%. Over time, the large size class showed considerable fluctuation, usually with high uncertainty. In comparison to large cockles, there was a large proportion of recruits (≤ 15 mm shell length) in the three most recent assessments, indicating consistent recruitment events. Recruitment was particularly strong in 2022–23, when 33.03% of the cockle population was in this size class (Table 27). The influx of recruits was also evident in the 2- to 3-mm decrease in mean and modal sizes to 17.93 mm and 17 mm shell length, respectively. The strength of recent recruitment events led to a shift in the unimodal population of medium-sized cockles towards a cohort of small individuals in the period between 2018–19 and 2022–23 (Figure 32).

The PCA showed that total cockle abundance in 2022–23 was mostly associated with finer grain sizes, as distinguished by PC1, which explained 34.6% of the variance (Figure 33).

The pipi population at Ōhiwa Harbour was restricted to stratum C, in the middle of Kutarere channel, with few individuals in the stratum C pipi bed (Figure 34, Table 28). There was a notable decline in the pipi population in 2022–23, which was evident in both the total abundance and density estimates (Table 29). The 2022–23 abundance estimate was a total of 1.47 million (CV: 10.61%) pipi, which occurred at an estimated mean density of 78 pipi per m^2. Although the current estimates were the lowest values in the survey series, the overall decline in the population has been ongoing since 2018–19, in a period when the sampling extent has mostly remained unchanged. The most recent reduction in the sampling extent was relatively small compared with the documented decreases in the pipi population.

Part of the continued population decline was related to the decrease in large pipi (≥ 50 mm shell length), even though this size class was only a small proportion of the population in recent surveys. For example, their population declined from an estimated abundance of 3.70 million (CV: 18.37%) large pipi and an estimated density of 109 pipi per m^2 in 2015–16 to the current abundance of 0.03 million (CV: 32.65%) large individuals and two individuals per m^2. The decline in large pipi also led to an increase in the CV associated with their estimates.

Length-frequency distributions of the three most recent surveys documented a consistently strong cohort of medium-sized pipi, which determined mean and modal sizes at 30 to 40 mm shell length (Table 30, Figure 35). There was variable recruitment over this period, with a recent influx of recruits (≤ 20 mm shell length) between 2020–21 and 2022–23, from 3.91% to 11.49% of the population. This influx changed the unimodal size structure to bimodal, with a small, second cohort of recruits. Compared with length frequencies in 2018–19, the current population size structure confirmed a general lack of growth by medium-sized pipi into the large size class.

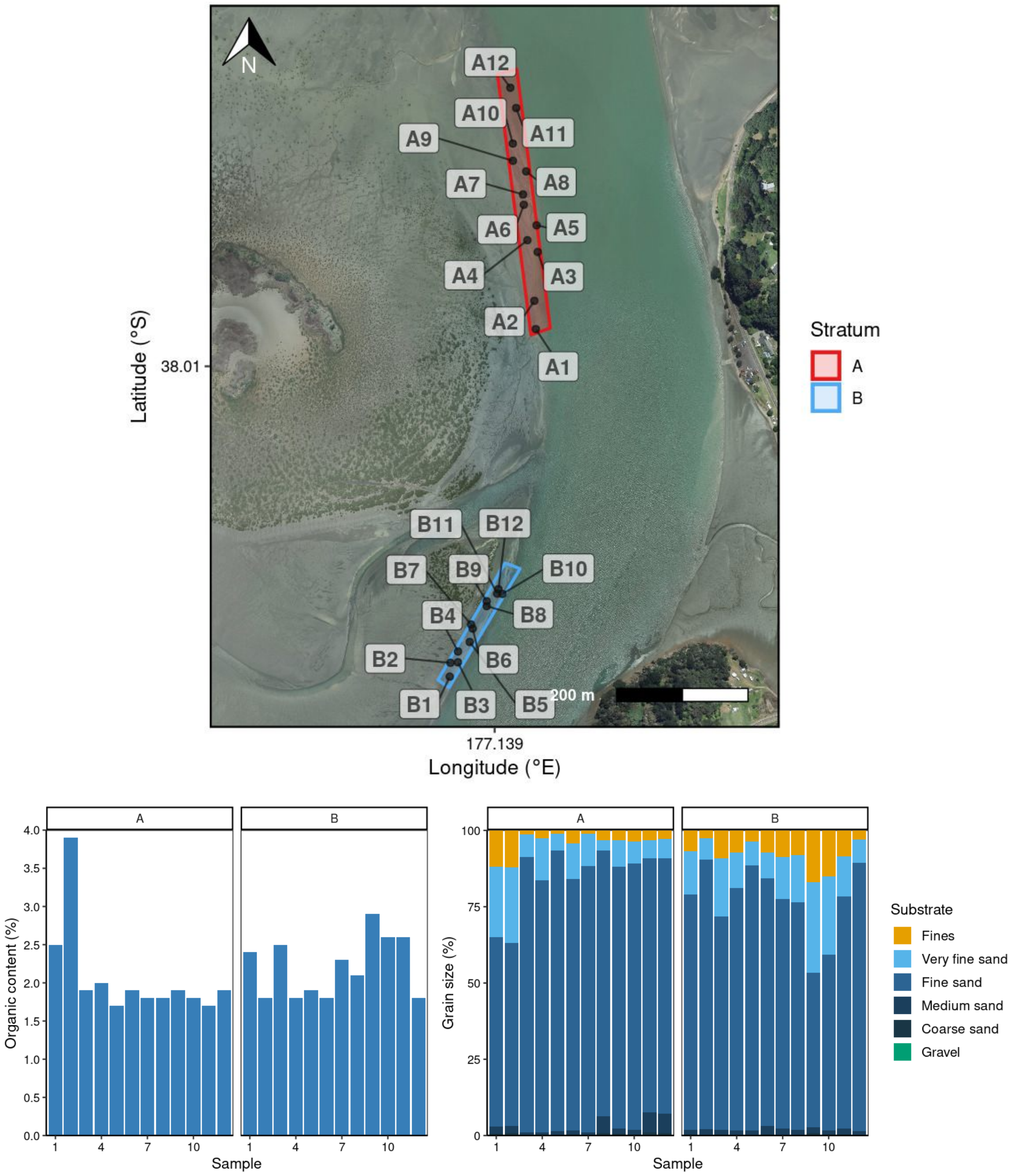


Figure 30: Sediment sample locations and characteristics at Ōhiwa Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.7.1 Cockles at Ōhiwa Harbour

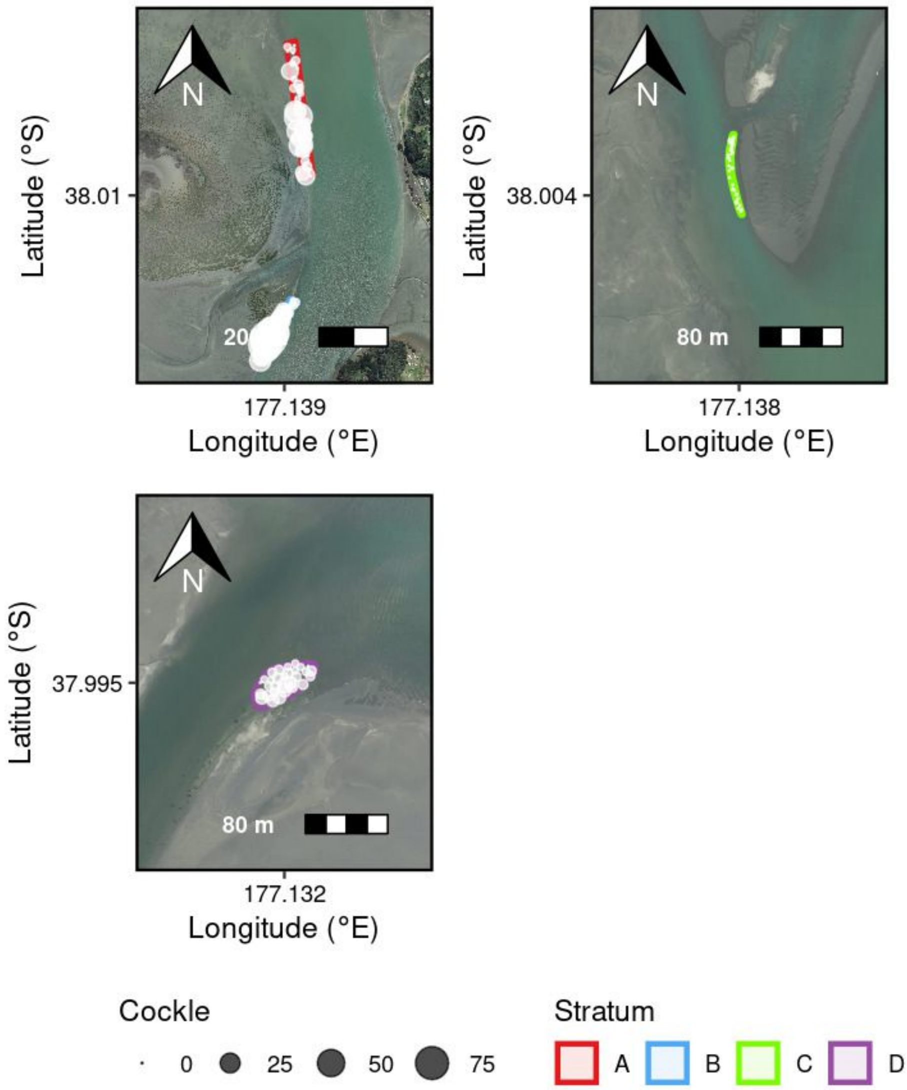


Figure 31: Map of sample strata and individual sample locations for cockles at Ōhiwa Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 25: Estimates of cockle abundance at Ōhiwa Harbour, by stratum, for 2022–23. 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	1.2	45	313	2.40	199	23.97
B	0.5	45	819	2.41	520	17.66
C	0.0	35	1	0.00	<1	>100
D	0.2	30	141	0.22	134	12.29

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	4.53	201	7.82	0.16	7	22.37
2005–06	2.7	3.69	137	7.07	0.17	6	15.69
2006–07	5.7	17.48	307	10.59	1.12	20	14.47
2009–10	2.1	6.47	308	8.79	0.03	1	51.49
2012–13	2.6	9.05	344	10.49	0.05	2	36.42
2015–16	3.4	11.27	334	13.38	0.08	2	99.96
2018–19	2.5	5.57	219	13.38	0.82	32	39.04
2020–21	2.6	12.61	476	19.44	0.42	16	20.71
2022–23	1.9	5.04	269	14.23	0.08	4	58.31

Table 27: Summary statistics of the length-frequency (LF) distribution of cockles at Ōhiwa 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	22.47	24	5–62	19.65	14.69
2020–21	20.20	20	7–36	15.15	3.35
2022–23	17.93	17	6–35	33.03	1.63

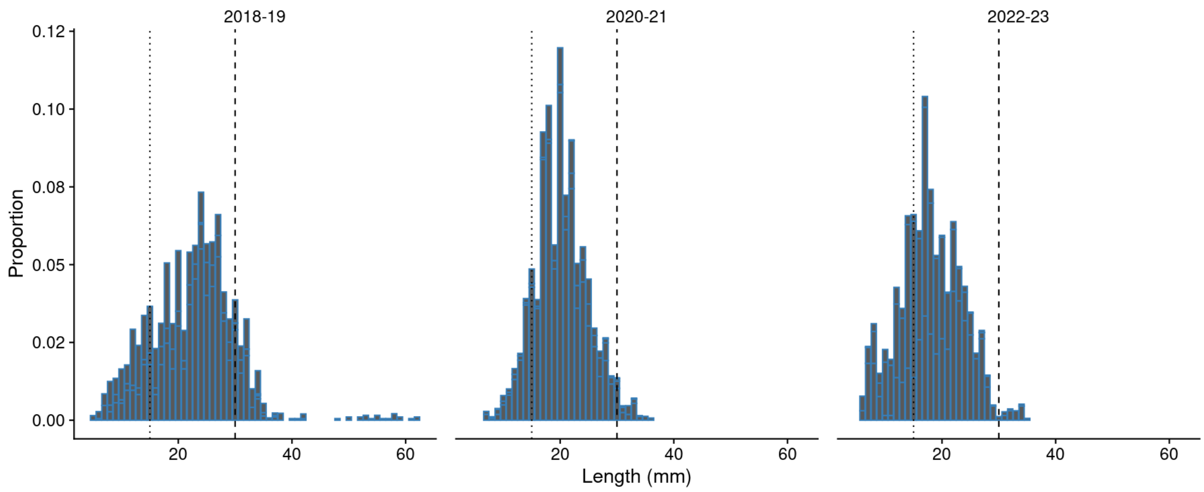


Figure 32: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ōhiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

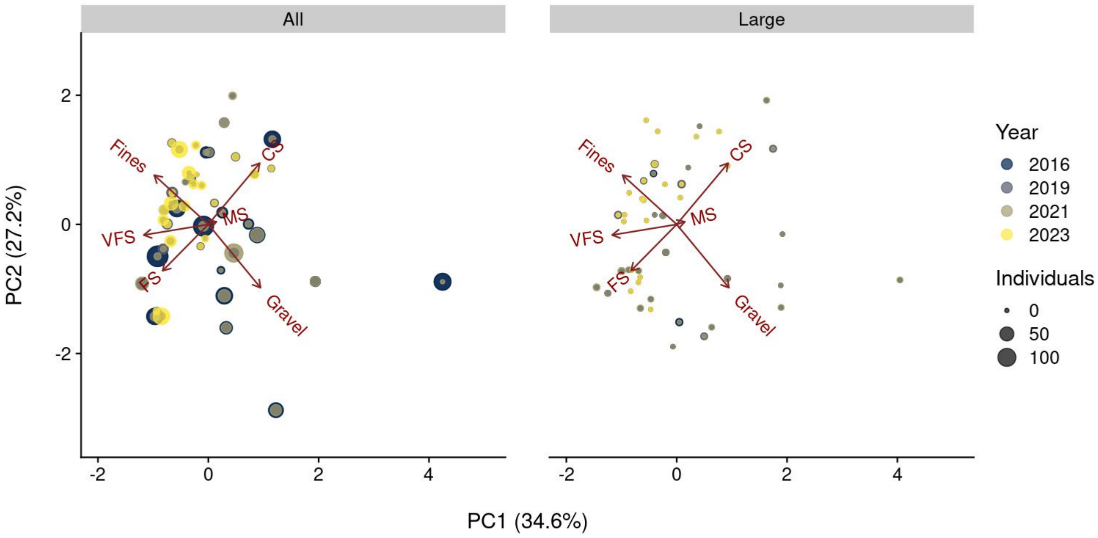


Figure 33: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Ōhiwa Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, 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.

3.7.2 Pipi at Ōhiwa Harbour

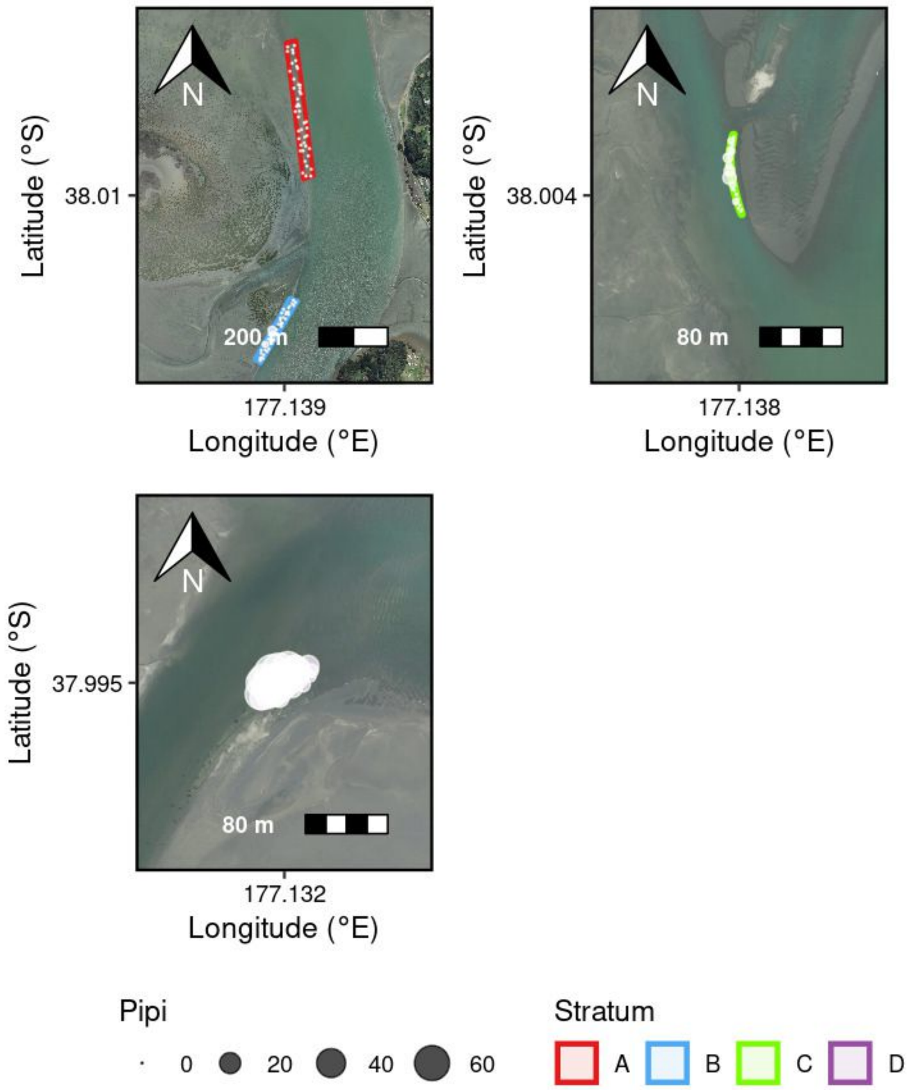


Figure 34: Map of sample strata and individual sample locations for pipi at Ōhiwa Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 28: Estimates of pipi abundance at Ōhiwa Harbour, by stratum, for 2022–23. 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	1.2	45	0	0.00	0	
B	0.5	45	3	0.01	2	73.85
C	0.0	35	20	0.01	16	42.01
D	0.2	30	918	1.45	874	10.71

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2001–02	2.2	5.67	252	6.88	2.14	95	7.46
2005–06	2.7	3.40	126	7.27	2.52	93	6.36
2006–07	5.7	8.27	145	10.52	2.14	38	13.78
2009–10	2.1	15.25	726	14.46	1.63	78	18.77
2012–13	2.6	41.59	1 581	14.39	1.03	39	31.52
2015–16	3.4	41.24	1 221	12.10	3.70	109	18.37
2018–19	2.5	13.05	514	13.00	1.24	49	19.69
2020–21	2.6	7.15	270	10.26	0.86	33	21.48
2022–23	1.9	1.47	78	10.61	0.03	2	32.65

Table 30: Summary statistics of the length-frequency (LF) distribution of pipi at Ōhiwa 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 (%)
2018–19	32.67	30	6–64	11.26	9.47
2020–21	39.55	40	9–64	3.91	12.09
2022–23	37.45	42	8–60	11.49	2.21

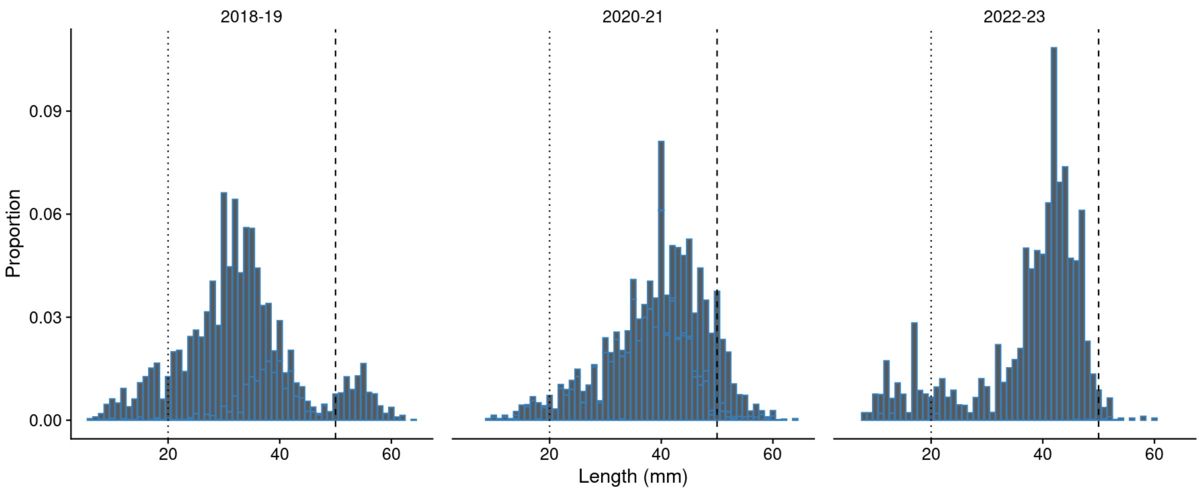


Figure 35: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ōhiwa Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Okoromai Bay

Okoromai Bay is a large intertidal mudflat in Hauraki Gulf, north of Auckland. It was first surveyed in 1999–2000, and the current assessment was the 13th survey at this site (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has been largely consistent, with the sampling focused on cockles only, because there are no pipi at this site. In 2022–23, the sampling extent was divided into four strata, and the survey effort was based on 90 sampling points.

The sediment in the bay was characterised by a low organic content ($<$3%) and a low proportion of sediment fines ($\leq$63 µm), although this grain size fraction exceeded 10% in two samples (Figure 36, and see details in Appendix B, Table B-1). The prevalent grain sizes were very fine and fine sands (grain sizes $>$65 µm and $>$125 µm), which varied in their prevalence across samples. There were small proportions of sediment in the other size fractions.

Cockles were predominantly in the lower intertidal area of the sampling extent, in strata A and B, with fewer cockles in other areas (Figure 37, Table 31). Total cockle abundance was estimated at 43.62 million (CV: 14.32%) individuals in 2022–23, and their estimated mean density was 220 cockles per m^2 (Table 32). The current population included a small population of large cockles ($\geq$30 mm shell length), which had an estimated abundance of 3.52 million individuals, and an estimated mean density of 18 large individuals per m^2; however, these estimates had a CV of 27.08%. All of the current estimates were markedly lower than estimates in the preceding assessments; e.g., since 2015–16, although there were some fluctuations over time.

Large cockles and recruits ($\leq$15 mm shell length) made up small proportions of the current population, with 8.07% and 14.61% of individuals in these two size classes, respectively (Table 33). Most of the population consisted of medium-sized individuals, with a modal shell length of 25 mm. This size class was boosted by a strong recruitment event in 2017–18 (60.38% of recruits), followed by the growth of recruits to larger sizes, exceeding the cut-off length of the medium size class (Figure 38).

The PCA of cockle abundance and sediment grain sizes showed an association of all cockles with very fine and fine sands, with PC1 explaining 40.6% of the variance in 2022–23 (Figure 39). There was a similar association for large cockles.

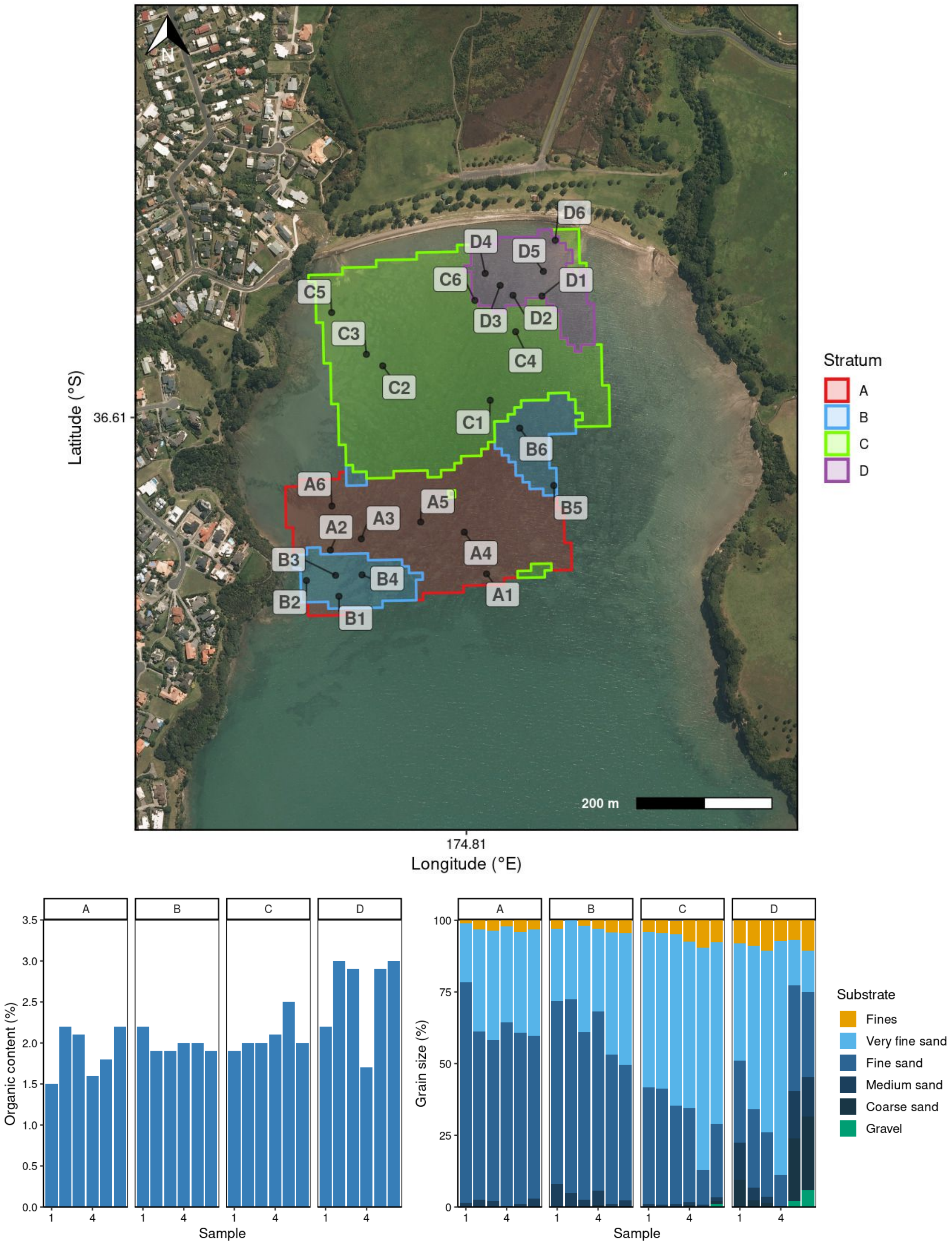


Figure 36: Sediment sample locations and characteristics at Okoromai Bay. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.8.1 Cockles at Okoromai Bay

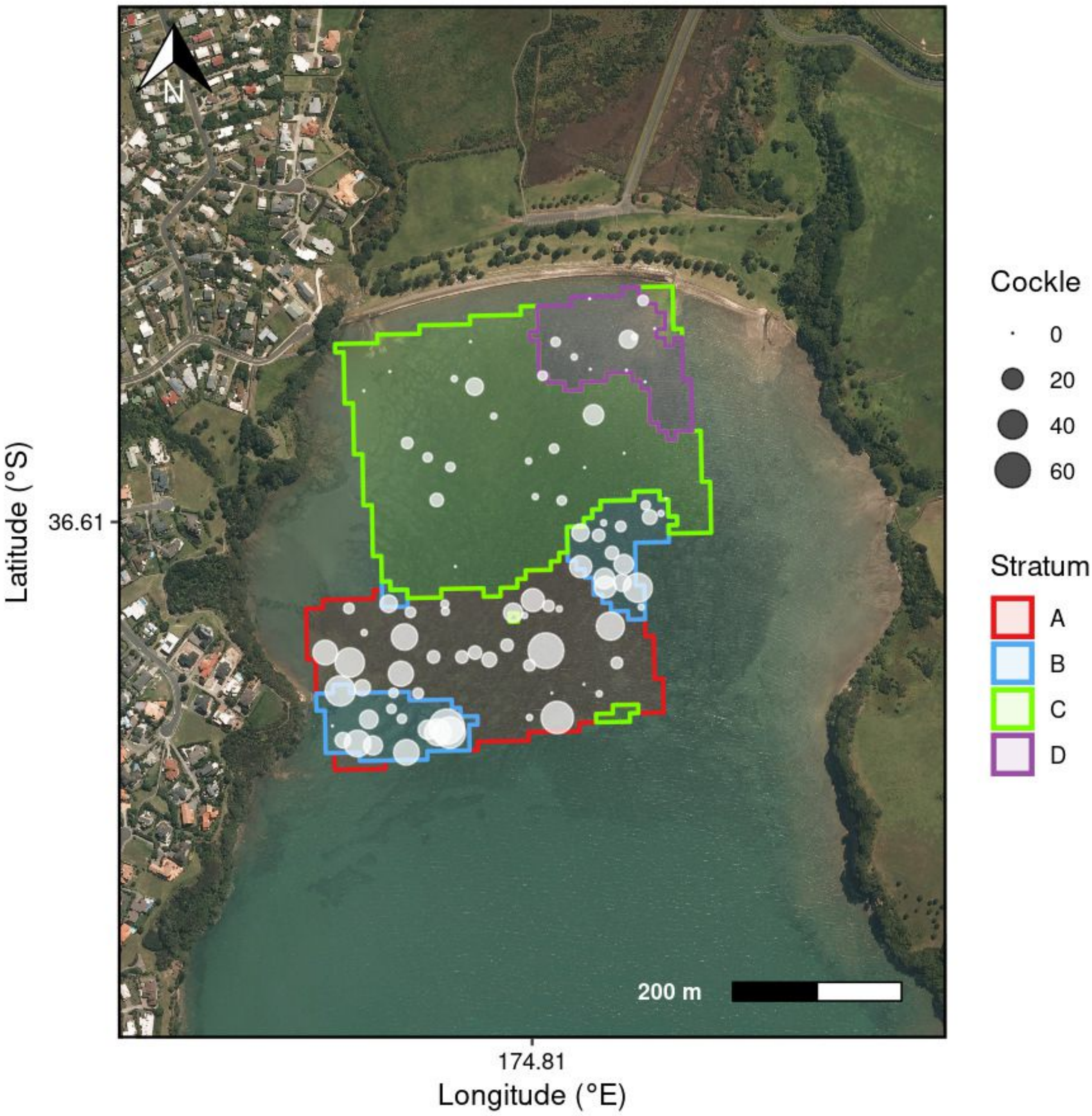


Figure 37: Map of sample strata and individual sample locations for cockles at Okoromai Bay, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 31: Estimates of cockle abundance at Okoromai Bay, by stratum, for 2022–23. 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	5.9	30	400	22.40	381	22.80
B	2.4	30	503	11.39	479	17.11
C	9.7	20	62	8.61	89	34.07
D	1.9	10	23	1.22	66	59.77

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	20.0	90.05	450	4.26	24.38	122	5.30
2001–02	24.0	27.26	114	7.78	8.66	36	8.31
2002–03	20.0	26.86	134	5.10	7.05	35	6.56
2003–04	20.0	27.96	140	11.48	12.01	60	10.62
2004–05	20.0	34.50	172	7.44	13.80	69	4.37
2006–07	20.0	17.39	87	9.08	7.03	35	12.18
2009–10	20.0	29.62	148	9.60	13.07	65	10.84
2012–13	20.0	28.50	142	10.61	13.61	68	11.92
2013–14	19.8	28.14	142	12.69	4.48	23	19.47
2015–16	19.8	34.78	175	19.45	8.48	43	19.44
2017–18	19.8	52.25	263	15.24	4.29	22	19.79
2020–21	19.8	64.37	325	15.53	6.10	31	24.50
2022–23	19.8	43.62	220	14.32	3.52	18	27.08

Table 33: Summary statistics of the length-frequency (LF) distribution of cockles at Okoromai 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 (%)
2017–18	15.54	10	3–43	60.38	8.21
2020–21	22.55	24	5–39	12.51	9.48
2022–23	22.03	25	6–38	14.61	8.07

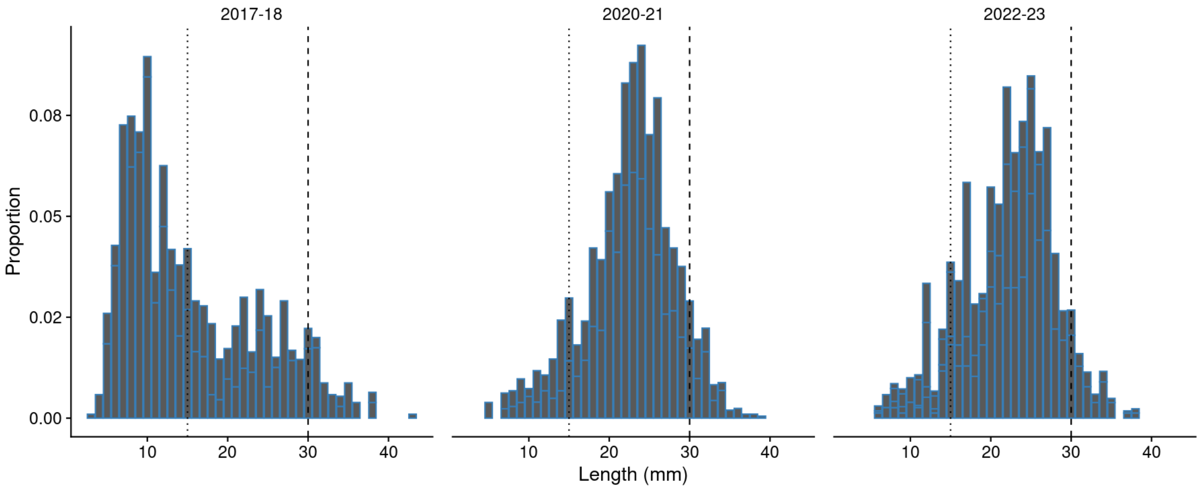


Figure 38: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Okoromai Bay. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

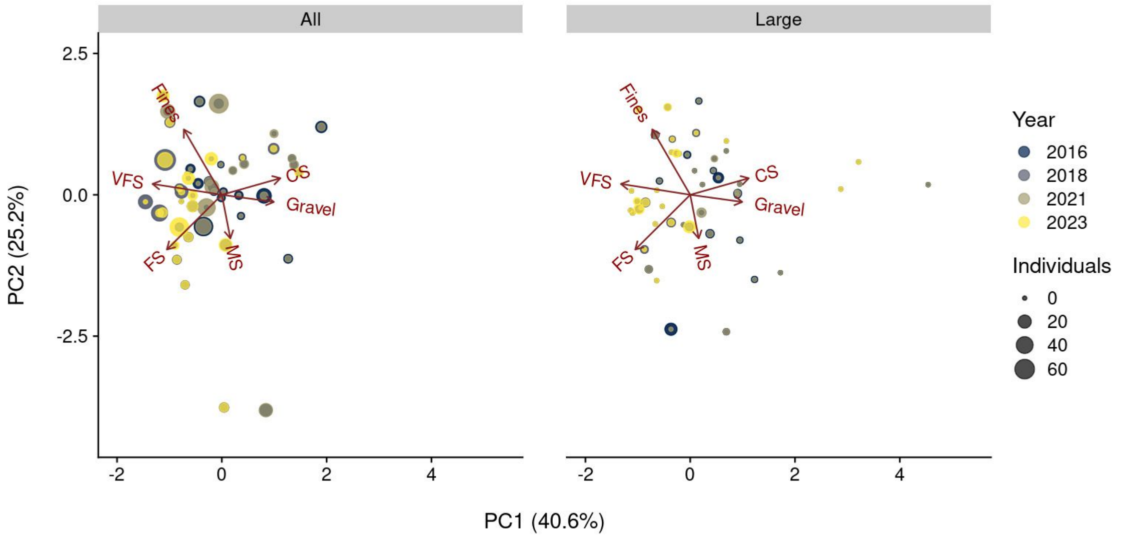


Figure 39: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Okoromai Bay. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, 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 Otūmoetai (Tauranga Harbour)

Otūmoetai is in western Bay of Plenty, in the south-eastern part of Tauranga Harbour. Bivalves at this site have been assessed in ten surveys, starting in 2000–01, and including the present assessment (see Appendix A, Tables A-1, A-2). The sampling extent at Otūmoetai includes a pipi bed along one of the side channels and a separate cockle bed in an intertidal sandflat area. Variation in the sampling extent in recent surveys has been caused by changes in the pipi bed, whereas the cockle strata have remained unchanged. In 2022–23 (and also in 2020–21), there was a notable reduction in the spatial distribution of pipi, reflected in the size of the sampling extent. In 2022–23, there were three strata across this sampling extent, and the field survey sampled 87 points.

The sediment organic content in the cockle strata was low (0.8 to 1.9%), and the sediment composition was largely determined by fine sand (grain size >125 µm) (Figure 40, and see details in Appendix B, Table B-1). There was little variation in the proportions of other grain size fractions, and the proportion of sediment fines (grain size ≤ 63 µm) was below 3.5% across all samples.

Cockles were evenly distributed throughout stratum A and also occurred in parts of the pipi bed, in stratum C, but were absent in stratum B (Figure 41, Table 34). This population had a total abundance estimate of 15.51 million (CV: 12.32%) cockles in 2022–23, which signified a decrease from the preceding abundance estimates (i.e., over 20 million cockles) in 2020–21 and 2018–19 (Table 35). Nevertheless, some of this decrease may have been related to the reduction in the sampling extent, and the estimated mean population density remained similar in 2022–23 at 349 cockles per m^2. The cockle population generally lacked large individuals (≥ 30 mm shell length), and population estimates of this size class had high uncertainty throughout the time series (e.g., CV: >100% in 2022–23).

Most of the current population comprised medium-sized cockles, with 26.84% of recruits (≤ 15 mm shell length) (Table 36, Figure 42). These two size classes also formed the unimodal cockle population in the two preceding surveys. Mean and modal sizes in this period were at, or just abouve, the 15-mm cut-off length of the recruits size class. This finding highlighted the significance of strong recruitment events for the cockle population at this site, and the general lack of growth by medium-sized cockles to larger sizes.

In relation to sediment grain sizes, total cockle abundance showed a shift from gravel towards finer grain size fractions, including sediment fines, in the most recent survey (Figure 43).

Pipi at Otūmoetai only occurred in stratum C, and were mostly in the lower part of this pipi bed (Figure 44, Table 37). The estimated population size of this species was 11.68 million (CV: 11.81%) pipi in this assessment, which was a notable reduction from their abundance estimate of 49.01 million (CV: 7.34%) pipi in 2020–21 (Table 38). Part of this decline may be owing to the reduction in the size of the pipi bed; however, there was also a marked decrease in their estimated mean density, from 752 pipi per m^2 in 2020–21 to 263 pipi per m^2 in 2022–23. Within this population, large pipi (≥ 50 mm shell length) remained scarce, with a current estimate of 0.13 million pipi in this size class, but with considerable uncertainty (CV: 39.84%) (and also for previous population estimates of this size class).

There were also few recruits (≤ 20 mm shell length) in this pipi population, with only a small proportion (0.90%) of individuals in this small size class (Table 39, Figure 45). Although medium-sized pipi have consistently determined the Otūmoetai (Tauranga Harbour) pipi population in recent assessments (i.e., since 2018–19), the continued lack of recruitment and large pipi has meant that the medium size class almost solely formed the resident population. Over this recent period, there has been a general lack of growth of the strong single cohort of medium-sized pipi to larger sizes, and mean and modal lengths have only shown a small increase to current shell lengths of 38.81 mm and 37 mm, respectively.

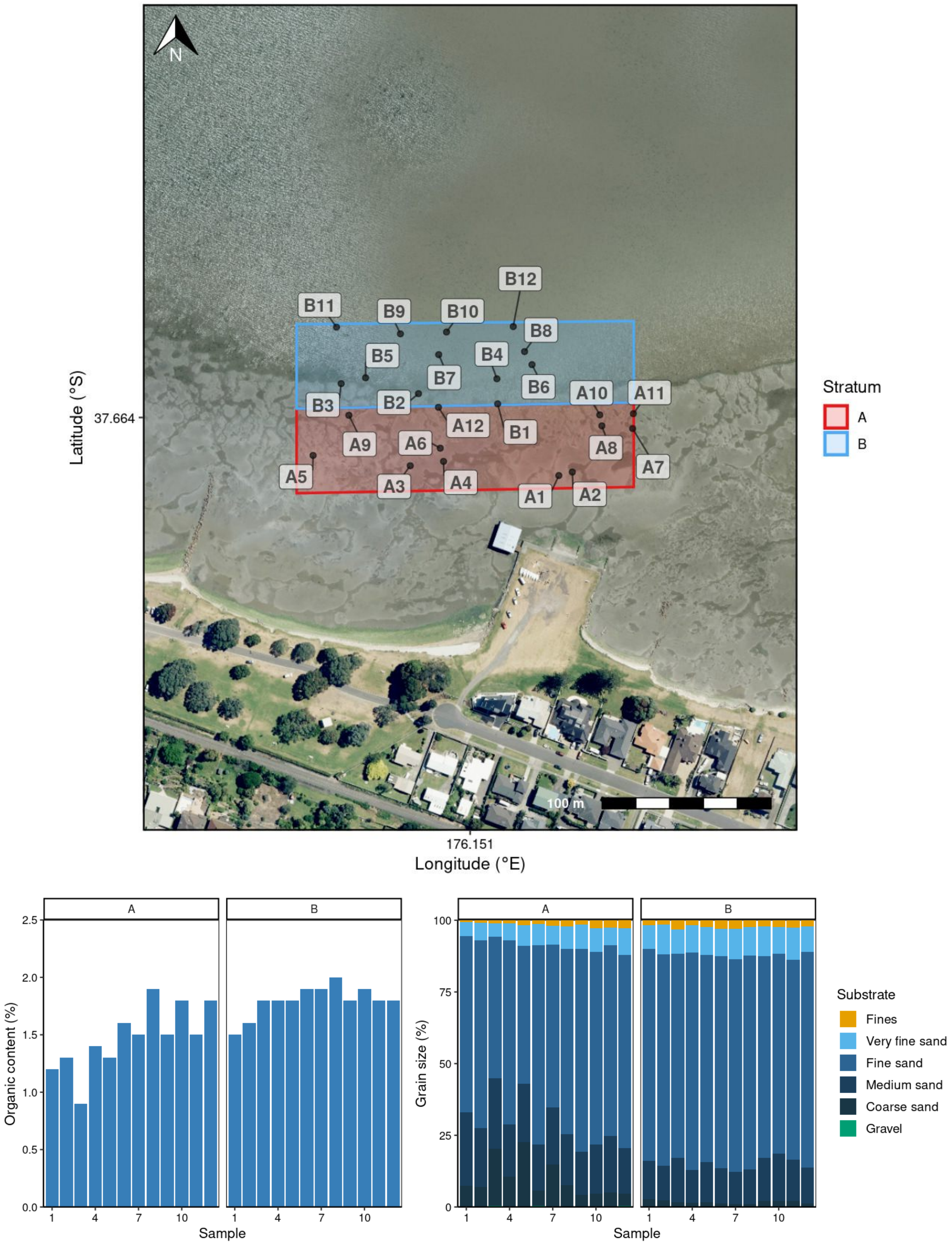


Figure 40: Sediment sample locations and characteristics at Otūmoetai (Tauranga Harbour). Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63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

3.9.1 Cockles at Otūmoetai (Tauranga Harbour)

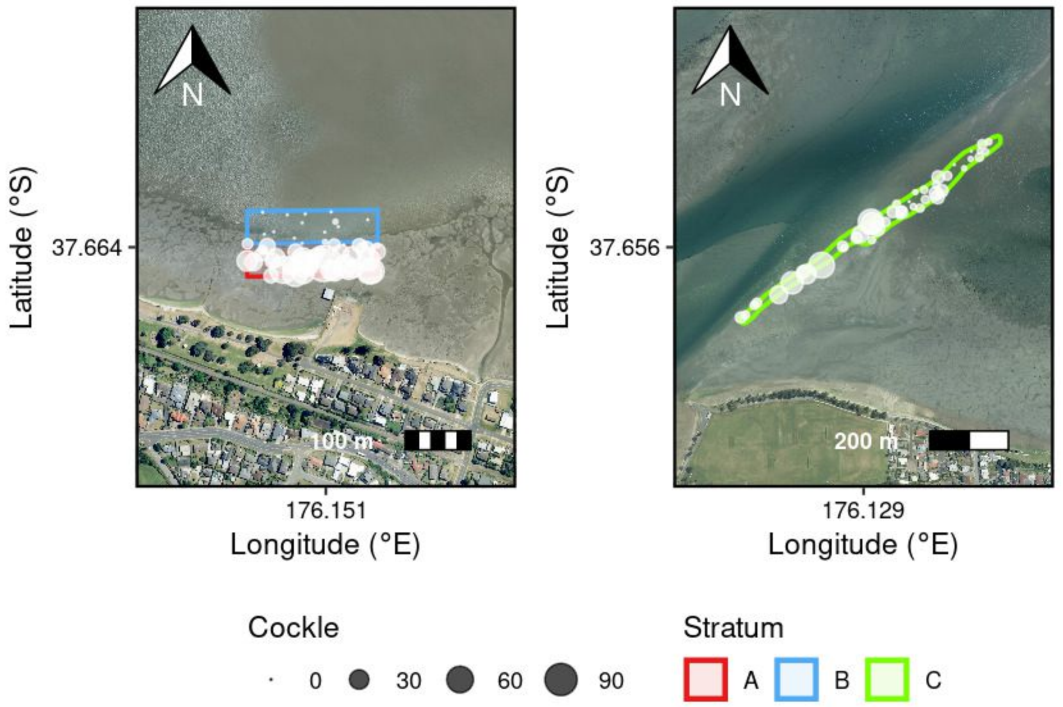


Figure 41: Map of sample strata and individual sample locations for cockles at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 34: Estimates of cockle abundance at Otūmoetai, by stratum, for 2022–23. 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	1.0	35	976	7.97	797	13.30
B	1.0	12	2	0.05	5	67.42
C	2.5	40	427	7.49	305	21.21

Table 35: Estimates of cockle abundance at Otūmoetai (Tauranga Harbour) for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	5.6	5.62	100	9.04	0.54	10	12.88
2002–03	5.6	11.25	201	5.71	0.03	<1	35.73
2005–06	4.6	2.21	48	10.27	0.02	<1	79.03
2006–07	4.6	10.67	232	10.13	0.04	<1	54.78
2009–10	5.6	14.73	263	10.85	0.20	4	80.85
2014–15	7.7	37.28	486	7.20	0.02	<1	>100
2016–17	8.1	40.11	496	14.56	0.34	4	>100
2018–19	8.1	21.95	272	10.48	0.01	<1	100
2020–21	6.5	22.43	344	10.78	0.00	0	
2022–23	4.4	15.51	349	12.32	0.01	<1	>100

Table 36: Summary statistics of the length-frequency (LF) distribution of cockles at Otūmoetai. 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	15.80	15	5–30	48.12	0.04
2020–21	16.73	17	5–29	38.56	0.00
2022–23	17.72	17	6–30	26.84	0.05

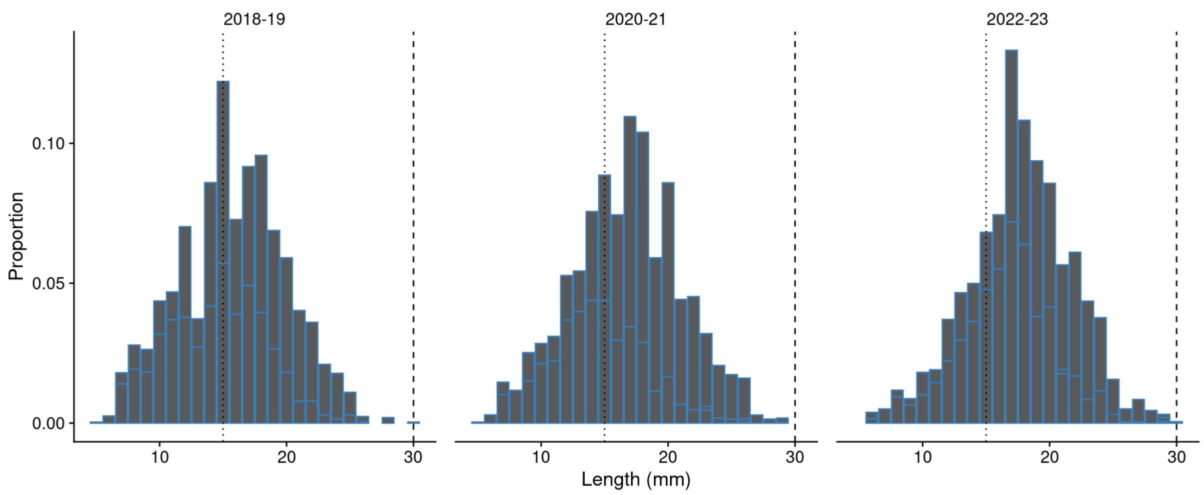


Figure 42: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

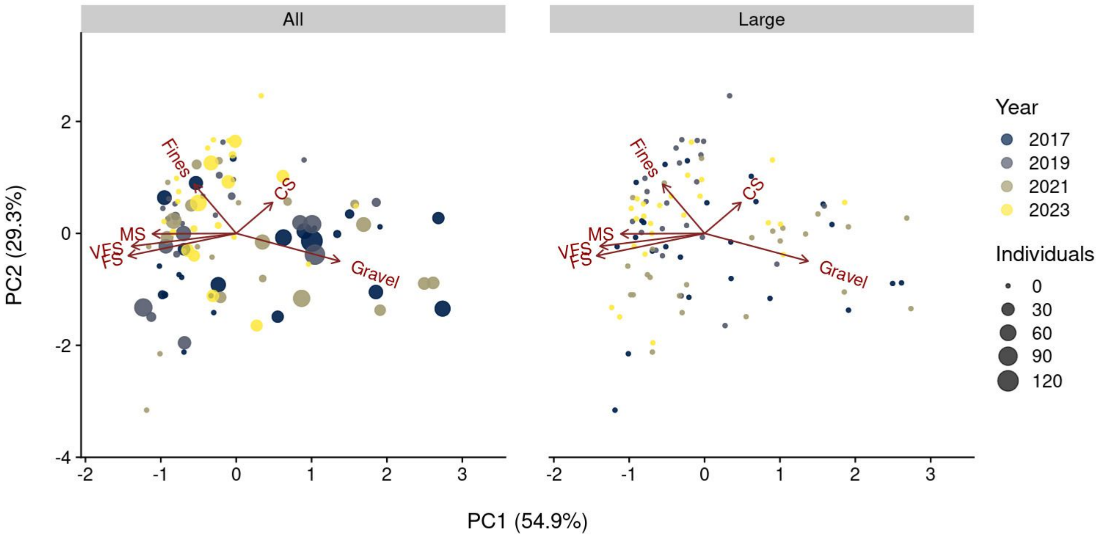


Figure 43: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Otūmoetai (Tauranga Harbour). Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.9.2 Pipi at Otūmoetai (Tauranga Harbour)

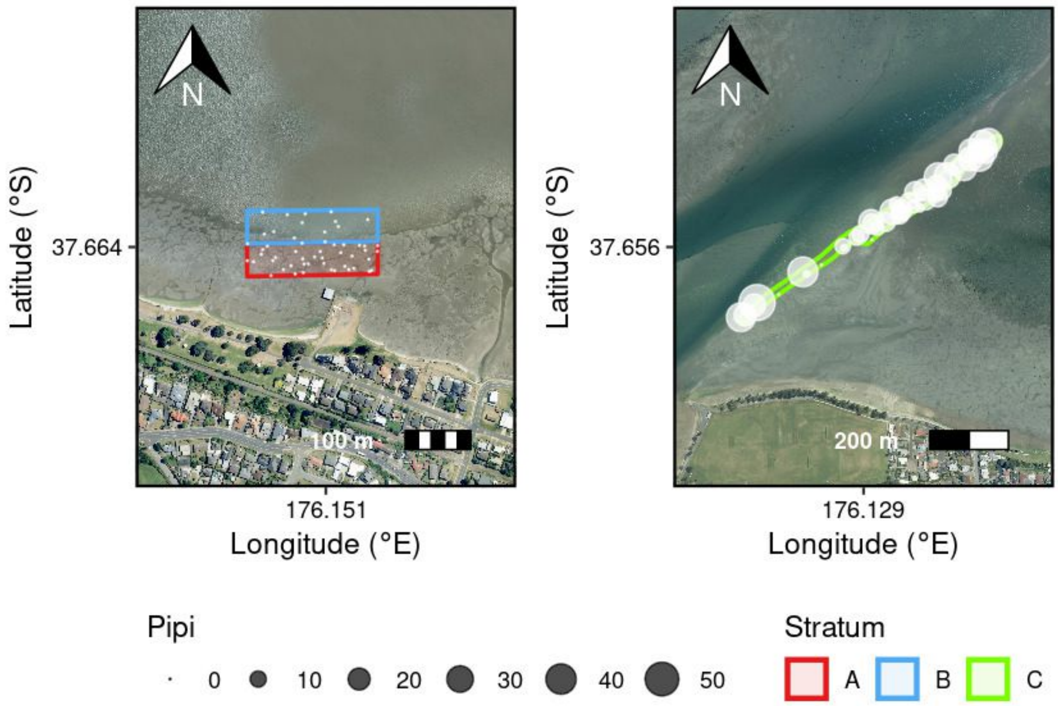


Figure 44: Map of sample strata and individual sample locations for pipi at Otūmoetai (Tauranga Harbour), with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 37: Estimates of pipi abundance at Otūmoetai, by stratum, for 2022–23. 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	1.0	35	0	0.00	0	
B	1.0	12	0	0.00	0	
C	2.5	40	666	11.68	476	11.81

Table 38: Estimates of pipi abundance at Otūmoetai (Tauranga Harbour) for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	5.6	24.76	442	3.30	9.17	164	3.56
2002–03	5.6	20.37	364	3.63	2.06	37	7.56
2005–06	4.6	34.26	745	2.76	1.62	35	7.11
2006–07	4.6	23.63	514	6.61	1.02	22	17.46
2009–10	5.6	17.35	310	7.23	0.63	11	27.44
2014–15	7.7	92.59	1 207	5.59	0.47	6	29.21
2016–17	8.1	71.90	889	11.16	0.13	2	56.94
2018–19	8.1	58.86	731	10.94	0.30	4	40.75
2020–21	6.5	49.01	752	7.34	0.13	2	48.62
2022–23	4.4	11.68	263	11.81	0.11	2	39.84

Table 39: Summary statistics of the length-frequency (LF) distribution of pipi at Otūmoetai. 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	30.85	30	7–52	5.66	0.52
2020–21	32.71	32	12–53	2.83	0.27
2022–23	38.81	37	10–52	0.90	0.90

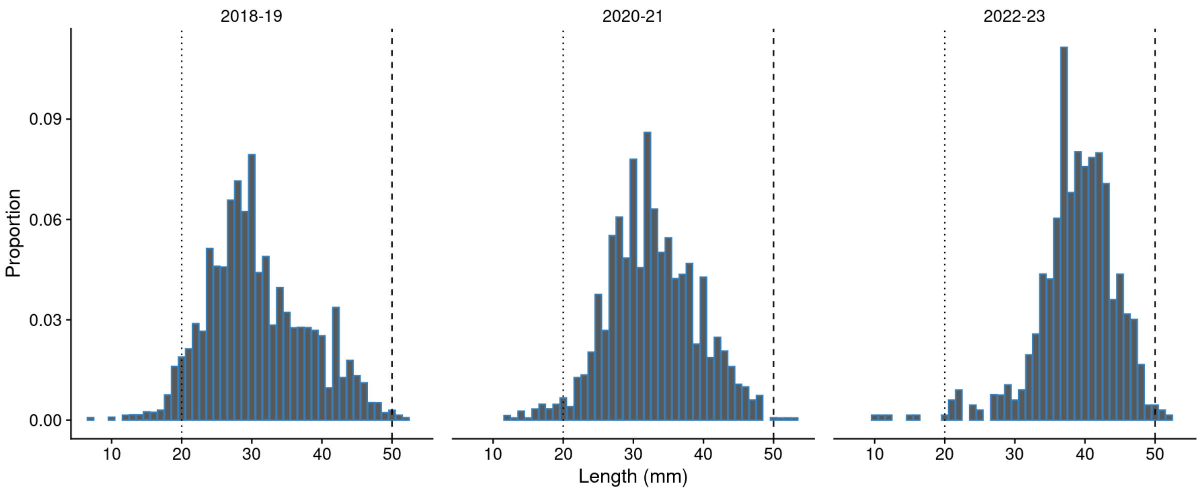


Figure 45: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Otūmoetai (Tauranga Harbour). Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.10 Pataua Estuary

Pataua Estuary is on Northland's east coast, north of Whangārei. Including the present assessment, bivalves in this estuary have been surveyed nine times since 2002–03 (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has included a cockle population on an extensive intertidal sandflat in the upper estuary, and a pipi bed associated with the main channel in the lower estuary. The present survey also included another pipi bed in a sheltered side channel, close to the estuary entrance. This pipi bed was added to the survey following reports by Northland Regional Council of a pipi mortality event in July 2022 (M. Pomarède pers. comm.). The current assessment was based on four strata, with a total of 132 sampling points, including 12 points allocated to phase 2.

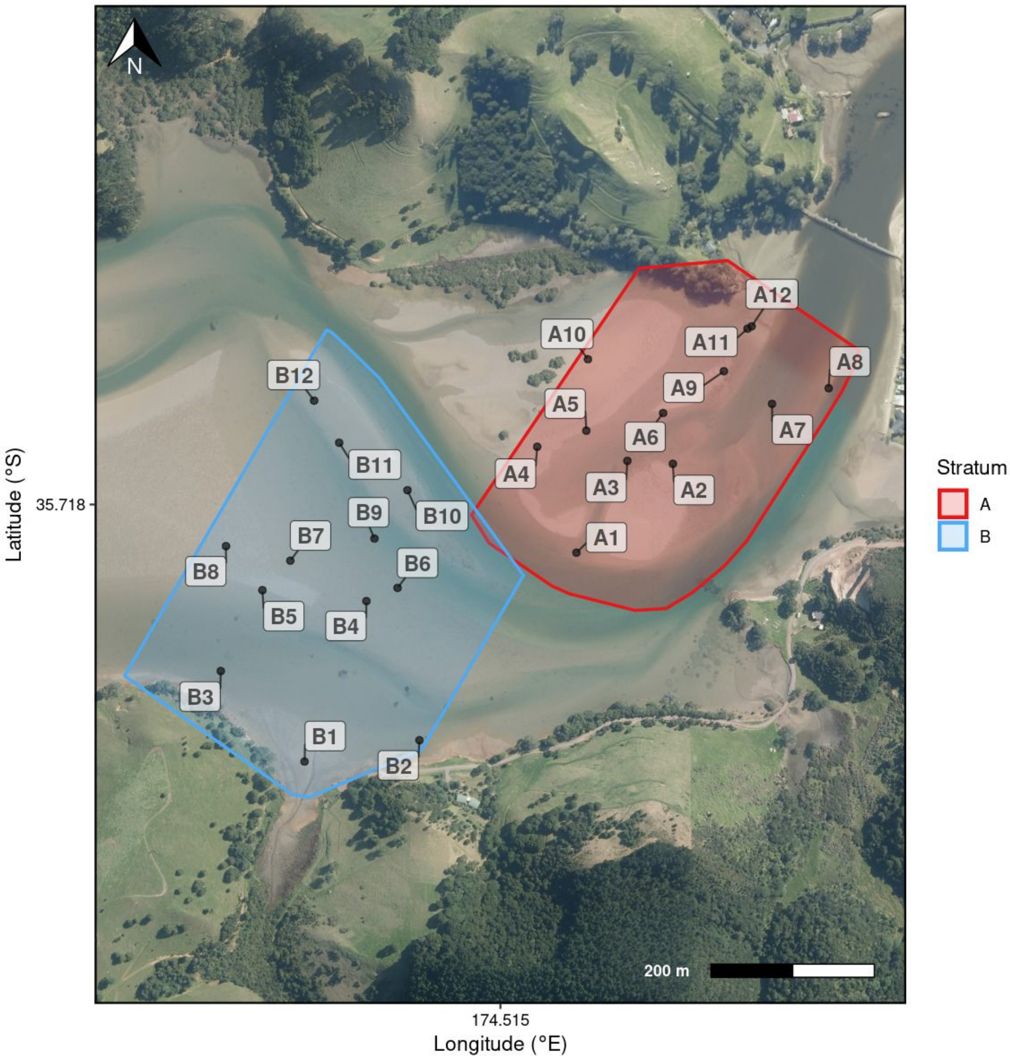
Sediment in the estuary was characterised by a low organic content, with a maximum of 3.5% organics in one sample (Figure 46, and see details in Appendix B, Table B-1). It was mostly composed of fine sand (grain size $>$125 µm), and smaller proportions of medium and coarse sands (grain sizes $>$250 and $>$500 µm). There was a small proportion of sediment fines (grain size $\leq$63 µm), which varied between 0 and 8.3% across samples.

The distribution of cockles was relatively even throughout strata A and B, excluding the deeper parts of the main channel (Figure 47, Table 40). There were also a few (16) individuals in stratum D. Across the sampling extent, the total cockle population in 2022–23 was estimated to have an abundance of 303.16 million (CV: 11.48%) cockles and a density of 1076 cockles per m^2 (Table 41). Both estimates were lower than values in previous recent surveys, including the assessment in the previous year (with estimates of 356.31 million (CV: 12.83%) cockles and 1278 cockles per m^2). There were few large cockles ($\geq$30 mm shell length) at this site, and their abundance estimate of 3.44 million individuals and average density of 12 large cockles per m^2 had considerable uncertainty (42.79%). This size class represented a minor part (1.13%) of the population, which was dominated by medium-size cockles, followed by recruits ($\leq$15 mm shell length) (Table 42, Figure 48). In the three most recent surveys, recruits made up a quarter to about a third of the population; in 2022–23, 25.60% of the population were recruits. Medium-sized cockles have consistently formed a single cohort with mean and modal shell lengths around 17 to 18 mm since 2019–20. Although this size class had regular recruitment through small-sized individuals, there was little growth of medium-sized cockles past the 30-mm threshold of the large size class.

There were no distinct associations between cockle abundance and sediment grain size fractions in the PCA (Figure 49). Nevertheless, there was a separation along PC1 (explaining 56.9% of variance) of the three finer grain size fractions and the coarser size classes, with total cockle abundance tending towards the coarse sediment grain sizes in 2022–23.

The pipi population in the estuary was restricted to the pipi beds, with no individuals in the cockle strata (Figure 50, Table 43). The pipi distribution along the main channel was in the downstream part of stratum C, whereas pipi in stratum D (the newly-added pipi bed) were more evenly distributed. Current population size and density estimates were 2.57 million (CV: 19.64%) pipi and 9 pipi per m^2 (Table 44). Although there have been some fluctuations over time, both estimates signified a decline in the pipi population since 2019–20, including the immediately preceding abundance and density estimates of 3.53 million (CV: 23.14%) pipi and 13 pipi per m^2 in 2021–22. Included in the total population was a small number of large pipi ($\geq$50 mm shell length), which also showed some fluctuations (and usually high CV values) throughout the time series. In 2022–23, this size class increased to 0.47 million (CV: 22.03%) individuals, from 0.23 million (CV: 35.33%) large pipi in 2021–22.

The recent increase in this size class was also evident in their overall proportion within the population, which almost tripled from the previous year to 18.43% in 2022–23 (Table 45). Recruits made up a similar part of the current population, with 11.83% of pipi at less than 20 mm shell length. The mean and modal sizes increased over this short period from 33.20 mm and 37 mm shell length in 2021–22 to 39.37 mm and 47 mm shell length in the current assessment. Although the population structure remained bimodal, the recent shift to larger sizes was also reflected in the length-frequency distributions (Figure 51).



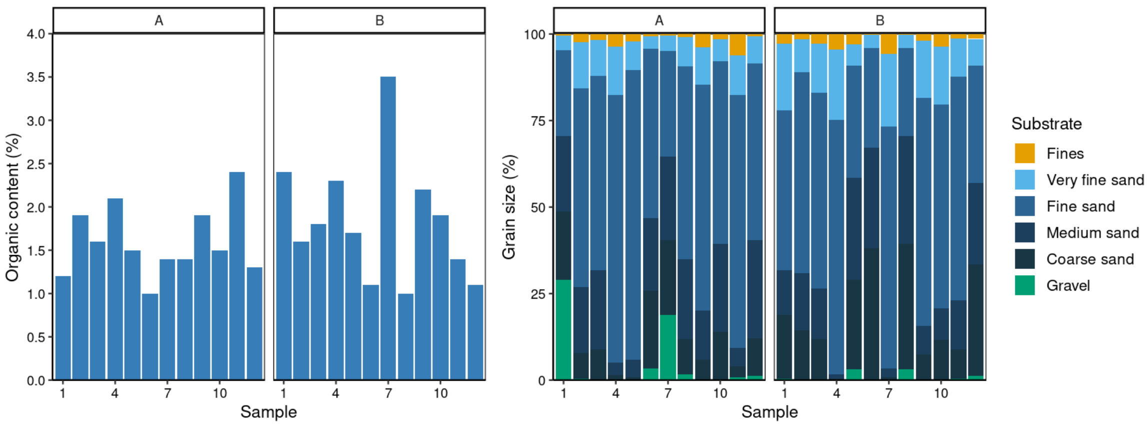


Figure 46: Sediment sample locations and characteristics at Pataua Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125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

3.10.1 Cockles at Pataua Estuary

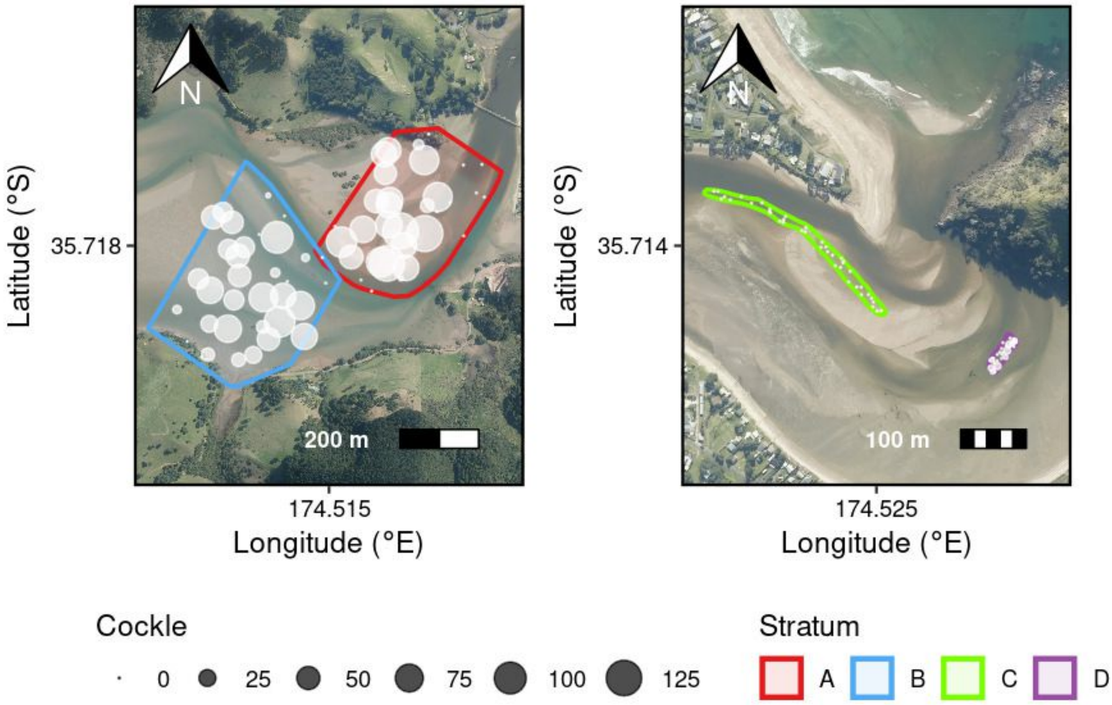


Figure 47: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 40: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2022–23. 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	12.3	33	1 409	149.70	1 220	17.41
B	15.3	33	1 156	153.44	1 001	15.02
C	0.5	39	0	0.00	0	
D	0.1	27	16	0.02	17	30.22

Table 41: Estimates of cockle abundance at Pataua Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	88.64	832	4.45	21.63	203	6.94
2003–04	10.4	123.54	1 182	3.02	13.56	130	8.90
2005–06	10.4	108.08	1 034	5.18	19.87	190	7.57
2013–14	26.3	410.54	1 561	5.30	6.54	25	15.94
2015–16	27.8	380.13	1 368	7.58	4.89	18	29.68
2017–18	27.7	406.39	1 467	11.78	4.54	16	44.37
2019–20	27.9	362.52	1 299	12.71	3.96	14	44.65
2021–22	27.9	356.31	1 278	12.83	2.25	8	50.01
2022–23	28.2	303.16	1 076	11.48	3.44	12	42.79

Table 42: Summary statistics of the length-frequency (LF) distribution of cockles at Pataua 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	18.41	17	5–48	28.48	1.09
2021–22	18.07	17	5–38	31.59	0.63
2022–23	18.85	18	5–36	25.60	1.13

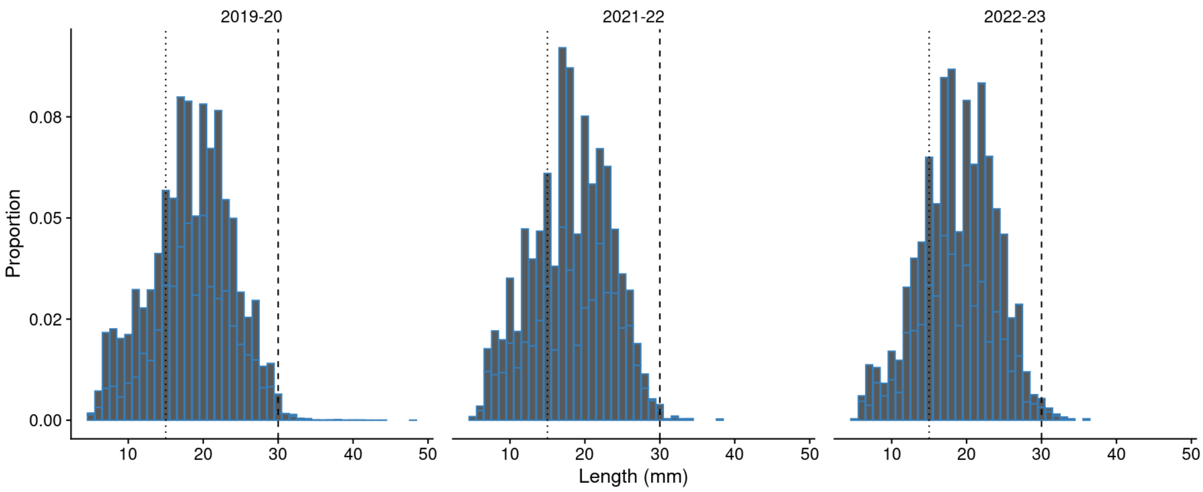


Figure 48: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

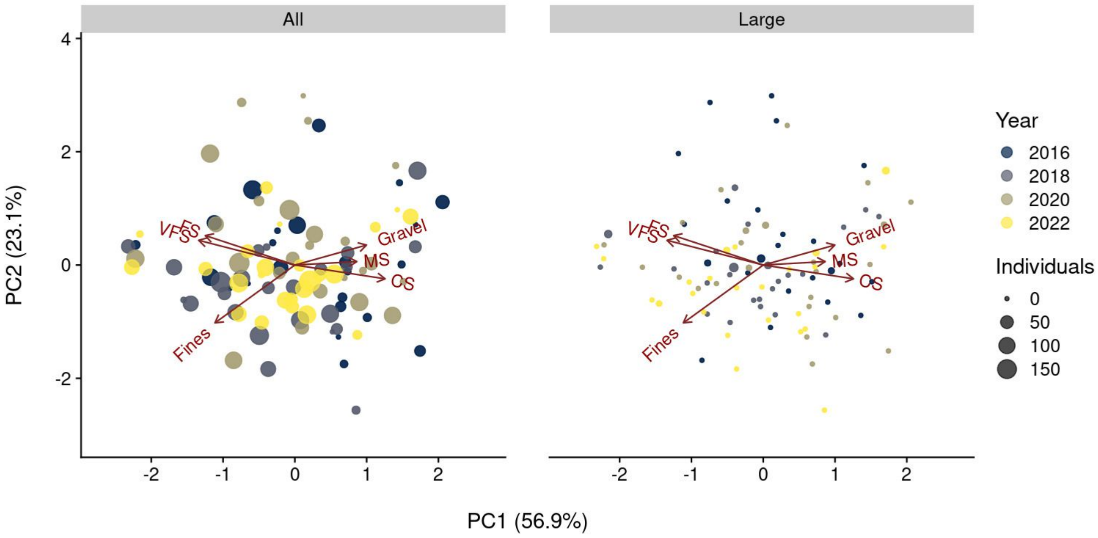


Figure 49: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Pataua Estuary. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

3.10.2 Pipi at Pataua Estuary

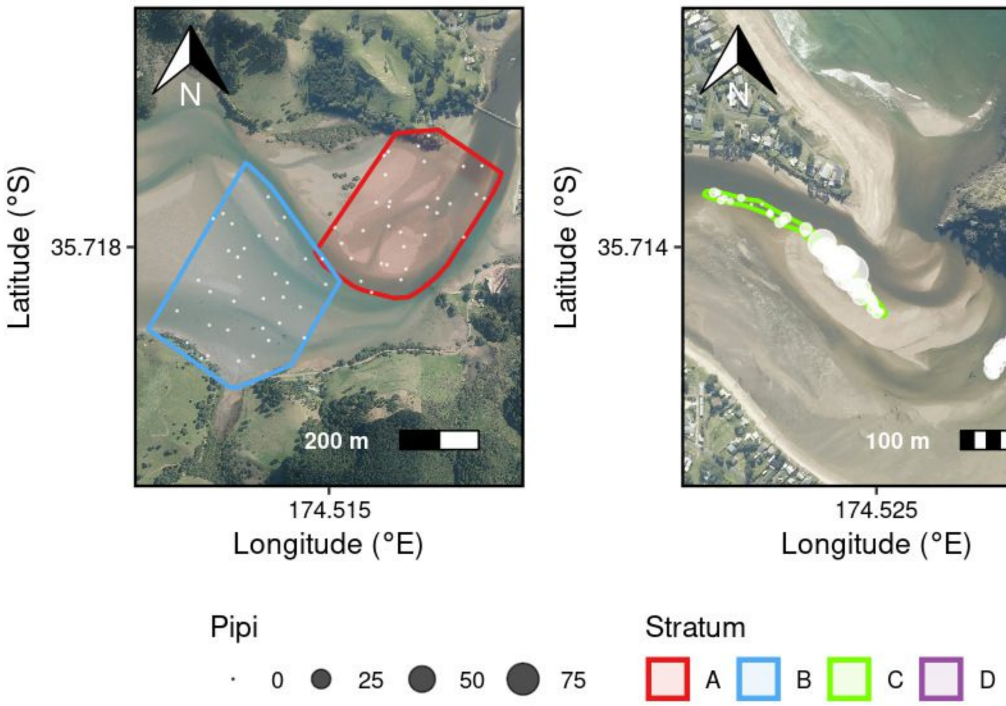


Figure 50: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 43: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2022–23. 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	12.3	33	0	0.00	0	
B	15.3	33	0	0.00	0	
C	0.5	39	673	2.32	493	21.77
D	0.1	27	227	0.25	240	10.70

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	10.7	16.58	156	14.00	0.02	<1	>100
2003–04	10.4	2.21	21	11.72	0.43	4	7.94
2005–06	10.4	1.18	11	9.73	0.45	4	32.47
2013–14	26.3	7.52	29	17.28	0.47	2	60.35
2015–16	27.8	6.45	23	14.67	0.19	<1	79.86
2017–18	27.7	2.04	7	35.38	0.19	<1	>100
2019–20	27.9	9.45	34	18.50	0.05	<1	52.35
2021–22	27.9	3.53	13	23.14	0.23	<1	35.33
2022–23	28.2	2.57	9	19.64	0.47	2	22.03

Table 45: Summary statistics of the length-frequency (LF) distribution of pipi at Pataua 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	34.82	38	8–60	8.16	0.48
2021–22	33.20	37	8–58	24.56	6.44
2022–23	39.37	47	9–58	11.83	18.43

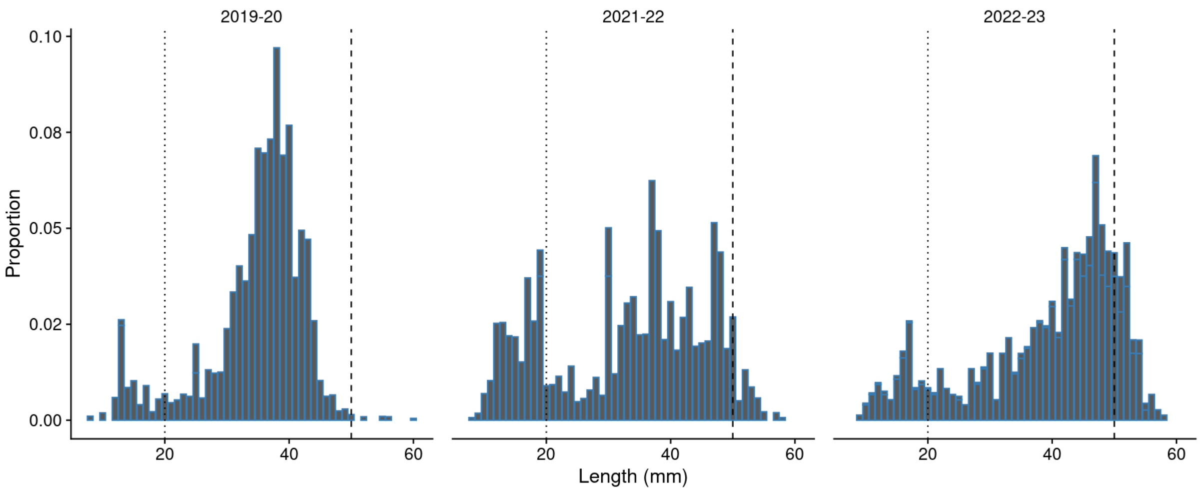


Figure 51: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Waiotahe Estuary

Waiotahe Estuary is a small estuary in eastern Bay of Plenty. This site was added to the northern survey series in 2000–01, and there have been a total of ten surveys in the monitoring series (see Appendix A, Tables A-1, A-2). Bivalves at this site were exposed to considerable faecal (*Escherichia coli*) contamination in 2017, and continue to be contaminated at present (Bay of Plenty Regional Council 2021). The sampling extent at this site encompasses a continuous area including the estuary channel, with little variation in the sampling extent since the start of the survey series. In the present assessment, the field survey sampled 154 points across three different strata, including 14 points in phase-2 sampling.

The sediment organic content in the estuary was low, ranging from 1.1 to 2.7% (Figure 52, and see details in Appendix B, Table B-1). There was some variation in sediment granulometry across samples, but fine sand (grain size $>$125 µm) was generally the prevalent grain size fraction. Most samples only contained a small proportion of sediment fines (grain size $\leq$63 µm), although four samples exceeded 10% of sediment in this grain size fraction.

Cockles at Waiotahe Estuary were restricted to the upper part of the sampling extent, stratum A (Figure 53, Table 46). Total abundance and mean density estimates for this species were 11.69 million (CV: 15.91%) cockles and 98 cockles per m^2 (Table 47). The current estimates were similar to the preceding estimates in 2019–20, which had signified a marked decrease in the cockle population from comparatively high estimates in 2013–14 and 2016–17. The current population included no large cockles ($\geq$ 30 mm shell length).

In contrast, 60.74% of the cockle population were recruits ($\leq$15 mm shell length), and these small-sized individuals also made up a substantial proportion of the population in the two preceding surveys (i.e., 31.44% in 2016–17 and 45.39% in 2019–20) (Table 48, Figure 54). With the increase in recruits, the unimodal population distinctly shifted towards smaller sizes in the two most recent surveys, and there was a 10-mm reduction in modal shell length between 2019–20 and 2022–23 to 12 mm. These data highlight the influence of regular strong recruitment events on the cockle population, but also a general lack of growth by recruits and medium-sized cockles to larger sizes, particularly beyond the 30-mm size class cut-off.

In relation to sediment grain sizes, total cockle abundance showed a shift from coarse sand towards finer grain size fractions, including sediment fines in 2022–23 (Figure 55).

The pipi distribution at Waiotahe Estuary showed an opposite pattern to that of cockles, with most pipi mid-estuary and in the northern part of the sampling extent (Figure 56, Table 49). Pipi population estimates indicated a further marked decline in the population from a comparatively large population size in 2013–14 and 2016–17 to low estimates in 2022–23: current pipi abundance was estimated at 27.90 million (CV: 25.01%) individuals and their average density at 233 pipi per m^2 (Table 50). These estimates were the lowest values since the start of the monitoring series. Large pipi ($\geq$50 mm shell length) continued to be scarce, and their estimates have been low with high uncertainty (CV values between 23.71 and >100%) since 2009–10.

Recruits ($\leq$20 mm shell length) also only contributed a small proportion (about 10%) of the population in recent surveys (since 2016–17), although their proportion increased to 17.80% in 2022–23. The length-frequency distributions confirmed that relatively small medium-sized pipi formed most of the unimodal population at present, with mean and modal sizes of 26.08 mm and 24 mm shell length, respectively.

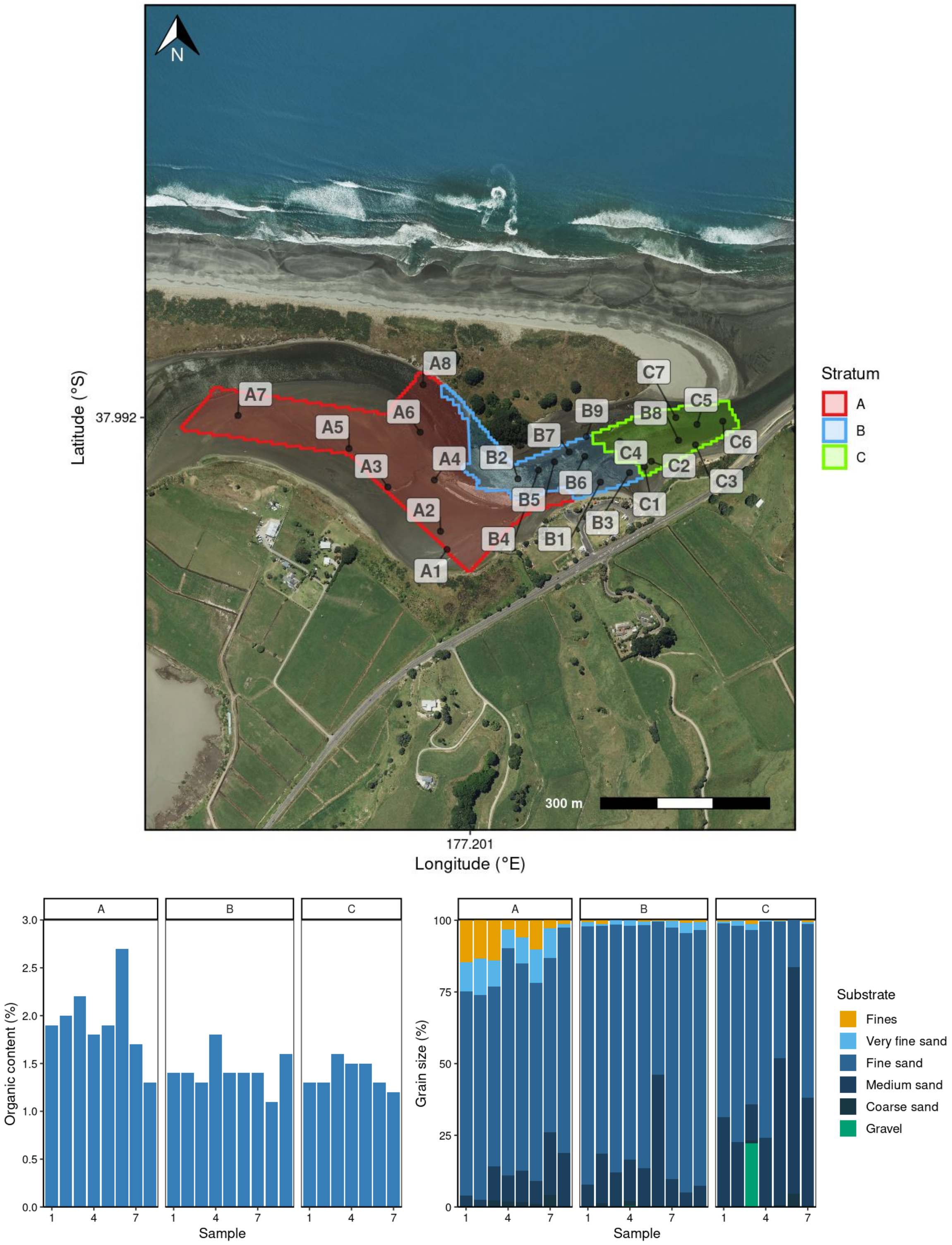


Figure 52: Sediment sample locations and characteristics at Waiotahe Estuary. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.11.1 Cockles at Waiotahe Estuary

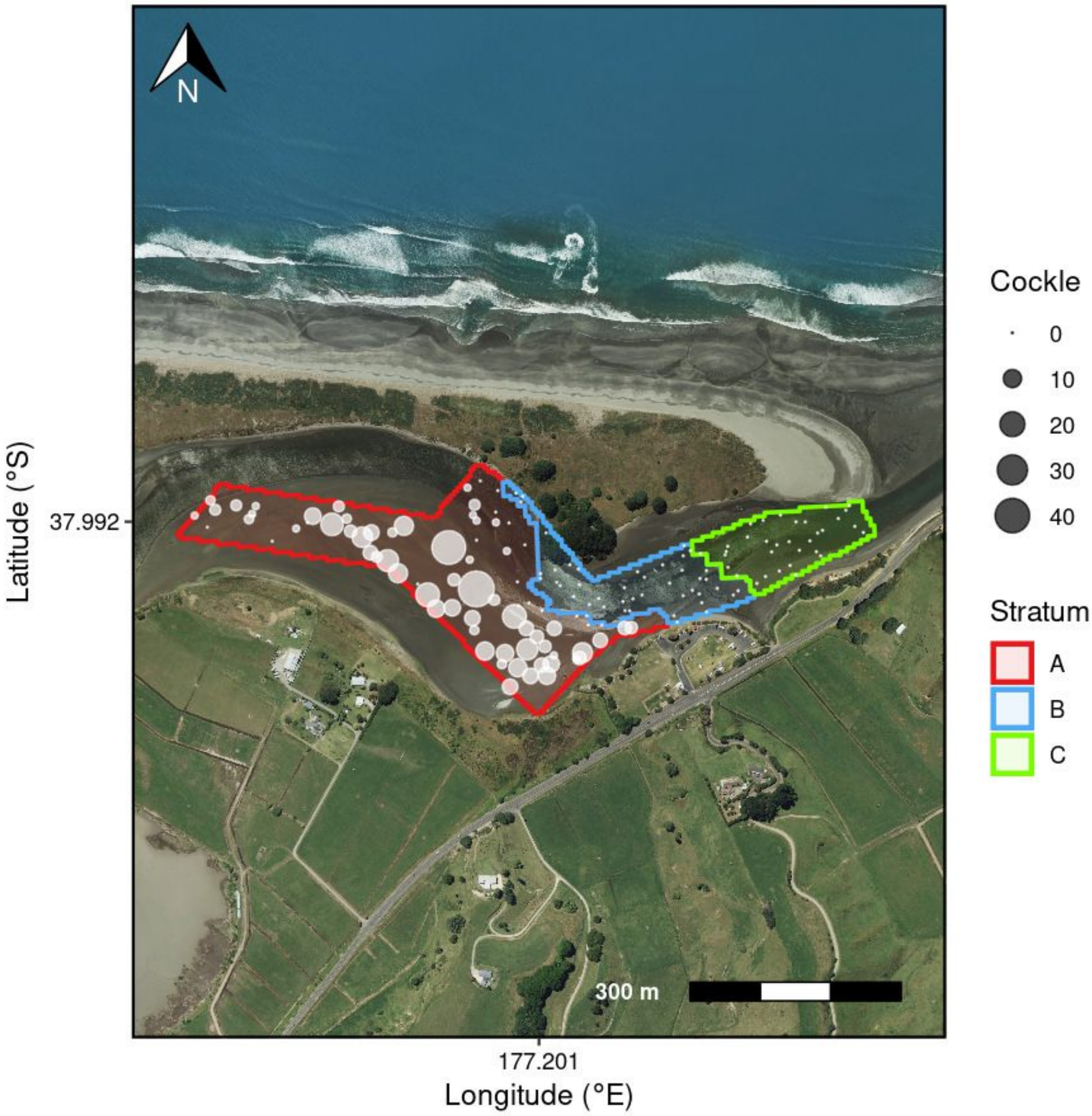


Figure 53: Map of sample strata and individual sample locations for cockles at Waiotahe Estuary, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 46: Estimates of cockle abundance at Waiotahe Estuary, by stratum, for 2022–23. 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	7.7	77	411	11.69	153	15.91
B	2.4	44	0	0.00	0	
C	1.9	33	0	0.00	0	

Table 47: Estimates of cockle abundance at Waiotahe Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	8.5	36.66	431	8.08	0.51	6	16.53
2002–03	8.5	36.67	431	8.08	0.52	6	16.42
2003–04	8.5	5.77	68	9.16	0.09	1	34.2
2004–05	9.5	1.13	12	12.12	0.04	<1	>100
2005–06	9.5	5.88	62	10.53	0.09	<1	52.32
2009–10	9.5	20.17	212	15.50	0.06	<1	70.81
2013–14	11.2	47.37	422	10.10	0.00	0	
2016–17	12.0	48.61	406	16.66	0.12	1	80.6
2019–20	12.0	13.51	113	12.26	0.07	<1	69.67
2022–23	12.0	11.69	98	15.91	0.00	0	

Table 48: Summary statistics of the length-frequency (LF) distribution of cockles at Waiotahe 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 (%)
2016–17	17.71	20	5–30	31.44	0.25
2019–20	16.57	22	6–31	45.39	0.54
2022–23	14.85	12	6–29	60.74	0.00

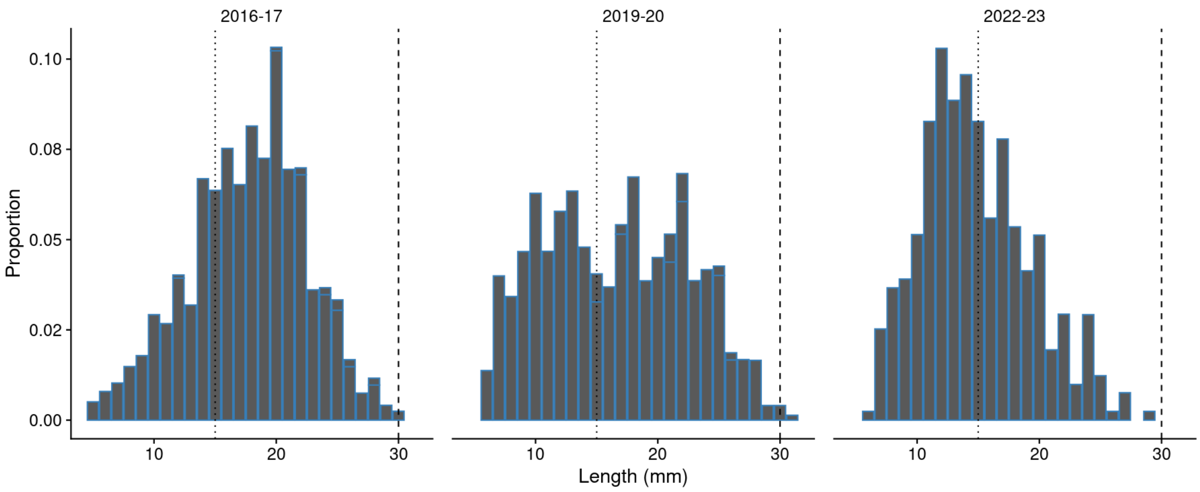


Figure 54: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Waiotahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

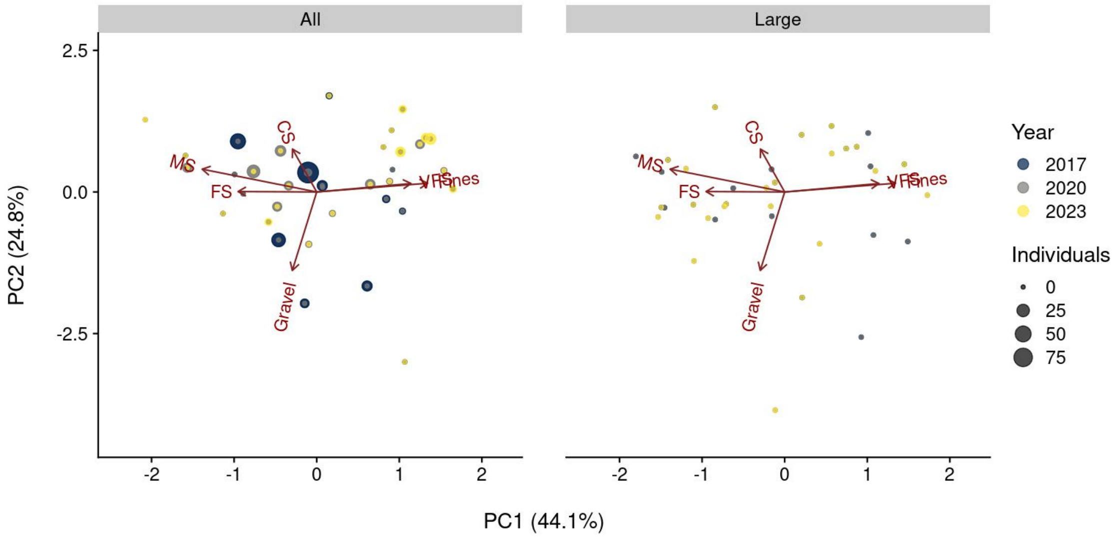


Figure 55: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Waiotahe Estuary. Sediment grain size fractions are defined as fines (silt and clay) ≤63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

3.11.2 Pipi at Waiotahe Estuary

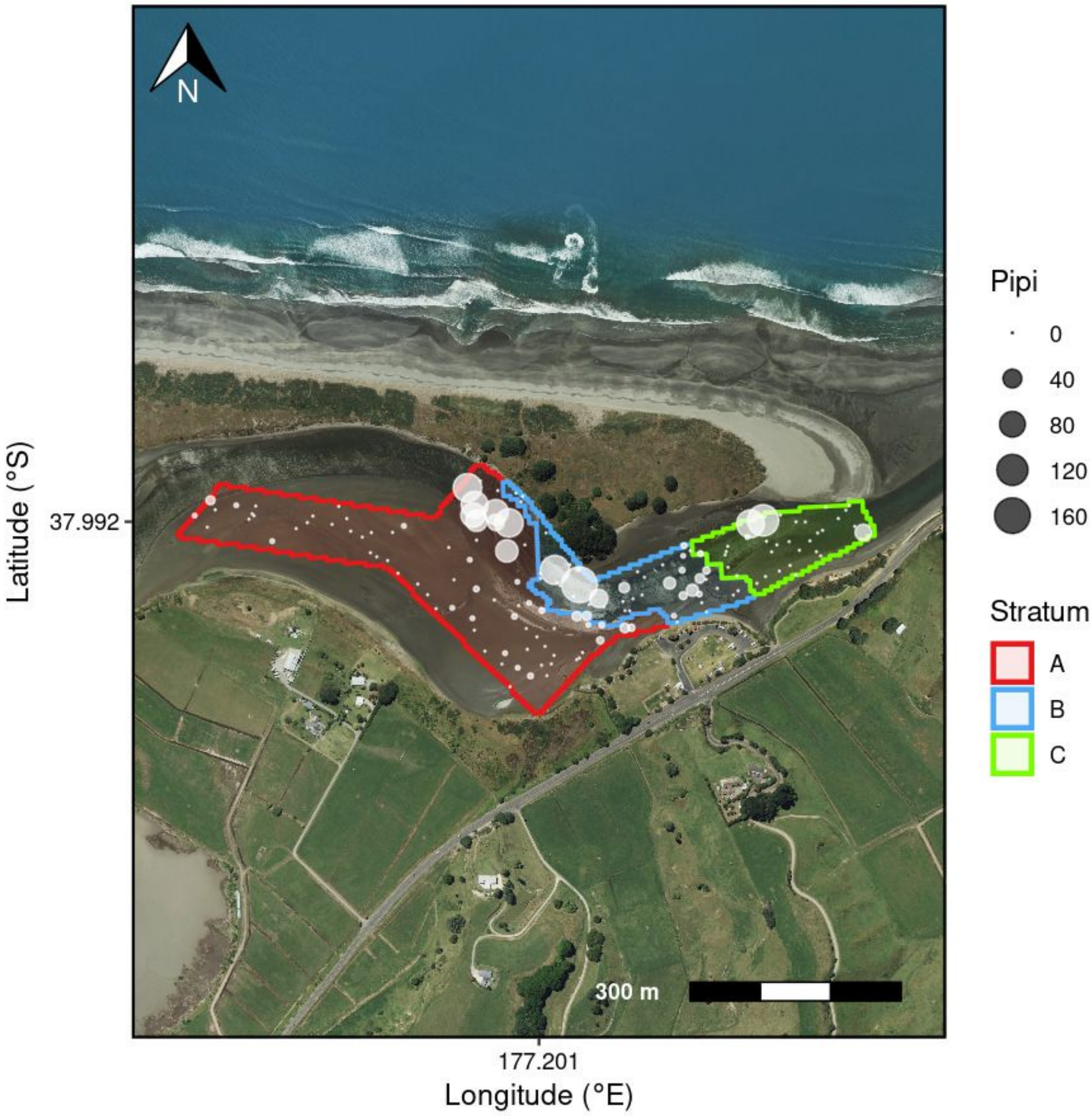


Figure 56: Map of sample strata and individual sample locations for pipi at Waiotahe Estuary, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 49: Estimates of pipi abundance at Waiotahe Estuary, by stratum, for 2022–23. 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	7.7	77	630	17.91	234	32.21
B	2.4	44	374	5.92	243	51.08
C	1.9	33	250	4.06	216	61.50

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	8.5	183.91	2 164	5.14	1.46	17	15.83
2002–03	8.5	183.91	2 164	5.14	1.46	17	15.83
2003–04	8.5	47.91	564	5.70	0.20	2	19.63
2004–05	9.5	41.41	436	5.00	0.81	9	12.1
2005–06	9.5	40.61	427	9.30	1.24	13	19.83
2009–10	9.5	96.71	1 018	12.48	3.56	38	23.71
2013–14	11.2	150.21	1 338	12.57	0.09	<1	65.16
2016–17	12.0	166.25	1 388	18.36	1.05	9	43.81
2019–20	12.0	80.45	672	17.15	0.69	6	55.33
2022–23	12.0	27.90	233	25.01	0.07	<1	>100

Table 51: Summary statistics of the length-frequency (LF) distribution of pipi at Waiotahe 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 (%)
2016–17	30.73	35	7–54	12.08	0.63
2019–20	31.15	34	9–59	14.86	0.86
2022–23	26.08	24	8–54	17.80	0.27

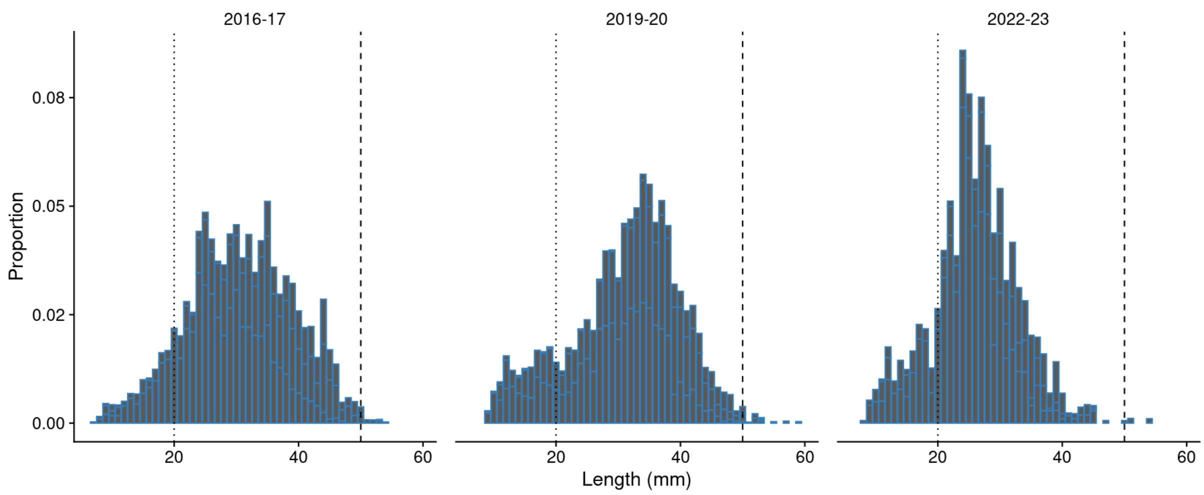


Figure 57: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Waiotahe Estuary. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Whangamatā Harbour

Whangamatā Harbour is a Waikato site, situated on the east coast of Coromandel Peninsula. The harbour has been included in 13 northern bivalve surveys since 1999–2000 (see Appendix A, Tables A-1, A-2). Since 2014–15, the sampling extent has been mostly consistent, encompassing strata on either side of the tidal side channel of Moanaanuanu Estuary. In this period, some variation in the sampling extent across surveys was caused by changes in the distribution of pipi, which were predominantly in a shallow intertidal area within the main harbour channel. The current survey sampled bivalves in three strata, with a total of 92 points.

Sediment within the cockle strata was low in organic content (1.5 to 3.5%), although it exceeded 8% in one sample (Figure 58, and see details in Appendix B, Table B-1). The bulk of the sediment was a combination of fine and medium sands (grain sizes >125 µm and >250 µm), with varying proportions of other grain size fractions. The proportion of sediment fines (grain size ≤ 63 µm) varied from 0.5 to 7.0% across all samples.

Cockles at Whangamatā Harbour were concentrated in stratum B, with only few individuals in the other strata (Figure 59, Table 52). Cockle population estimates for 2022–23 were 97.58 million (CV: 9.32%) individuals, and an estimated mean density of 1206 individuals per m^2 (Table 53). These estimates marked a notable increase in the total cockle population, and highlighted that this population was characterised by fluctuations throughout the survey series. For example, the recent increase followed distinct population decreases in the preceding three surveys (i.e., since 2014–15). Although there have been few large cockles (≥ 30 mm shell length) in the population since 2006–07, this size class also showed some fluctuations over time. It underwent a recent decrease from the preceding survey in 2020–21 to abundance and density estimates of 1.88 million (CV: 29.45%) large cockles and 23 large cockles per m^2 in 2022–23. Although the proportion of large cockles has been consistently small in the three most recent surveys, there was a recent decline in their proportion to 1.93% of the current population in 2022–23 (Table 54). In comparison, recruits (≤ 15 mm shell length) were a significant part of the population in these recent surveys, making up a quarter to a third of individuals; in 2022–23, these small-sized individuals represented 35.34% of the population. The population size structure remained unimodal in recent assessments, with a strong cohort of medium-sized cockles (Figure 60). Changes in mean and modal sizes corresponded with changes in the proportion of recruits; e.g., both size metrics decreased in 2022–23 with the increase in the proportion of recruits and the concomitant decrease in large cockles. The current mean and modal sizes were just above the recruits cut-off size of 15 mm, with a mean shell length of 18.03 mm and modal size of 17 mm shell length.

There was no clear association of cockle abundance with particular sediment grain size fractions at this site (Figure 61). This lack of a pattern was evident across surveys, including the most recent assessment.

Pipi were predominantly in stratum C, a shallow intertidal pipi bed within the main harbour channel (Figure 62, Table 55). Their total abundance was estimated at 4.57 million (CV: 13.03%) pipi in 2022–23 (Table 56). The corresponding mean density estimate was 56 pipi per m^2. Both estimates documented a continued decrease in the pipi population at this site, from relatively high estimates in 2018–19 of 10.01 million (CV: 27.66%) pipi and 133 pipi per m^2. Nevertheless, similar to the cockle population, the pipi population at Whangamatā Harbour fluctuated over time, including lower estimates in earlier surveys (e.g., 2014–15). These fluctuations were also reflected in the population of large pipi (≥ 50 mm shell length) (although their estimates frequently had high CV values). The 2022–23 estimates for large pipi were 0.77 million (CV: 25.44%) individuals, with a mean density of ten large pipi per m^2. Both estimates were decreases from the preceding three surveys. Inspite of this decrease, large pipi still made up 16.93% of the current population, with recruits (≤ 20 mm shell length) contributing 25.05% of individuals (Table 57). In the previous two surveys, large pipi contributed about a quarter of individuals, while the proportion of recruits was small (8.94% and 1.26%). Through these changes, the population changed from a unimodal to a bimodal size structure, with a comparatively small cohort of medium and large pipi, and a second cohort of recruits. There was an 8-mm decrease in mean size to 35.28 mm, but the modal size remained similar in 2022–23 at 47 mm shell length.

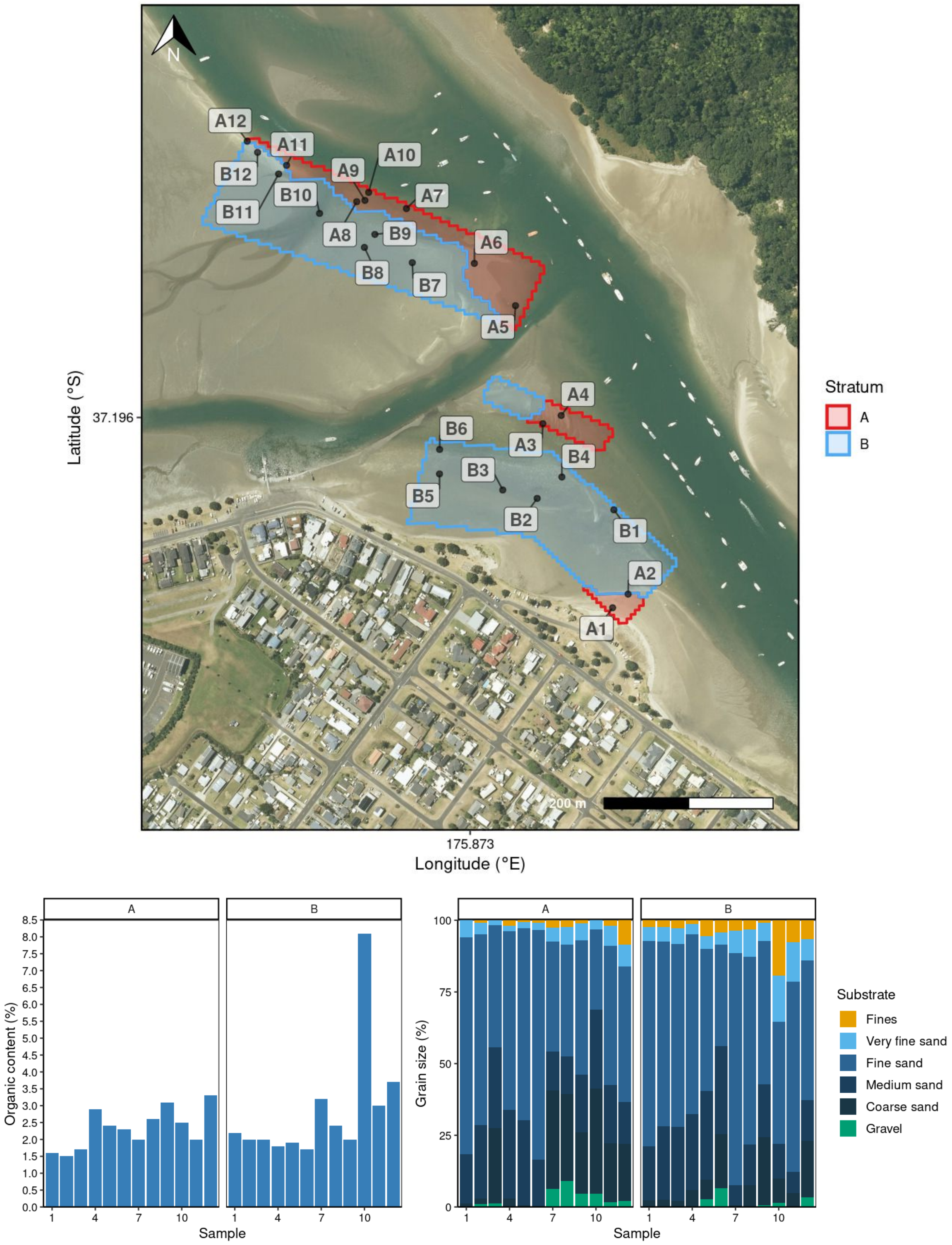


Figure 58: Sediment sample locations and characteristics at Whangamatā Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine,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

3.12.1 Cockles at Whangamatā Harbour

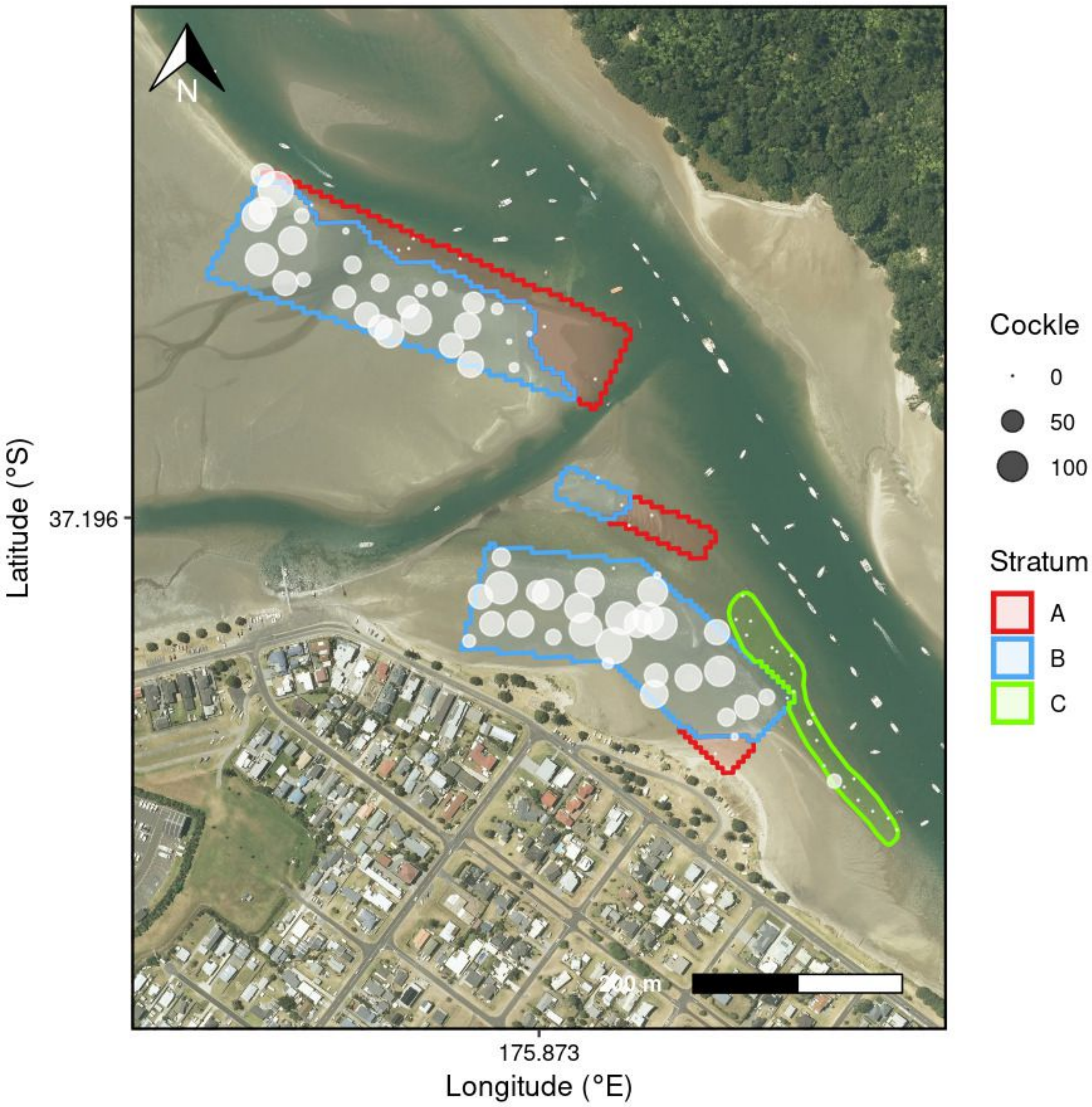


Figure 59: Map of sample strata and individual sample locations for cockles at Whangamatā Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 52: Estimates of cockle abundance at Whangamatā Harbour, by stratum, for 2022–23. 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	1.6	12	58	2.19	138	94.50
B	5.9	60	3 410	95.22	1 624	9.30
C	0.6	20	19	0.18	27	94.61

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	70.55	1 287	4.31	17.14	313	6.65
2000–01	5.5	60.33	1 101	4.29	13.95	255	7.60
2001–02	5.5	38.80	708	4.08	6.87	125	7.24
2002–03	5.5	29.78	543	6.61	8.03	146	9.27
2003–04	5.5	43.47	793	4.18	13.10	239	5.18
2004–05	5.5	38.85	709	4.64	9.94	181	4.62
2006–07	24.6	348.01	1 414	0.71	2.86	12	12.99
2010–11	5.9	84.83	1 441	7.06	1.38	23	18.66
2014–15	7.6	104.53	1 372	6.59	2.73	36	19.83
2016–17	7.7	86.78	1 125	7.86	4.00	52	24.60
2018–19	7.5	78.98	1 047	11.38	2.41	32	36.69
2020–21	8.2	61.20	748	8.70	3.49	43	19.09
2022–23	8.1	97.58	1 206	9.32	1.88	23	29.45

Table 54: Summary statistics of the length-frequency (LF) distribution of cockles at Whangamatā 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	18.74	20	4–58	31.45	3.05
2020–21	20.37	24	4–42	23.83	5.69
2022–23	18.03	17	4–41	35.34	1.93

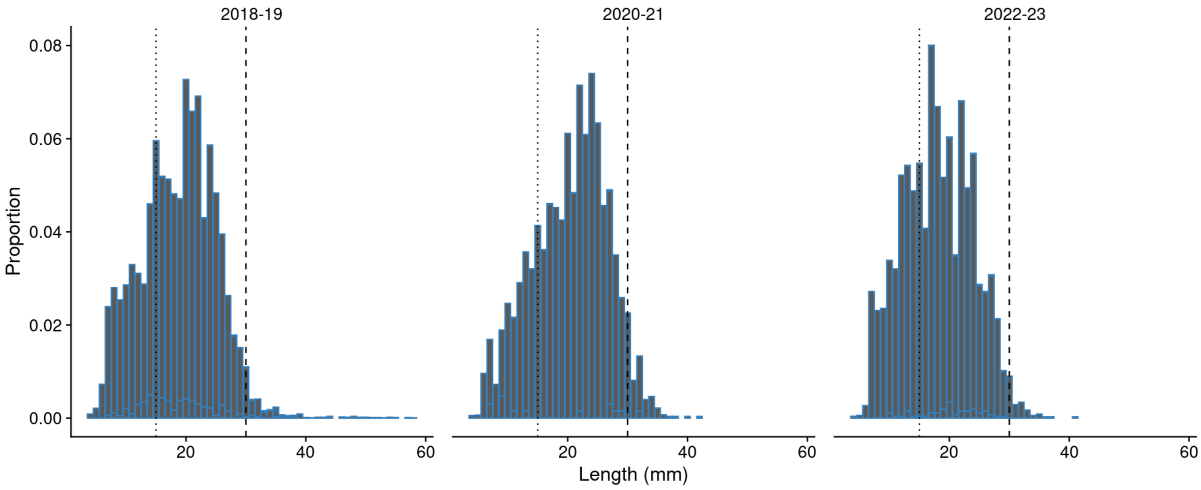


Figure 60: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

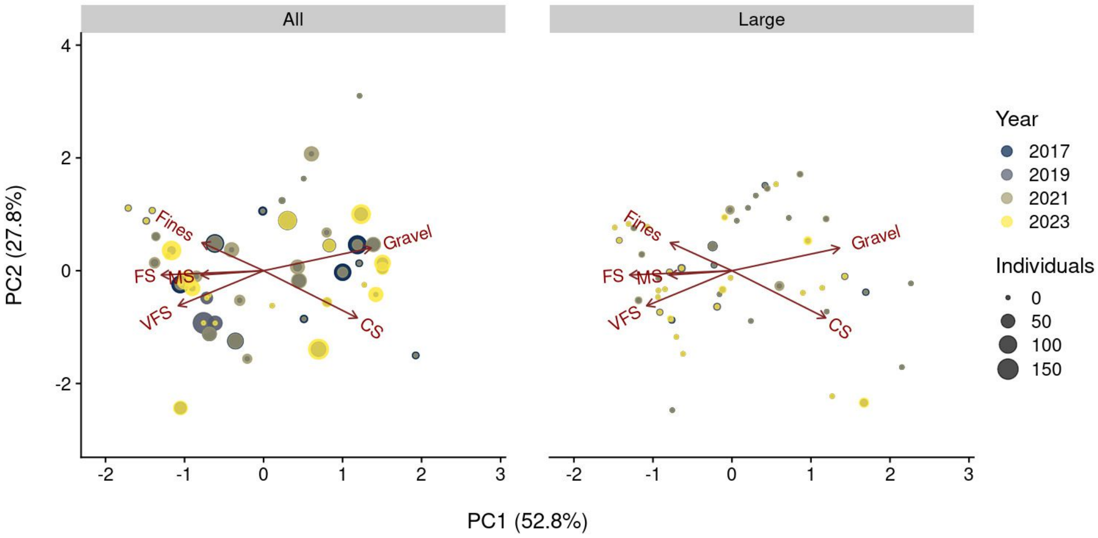


Figure 61: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Whangamatā Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 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 Whangamatā Harbour

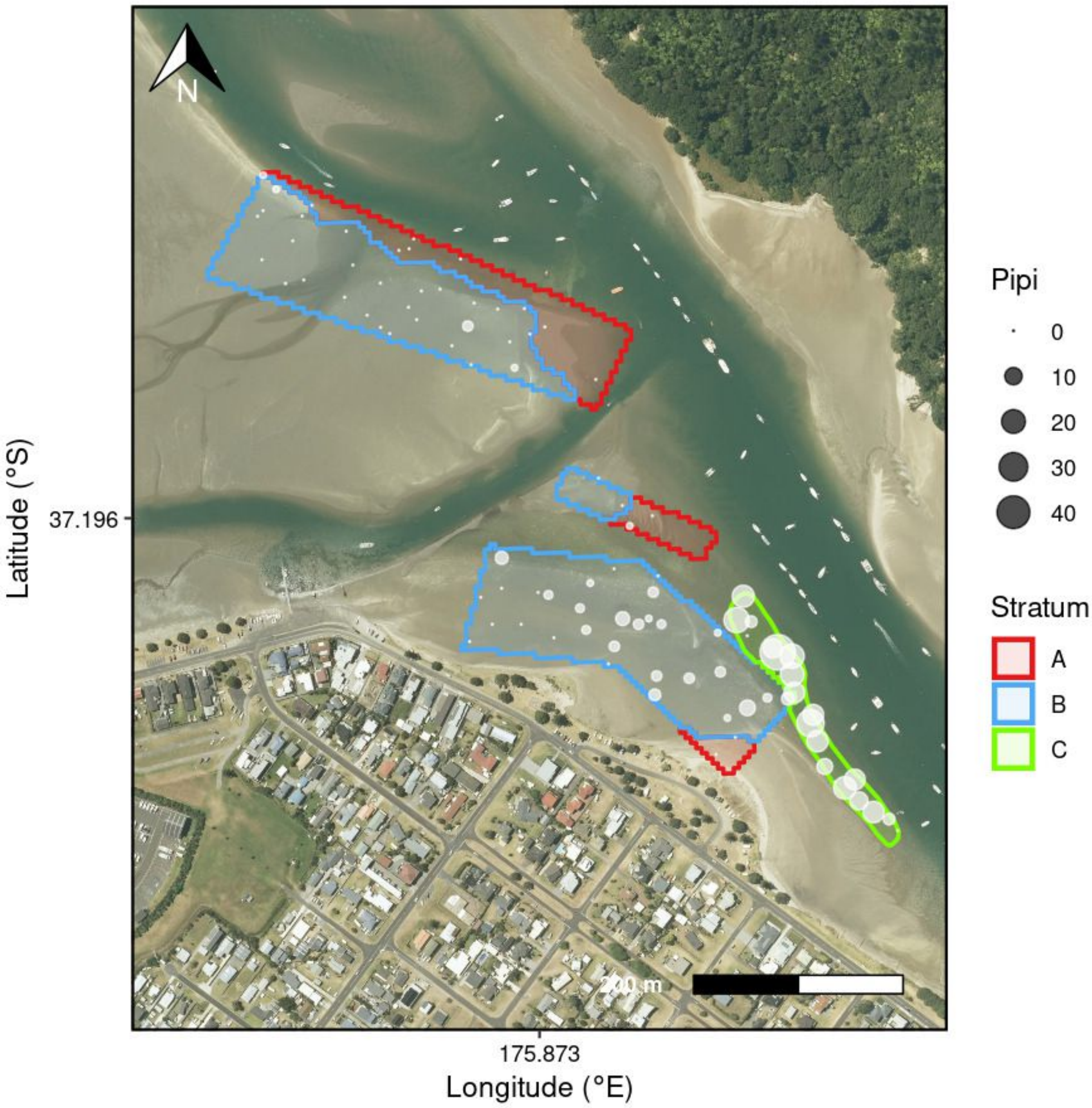


Figure 62: Map of sample strata and individual sample locations for pipi at Whangamatā Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 55: Estimates of pipi abundance at Whangamatā Harbour, by stratum, for 2022–23. 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	1.6	12	2	0.08	5	67.42
B	5.9	60	65	1.82	31	21.08
C	0.6	20	290	2.68	414	16.93

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	15.07	275	9.25	7.25	132	10.78
2000–01	5.5	11.86	216	11.17	5.05	92	21.86
2001–02	5.5	6.38	116	10.45	2.71	50	19.77
2002–03	5.5	5.95	109	10.95	1.60	29	10.55
2003–04	5.5	4.84	88	7.82	2.03	37	9.50
2004–05	5.5	2.30	42	11.13	1.26	23	12.05
2006–07	24.6	3.26	13	7.50	1.49	6	15.43
2010–11	5.9	5.56	94	15.02	1.62	27	39.20
2014–15	7.6	3.79	50	19.69	1.53	20	75.18
2016–17	7.7	7.65	99	24.21	3.87	50	20.49
2018–19	7.5	10.01	133	27.66	2.79	37	43.95
2020–21	8.2	7.79	95	8.64	1.79	22	18.97
2022–23	8.1	4.57	56	13.03	0.77	10	25.44

Table 57: Summary statistics of the length-frequency (LF) distribution of pipi at Whangamatā 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 (%)
2018–19	40.82	34	6–66	8.94	27.90
2020–21	43.31	46	14–62	1.26	23.01
2022–23	35.28	47	10–60	25.05	16.93

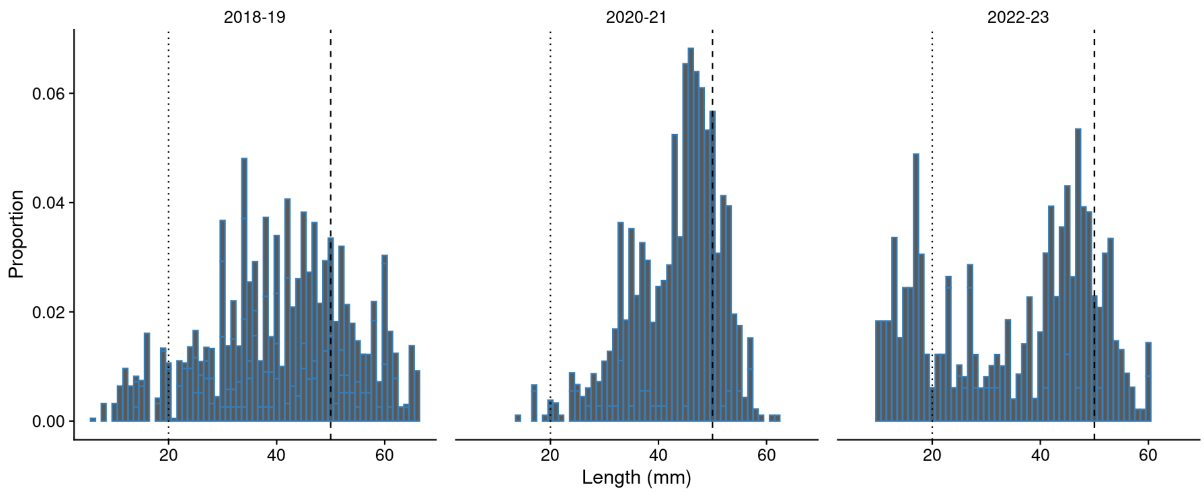


Figure 63: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangamatā Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.13 Whangapoua Harbour

Whangapoua Harbour is another site in the Waikato region, and on the eastern side of Coromandel Peninsula. The first northern survey of the harbour was in 2002–03, and there have been a total of nine assessments, including this survey (see Appendix A, Tables A-1, A-2). The sampling extent covers two separate areas within the harbour, with two disjunct strata each at Matarangi and in its western area. Three of these strata are cockle beds, with a pipi bed in the remaining stratum close to the harbour entrance in the main channel. Across these strata, the sampling effort in 2022–23 was a total of 140 points.

Sediment samples at Whangapoua Harbour were low in organic content (<2.7%) and in the proportion of sediment fines (grain size ≤63 µm), with a maximum of 6.1% in this grain size fraction (Figure 64, and see details in Appendix B, Table B-1). Most of the sediment consisted of fine and medium sands (grain sizes >125 µm and >250 µm), with the prevalence of either of these grain size fractions dependent on the stratum. Sediment in strata B and C also contained very fine sand (grain size >63 µm).

The cockle population was evenly distributed throughout the three designated cockle strata, strata A to C (Figure 65, Table 58). Across the entire sampling extent, the 2022–23 population was estimated to consist of 31.30 million (CV: 10.05%) cockles, occurring at a mean density of 617 cockles per m^2 (Table 59). Following a marked decline in the preceding survey in 2020–21, these estimates documented a further reduction in the cockle population at Whangapoua Harbour. In contrast to this total population trend, individuals in the large size class (≥30 mm shell length) showed an increase, even though their numbers and density remained small (1.84 million large cockles at a density of 36 large individuals per m^2; CV: 15.53%).

The overall population decrease and coincidental increase in large cockles led to a higher proportion of the latter size class within the current population: large cockles made up 5.89% of the population in 2022–23 (Table 60). At the same time, the proportion of recruits (≤15 mm shell length) remained largely unchanged from the preceding survey, at 13.96% in 2022–23, although this size class represented almost a third of the population in 2018–19. Nevertheless, the growth of medium-sized cockles to greater sizes meant that recruits made up a small second cohort in the current population (Figure 66). The growth in the former size class was also reflected in a distinct (5-mm) increase in modal size to 25 mm shell length in 2022–23.

Exploring the relationship between cockle abundance and the different grain size fraction indicated some separation along axis 1 of the PCA (Figure 67). This axis explained 58% of the variance in the current data, with a general association between cockle abundance and comparatively fine grain size fractions.

Pipi at Whangapoua Harbour were restricted to the pipi bed (Figure 68, Table 61). Their population showed a marked decline from previous estimates in 2020–21, with abundance decreasing from 5.50 million (CV: 13.42%) pipi in the preceding survey to 1.50 million (CV: 9.96%) individuals in the present assessment (Table 62). There was a similar drop in their estimated density from 104 pipi per m^2 to 7 individuals per m^2 in 2022–23. The population included a small number of large pipi (≥50 mm shell length) with current abundance and density estimates of 0.34 million (CV: 11.34%) large pipi and 7 large pipi per m^2.

Consideration of length-frequency distributions from the three most recent assessments showed that some of the most recent decline in the pipi population was related to the proportion of recruits (≤20 mm shell length) (Table 63). This size class made up over 20% of the population in 2018–19 and 2020–21, compared with 4.86% in 2022–23. In addition to this change, there was overall shift in the medium size class towards larger sizes, including growth into the large size class, which led to a notable proportion (22.70%) of large pipi within the overall population. This growth was also reflected in a marked recent increase in mean and modal sizes; e.g., the latter increased from 30 mm to 47 mm shell length between 2020–21 and 2022–23.

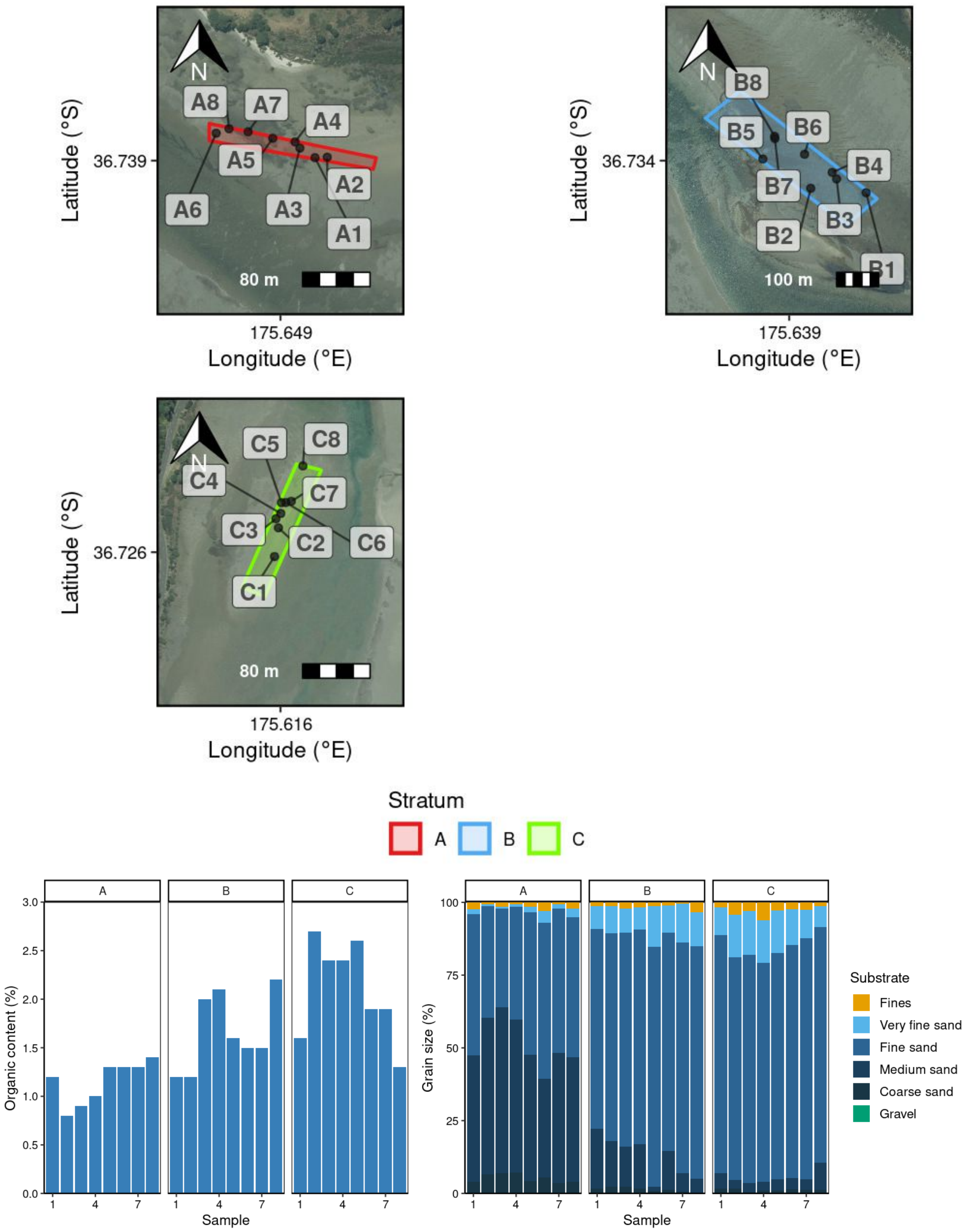


Figure 64: Sediment sample locations and characteristics at Whangapoua Harbour. Labels correspond to stratum and sample number. Graphs show organic content (% dry weight) and cumulative grain size (%). Sediment grain size fractions include fines (silt and clay, ≤63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-1).

3.13.1 Cockles at Whangapoua Harbour

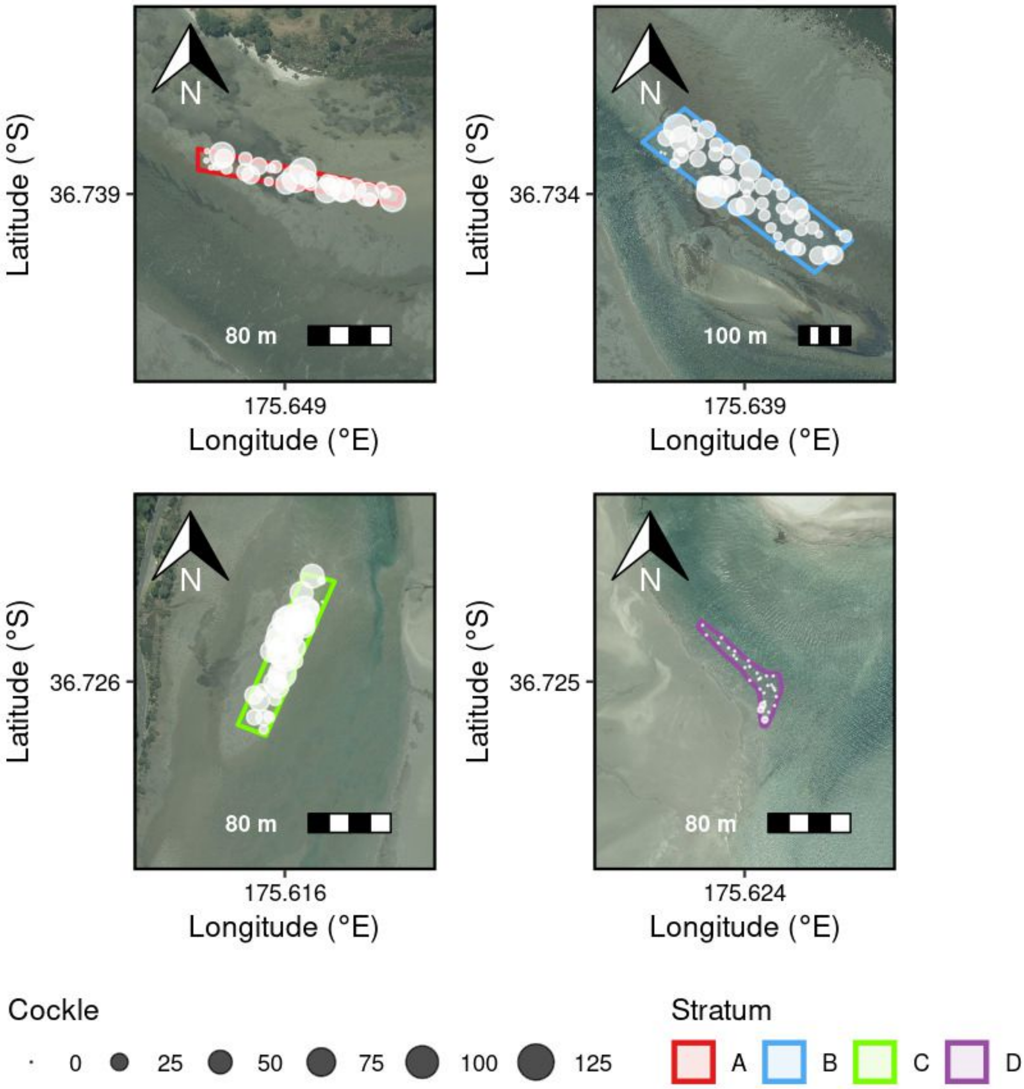


Figure 65: Map of sample strata and individual sample locations for cockles at Whangapoua Harbour, with the size of the circles proportional to the number of cockles (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 58: Estimates of cockle abundance at Whangapoua Harbour, by stratum, for 2022–23. 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	779	2.52	742	14.85
B	4.1	50	978	22.81	559	13.26
C	0.5	30	1 307	5.96	1 245	13.04
D	0.2	30	6	0.01	6	55.71

Table 59: Estimates of cockle abundance at Whangapoua Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density, and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	1.7	11.30	680	4.87	2.71	163	7.69
2003–04	5.2	19.19	369	4.23	6.37	122	8.45
2004–05	5.2	33.19	638	4.07	5.18	100	9.22
2010–11	5.2	32.06	617	9.71	2.83	54	18.88
2014–15	6.3	33.67	533	9.54	1.43	23	15.18
2016–17	5.3	43.80	827	16.02	1.08	17	16.30
2018–19	5.3	64.97	1 229	10.62	0.52	10	27.22
2020–21	5.3	46.59	884	8.85	0.49	9	18.95
2022–23	5.1	31.30	617	10.05	1.84	36	15.53

Table 60: Summary statistics of the length-frequency (LF) distribution of cockles at Whangapoua 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	18.25	21	5–38	28.93	0.80
2020–21	20.26	20	5–36	11.42	1.04
2022–23	22.12	25	5–36	13.96	5.89

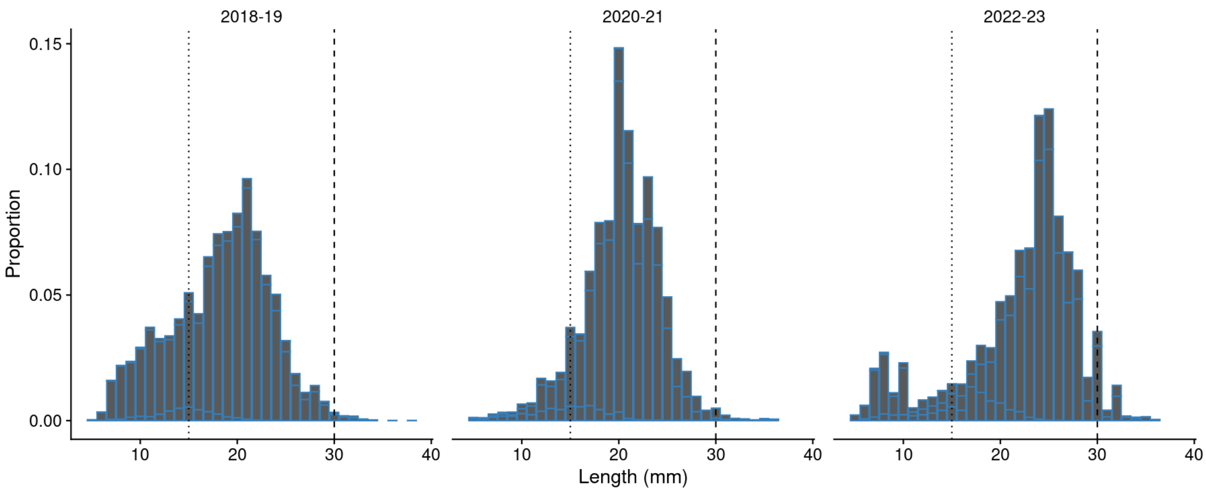


Figure 66: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

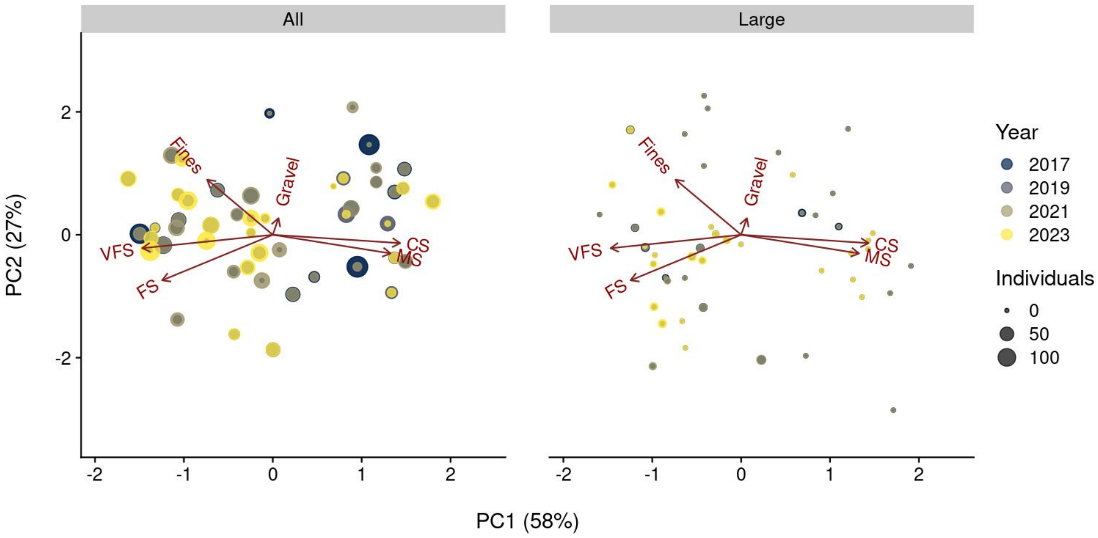


Figure 67: Cockle abundance along two principal components (standardised PCs, including % variance explained) of sediment granulometry for all cockle size classes (all) and large cockles (≥30 mm shell length) at Whangapoua Harbour. Sediment grain size fractions are defined as fines (silt and clay) ≤63 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.

3.13.2 Pipi at Whangapoua Harbour

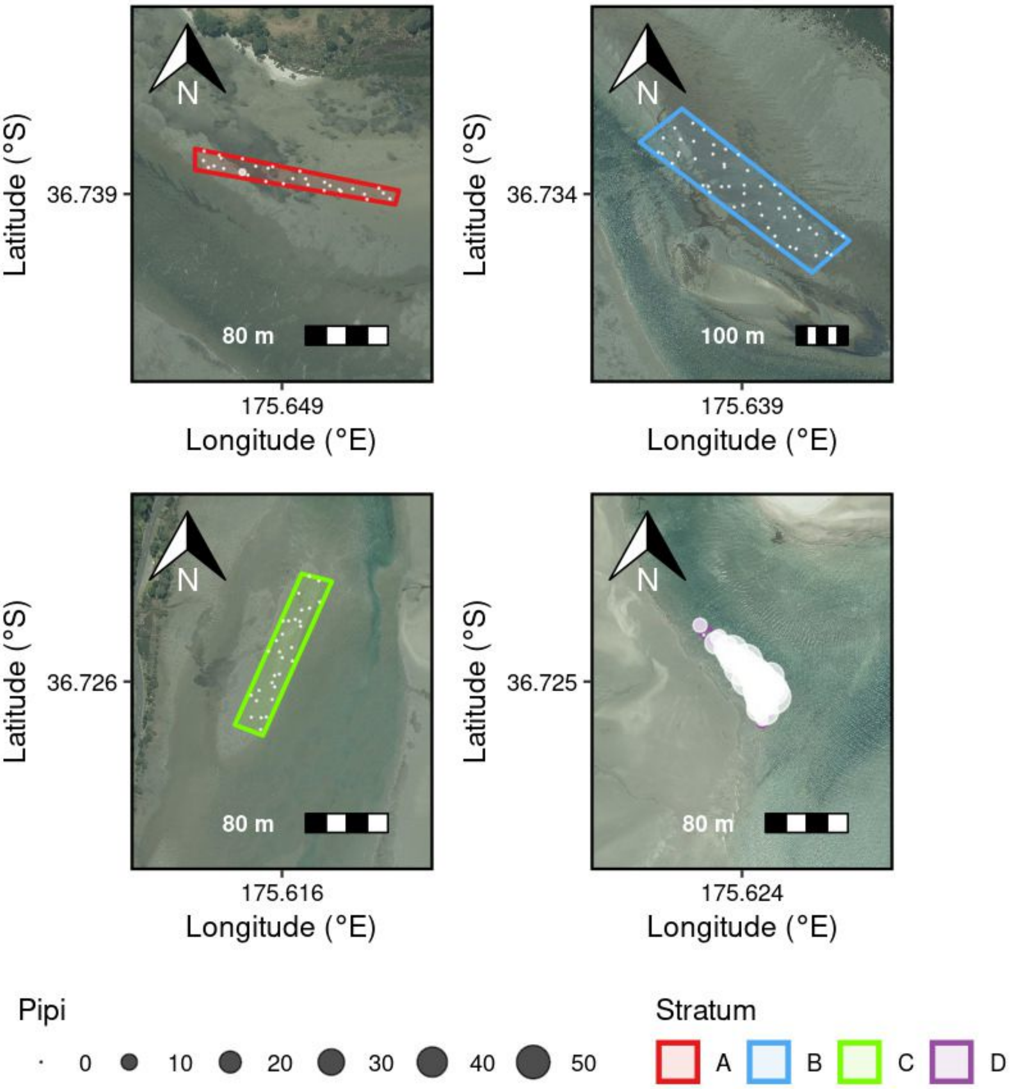


Figure 68: Map of sample strata and individual sample locations for pipi at Whangapoua Harbour, with the size of the circles proportional to the number of pipi (per 0.035 m^2) found at each location. Samples with zero counts are shown as small dots.

Table 61: Estimates of pipi abundance at Whangapoua Harbour, by stratum, for 2022–23. 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	1	0.00	<1	>100
B	4.1	50	0	0.00	0	
C	0.5	30	0	0.00	0	
D	0.2	30	904	1.49	861	9.97

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	1.7	5.62	338	10.16	1.73	104	8.28
2003–04	5.2	5.05	97	9.98	1.75	34	7.90
2004–05	5.2	7.47	144	5.25	3.75	72	5.08
2010–11	5.2	2.74	53	18.82	1.18	23	22.54
2014–15	6.3	2.27	36	20.24	0.34	5	22.32
2016–17	5.3	2.01	38	21.05	0.66	10	29.84
2018–19	5.3	4.17	79	14.71	1.44	27	13.32
2020–21	5.3	5.50	104	13.42	0.41	8	18.90
2022–23	5.1	1.50	30	9.96	0.34	7	11.34

Table 63: Summary statistics of the length-frequency (LF) distribution of pipi at Whangapoua 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 (%)
2018–19	36.49	52	8–66	23.59	34.64
2020–21	30.65	30	6–64	21.28	7.51
2022–23	41.26	47	9–63	4.86	22.70

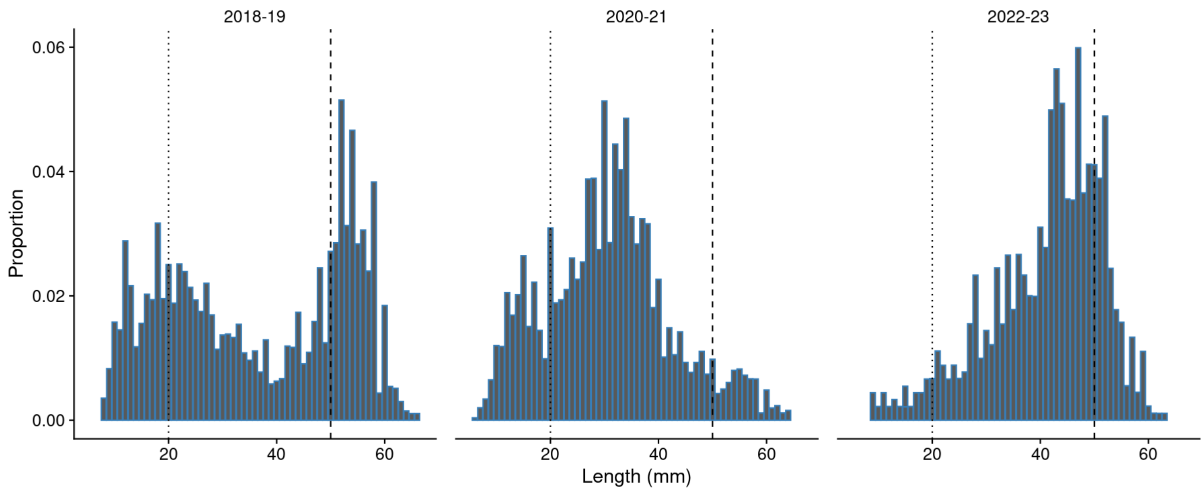


Figure 69: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangapoua Harbour. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

All of the 13 northern sites assessed in 2022–23 contained cockle populations (Table 64). The cockle populations occurred across a variety of soft-sediment habitats, from extensive intertidal sand or mud flats in different types of estuaries and inlets (e.g., Aotea Harbour, Ōhiwa Harbour, Pataua Estuary) to semi-enclosed bays (e.g., Kawakawa Bay (West)) and open beaches (e.g., Eastern Beach, Grahams Beach).

At all of these sites, except Grahams Beach, the population estimates had CV values below 20%. At Grahams Beach, increased sampling effort through phase-2 sampling failed to reduce the CV below 20%. This beach had the lowest population abundance estimate with a total of 4.42 million individuals in 2022–23. In comparison, Pataua Estuary supported the largest cockle population in 2022–23, which had an estimated abundance of 303.16 million individuals. The second largest population was at Kawakawa Bay (West), where the total population estimate was 156.07 cockles in 2022–23.

Because of the diversity of the survey sites, including differences in the size of sampling areas, density estimates provide a more meaningful comparison than abundance estimates. In this context, Whangamatā Harbour and Pataua Estuary supported the highest cockle densities with estimates of 1206 and 1076 cockles per m^2, respectively. Densities were also relatively high (at several hundred individuals per m^2) at most of the remaining sites. Notable exceptions were Waiotahe Estuary (98 cockles per m^2) and Grahams Beach with the lowest population density of 17 cockles per m^2.

Few of the populations included a notable number of large cockles (≥30-mm shell length) and all of the current abundance and density estimates for this size class had CV values exceeding 20%. Comparing their densities across sites, Eastern Beach had the highest density estimate (over 50 large individuals per m^2), followed by Cockle Bay and Whangapoua Harbour (42 and 36 large cockles per m^2).

Table 64: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2022–23 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all cockles (total) and for large cockles (≥30 mm shell length).

Survey site	Population estimate			Population ≥30 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Aotea Harbour	88.00	454	8.23	0.56	3	38.63
Cockle Bay	32.28	205	16.54	6.65	42	45.02
Eastern Beach	43.24	193	15.43	12.02	54	23.77
Grahams Beach	4.42	17	25.91	0.00	0	
Hokianga Harbour	27.19	270	12.89	0.12	1	51.31
Kawakawa Bay	156.07	256	14.29	15.33	25	36.15
Ōhiwa Harbour	5.04	269	14.23	0.08	4	58.31
Okoromai Bay	43.62	220	14.32	3.52	18	27.08
Otūmoetai	15.51	349	12.32	0.01	<1	>100
Pataua Estuary	303.16	1 076	11.48	3.44	12	42.79
Waiotahe Estuary	11.69	98	15.91	0.00	0	
Whangamatā Harbour	97.58	1 206	9.32	1.88	23	29.45
Whangapoua Harbour	31.30	617	10.05	1.84	36	15.53

Comparing cockle densities over time revealed declines at most of the 2022–23 sites at some point in the time series, although some of the recent decreases were relatively small (Figure 70). In addition, most of the cockle populations maintained relatively high density estimates in recent assessments, including the current study. Nevertheless, Grahams Beach had comparatively low density estimates throughout the time series, and the recent decline led to density estimates that were similar to low values in 2012–13 and 2013–14. At Waiotahe Estuary, there was a pronounced drop in cockle densities in 2019–20, and the current density estimate remained similarly low.

Combined length-frequency distributions provide a comparison of population size structures over time (Figure 71). This comparison showed that cockle populations at the current northern sites were consistently dominated by individuals in the medium size class. Dependent on the strength of recruitment events, there was a downward size shift towards the 15-mm cut-off length of the medium size class. This shift towards smaller sizes was also caused by reductions in the large cockle populations. Although large cockles were a notable part of the unimodal population structures in early surveys, their proportion within the total population became smaller in most of the surveys after 2004–05.

Time-series data of large cockle densities documented that this size class was absent or scarce at a number of sites throughout the monitoring series (Figure 72). At Grahams Beach, this size class was consistently lacking since the start of the surveys, whereas large cockles usually occurred at only low densities (generally less than 20 individuals per square metre) at Aotea Harbour, Hokianga Harbour, Ōhiwa Harbour, Otūmoetai (Tauranga Harbour), and Waiotahe Estuary. Their densities were also comparatively low at Kawakawa Bay (West). In contrast, five sites, Cockle Bay, Okoromai Bay, Pataua Estuary, Whangamatā Harbour, and Whangapoua Harbour had high densities of large cockles in earlier surveys, but have experienced marked declines in this size class since then. At Eastern Beach, large cockles were absent at the start of the survey series, but showed a relatively steady increase to medium densities (>50 individuals per square metre) in recent assessments.

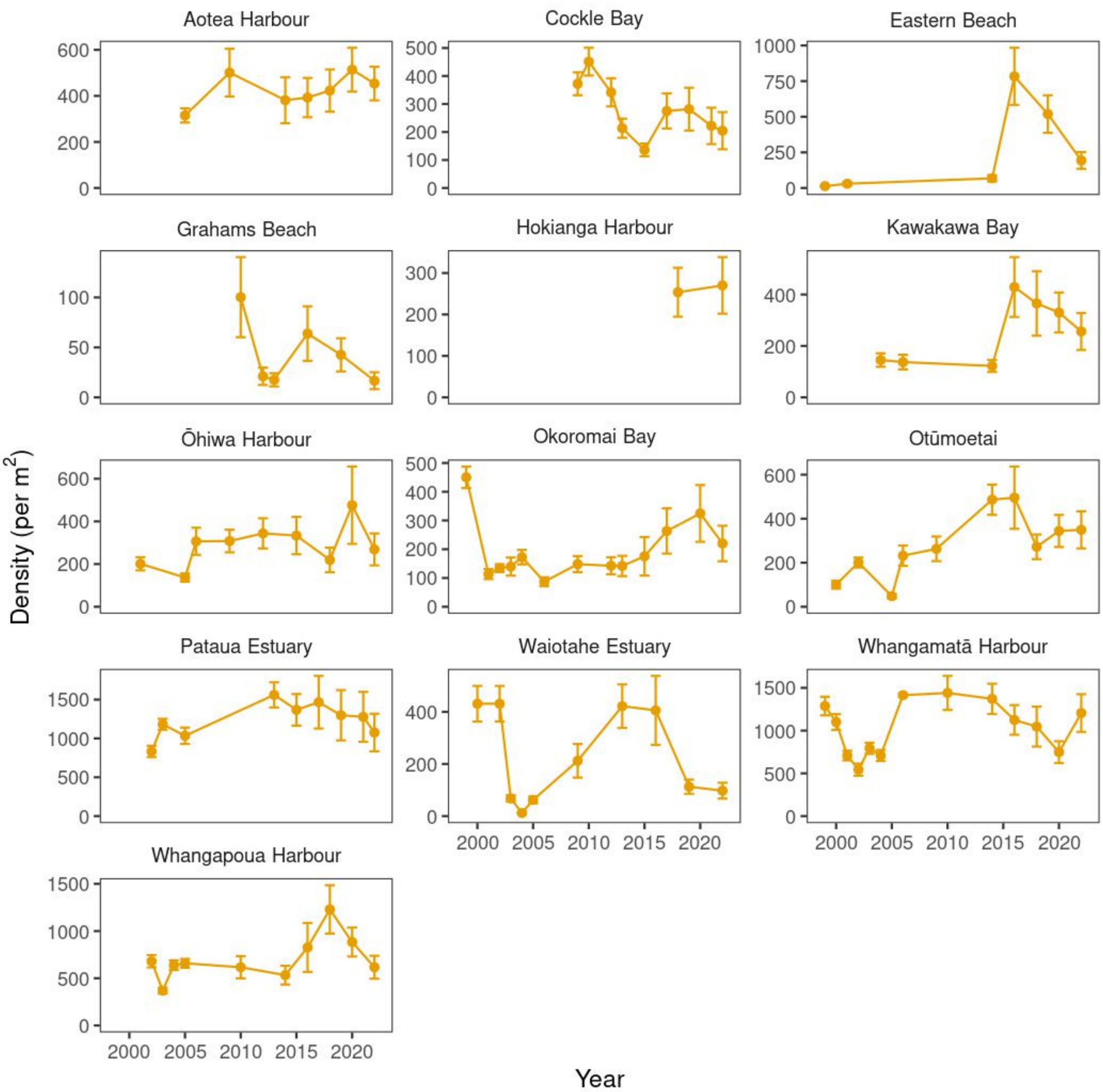


Figure 70: Estimated density of cockles for all sites included in the 2022–23 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

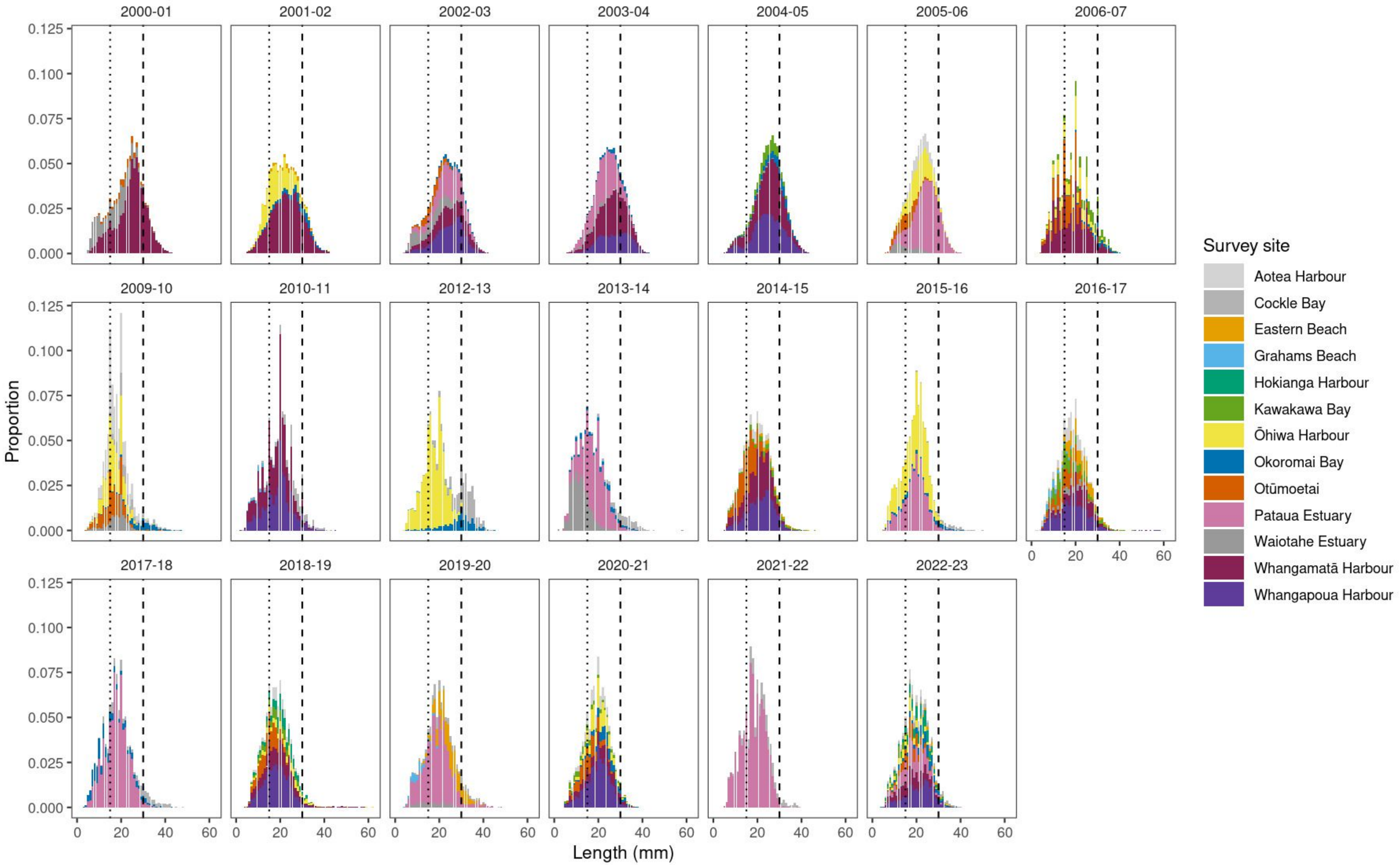


Figure 71: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2022–23 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

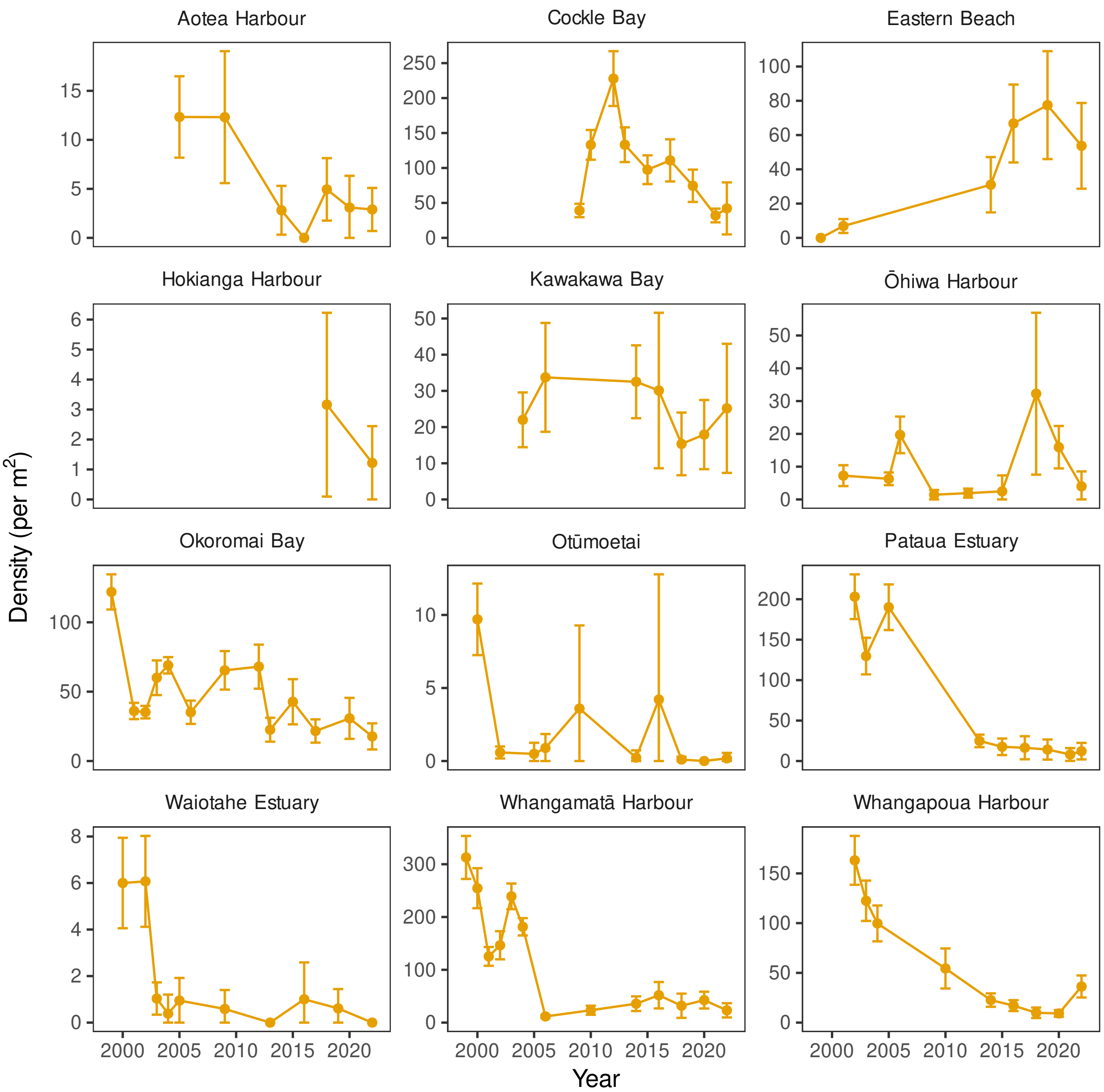


Figure 72: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.2 Pipi populations

Eight of the 2022–23 survey sites supported pipi populations, which varied considerably in size (Table 65). At two of these sites, Grahams Beach and Waiotahe Estuary, the population estimates had high uncertainty even with phase-2 sampling; the CV values were 32.09% and 25.01%, respectively. Most of the pipi populations were small, ranging from 1.47 million pipi at Ōhiwa Harbour to 39.27 million individuals at Hokianga Harbour. Similarly, pipi population densities were low, with the highest density estimates also at Hokianga Harbour with 390 pipi per m^2 followed by Otūmoetai (Tauranga Harbour) with 263 pipi per m^2.

Within the current populations, large pipi ($\geq$50 mm shell length) were either absent (Grahams Beach) or scarce, and their population estimates at most sites had high CV values. Their small population sizes were also reflected in the density estimates, indicating a general dearth of large individuals of this species at the 2022–23 survey sites.

Temporal trends in pipi densities indicated a universal decrease at each of the current sites (Figure 73). At Pataua Estuary, Waitoahe Estuary, Whangamatā Harbour, and Whangapoua Harbour, this decline occurred early in the survey series. At Hokianga Harbour, there was a substantial decline in pipi density between the first and second survey, although the latter density estimate remained relatively high (at 390 pipi per m^2). Subsequent recovery varied dependent on the site, but none of the populations returned to the high densities that were initially recorded, even though some sites showed some increases in pipi densities over time. At Grahams Beach, Ōhiwa Harbour, and Otūmoetai (Tauranga Harbour), low population densities at the start of the monitoring increased to relatively high estimates over time, before declining again close to their low initial estimates. This pattern was particularly pronounced at Ōhiwa Harbour and also Otūmoetai (Tauranga Harbour), where pipi densities changed from several hundred to over 1000 individuals per square metre before their subsequent decrease.

The general scarcity of large pipi and the prevalence of medium-sized individuals (and to some extent recruits; $\leq$20 mm shell length) was also documented in the combined length-frequency distributions (Figure 74). Most survey years showed a unimodal size structure across sites, largely determined by the medium pipi size class, and influenced by recruits. In some years, this general size composition differed in having a second cohort of larger sized individuals, or a single cohort that was centred close to or on the 50-mm cut-off length of the large size class.

Examining the density of large pipi at the 2022–23 sites over time showed that this size class was generally absent at Grahams Beach, and only occurred at low densities at Pataua Estuary throughout the time series (Figure 75). At Otūmoetai (Tauranga Harbour), there was a marked decline in the high density of large pipi at the start of the survey series, and density estimates have remained low since then. A similar trend but with some flucutuations occurred at Ōhiwa Harbour, Whangamatā Harbour, and Whangapoua Harbour, where large pipi densities have remained low from previously high estimates early in the survey series. At Waiotahe Estuary, their population density was comparatively lower than at the other sites, and showed an increase before dropping to low estimates in recent surveys.

Table 65: Estimates of pipi abundance for all sites where more than ten pipi were sampled in the 2022–23 survey. For each site, the table includes the estimated mean number, the mean density, and coefficient of variation (CV) for all pipi (total) and for large pipi (≥50 mm shell length).

Survey site	Population estimate			Population ≥50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Grahams Beach	4.51	17	32.09	0.00	0	
Hokianga Harbour	39.27	390	14.37	0.00	<1	>100
Ōhiwa Harbour	1.47	78	10.61	0.03	2	32.65
Otūmoetai	11.68	263	11.81	0.11	2	39.84
Pataua Estuary	2.57	9	19.64	0.47	2	22.03
Waiotahe Estuary	27.90	233	25.01	0.07	<1	>100
Whangamatā Harbour	4.57	56	13.03	0.77	10	25.44
Whangapoua Harbour	1.50	30	9.96	0.34	7	11.34

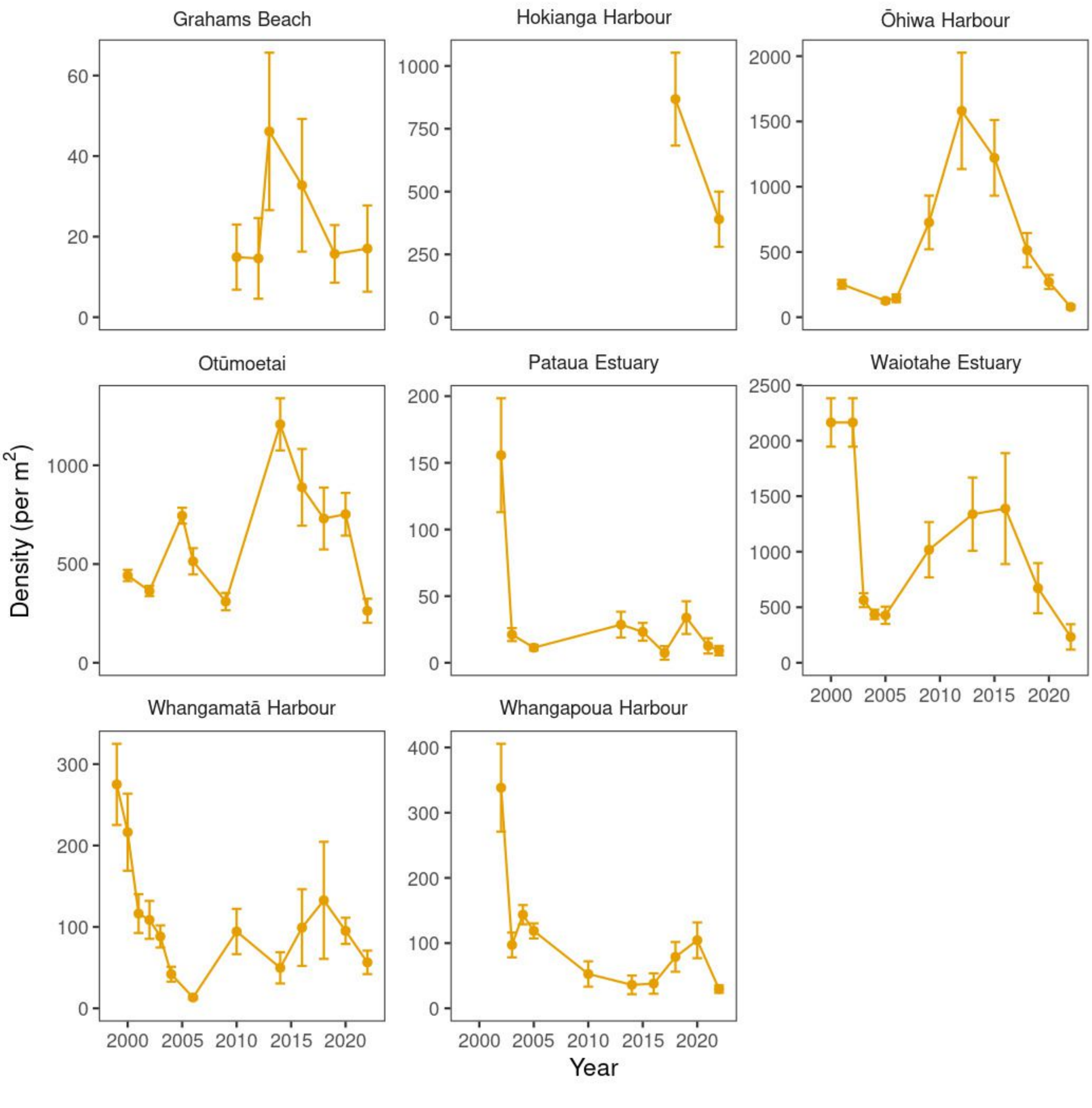


Figure 73: Estimated density of pipi for all sites included in the 2022–23 survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

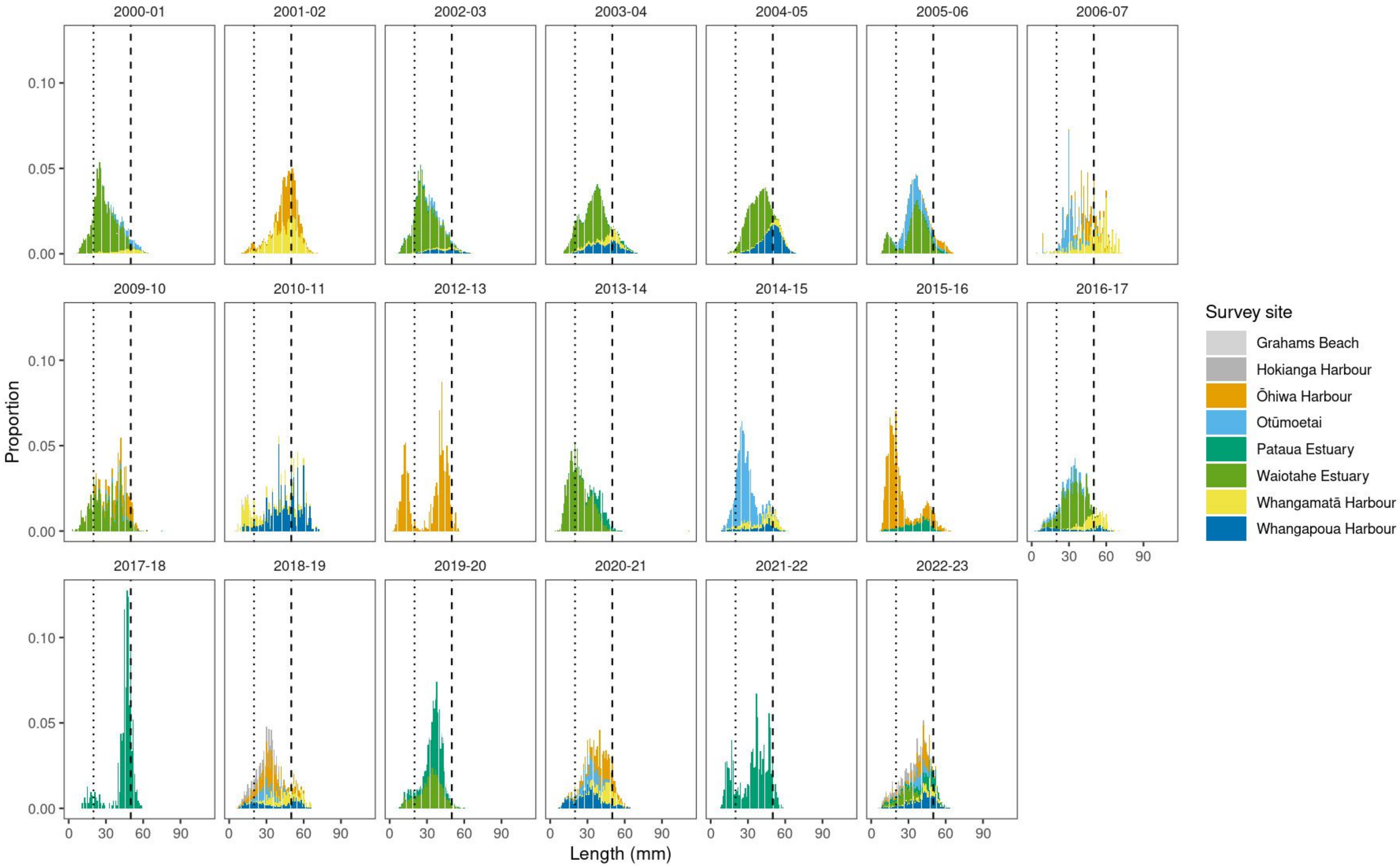


Figure 74: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2022–23 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

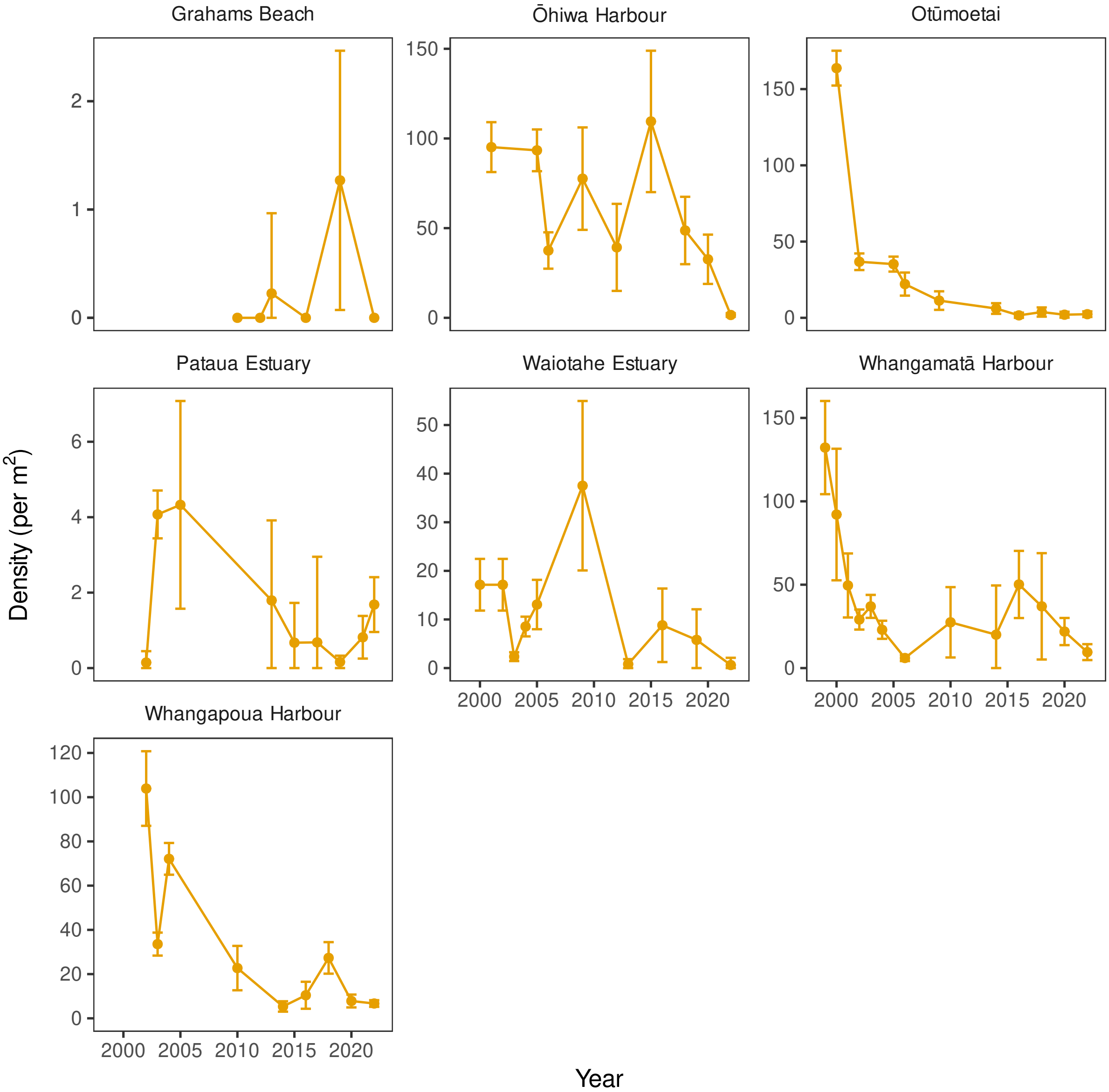


Figure 75: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. Shown are the mean estimated densities across years, with bars indicating the 95% confidence interval. (Note, different scales on the y-axes. Not all sites were surveyed each year, and the sampling extent may vary across years.)

4.3 Sediment data

Comparison of sediment characteristics across the 2022–23 survey sites showed that average organic matter content was low, at less than 3% (Figure 76). For the sediment grain size compositions, there was notable variation in the dominant size fractions at some sites, and also in the proportion of sediment fines (grain size ≤63 µm) and gravel (grain size >2000 µm).

Dependent on the site, either fine or medium sand (grain sizes >125 and >250 µm) made up the bulk of the sediment. Sediment at Kawakawa Bay (West) and Okoromai Bay had a high proportion of very fine sand (grain size ≤63 µm), whereas Aotea Harbour and Cockle Bay had a relatively high average proportion (about 10%) of sediment fines. This grain size fraction also (greatly) exceeded the 10% cut-off in individual samples at Aotea Harbour, Hokianga Harbour, Cockle Bay, Eastern Beach, Kawakawa Bay (West), Ōhiwa Harbour, Whangamatā Harbour, and Waiotahe Estuary.

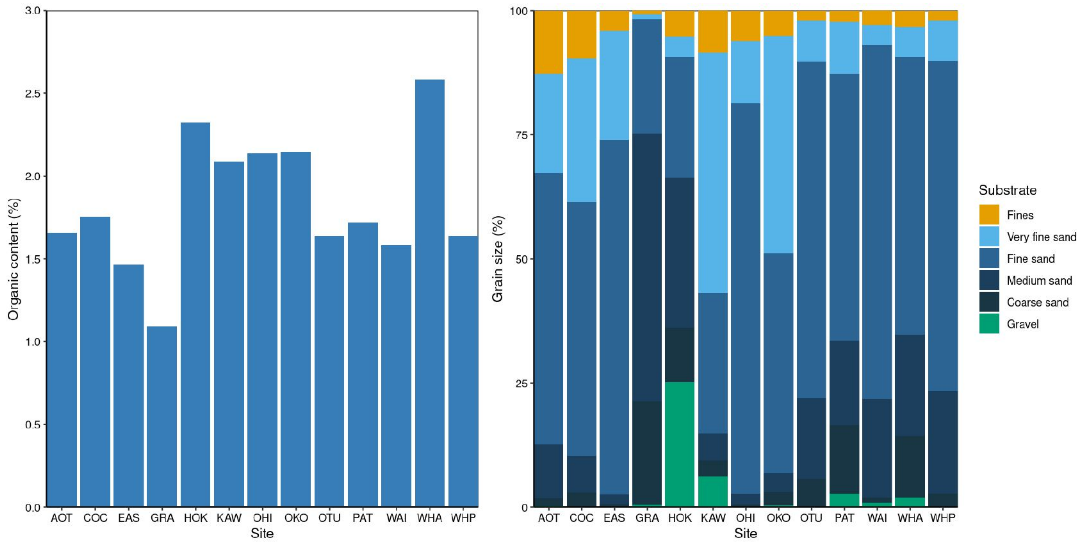


Figure 76: Sediment organic content and grain size composition (averages per site) at the 2022–23 northern survey sites with cockle strata. Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand >63 µm, fine sand >125 µm, medium sand >250 µm, coarse sand >500 µm, and gravel >2000 µm. The sites were Aotea Harbour, Cockle Bay, Eastern Beach, Grahams Beach, Hokianga Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Pataua Estuary, Waiotahe Estuary, Whangamatā Harbour, and Whangapoua Harbour.

4.4 Geostatistical model predictions of cockle density

Data from the current survey were also used in geostatistical models to examine spatio-temporal patterns in the predicted densities of all cockle and of the large cockle size class (see Tremblay-Boyer et al. 2021 for details, and previous modelling by Berkenbusch et al. 2022). Maps generated from the models allowed the identification of high-density areas at each site over time (see Appendix C).

Apart from Grahams Beach, all of the current survey sites were similar in that the predicted high-density areas were consistent between the total cockle population and large individuals; however, the spatial extent was generally more restricted for the latter size grouping. This pattern was particularly pronounced at Otūmoetai (Tauranga Harbour). At Grahams Beach, the time series of predicted densities highlighted the lack of any high-density areas throughout the survey series (Figure C-4).

There were no distinct shifts in high-density areas over time, but their spatial extent decreased notably at Eastern Beach, Kawakawa Bay (West), Ōhiwa Harbour, Pataua Estuary, and Waiotahe Estuary. At Eastern Beach and Waiotahe Estuary, this decrease led to the disappearance of predicted high cockle density areas in recent surveys. At Ōhiwa Harbour, this change occurred at different times across the two cockle strata.

At Hokianga Harbour, Okoromai Bay, Otūmoetai (Tauranga Harbour), Whangamatā Harbour, and Whangapoua Harbour, high-density areas persisted throughout the time series, for both the total population and for large cockles. At Hokianga Harbour, the spatial distribution of high-density areas for both population metrics became more widespread between the two surveys.

5. DISCUSSION

The 2022–23 survey sites represented a wide geographical spread across the northern North Island regions. There were five sites in Auckland (Cockle Bay, Eastern Beach, Grahams Beach, Kawakawa Bay (West), Okoromai Bay), two sites in Northland (west and east coasts; Hokianga Harbour, Pataua Estuary), three sites in Waikato (west and east coasts; Aotea Harbour, Whangamatā Harbour, Whangapoua Harbour), and three sites in Bay of Plenty (Otūmoetai (Tauranga Harbour), Ōhiwa Harbour, Waiotahe Estuary). At these sites, cockle and pipi beds inhabited a wide range of sedimentary habitats, from open beaches to sheltered bays, estuaries, and large tidal inlets. Dependent on the site, the field survey sampled a bay or beach in its entirety (e.g., Kawakawa Bay (West), Eastern Beach), or specific areas that supported cockle or pipi populations (e.g., Hokianga Harbour, Ōhiwa Harbour).

At two of the current sites, Cockle Bay and Eastern Beach, fishery closures have prohibited the take of shellfish for a number of years. At Cockle Bay, a permanent closure was implemented in May 2021, following a seasonal (summer) closure since 2008 (Department of Internal Affairs 2008, 2021). Eastern Beach has been closed to the take of any shellfish since 1994 (Department of Internal Affairs 1994, 1995).

Most of the 2022–23 cockle populations had relatively high abundance and density estimates, and were largely determined by medium-sized individuals. At a number of sites, this size class was also prevalent in the immediately-preceding assessments, signifying stable populations that were characterised by a unimodal cohort of medium-sized cockles. The latter was frequently augmented by notable recruitment, often providing a regular influx of small individuals. Recruits made up a substantial proportion (i.e., over 25%) of the cockle population at ten of the 2022–23 survey sites: at Aotea Harbour, Cockle Bay, Grahams Beach, Hokianga Harbour, Kawakawa Bay (West), Ōhiwa Harbour, Otūmoetai (Tauranga Harbour), Pataua Estuary, Waiotahe Estuary, and Whangamatā Harbour. At Kawakawa Bay (West) and Waiotahe Estuary, their proportions were 50 and 60% of the total population, respectively.

Notwithstanding the importance of recruitment, the considerable influence of recruits on some of the northern populations appears precarious, given the vulnerability of small-sized individuals and potential limitations to their persistence and growth (e.g., inadequate food supply, high sediment resuspension). This aspect was evident at some of the sites, where recent declines were in part explained by reductions in the proportion of recruits. For example, at Grahams Beach, the marked drop in the total population between 2016–17 and 2022–23 was related to the substantial decrease in the proportion of recruits, from over 80% in the two previous surveys to 24% in 2022–23.

At Cockle Bay and Eastern Beach, long-term fishery restrictions mean that there has been no fishing pressure on resident cockle populations for a considerable period of time (although there has been some illegal take; e.g., see Ministry for Primary Industries 2021). Both sites were distinct from the remaining sites in 2022–23 in supporting a comparatively large population of large cockles, which made up 20.6% and 27.8% of their current population, respectively. Observed downward trends in the populations at both sites were in part explained by declines in the population of large cockles. At Cockle Bay, the decline in large cockles has been ongoing since 2013–14 (although their estimates showed a small increase in 2022–23). In addition, the preceding survey of this bay in 2021–22 reported localised patches of recently-dead cockles (Berkenbusch et al. 2022), and this unexplained mortality event may have been more widespread and significant than observations during the preceding field survey suggested.

Another factor that may contribute to population decreases at Cockle Bay is degrading sediment habitat quality at this site; similar degradation may also affect the cockle population at Eastern Beach. Both sites had sediment samples with a proportion of fines that may have exceeded the tolerance level of cockles; their highest densities have been shown to be in sediments containing less than 11% in this grain size fraction (Thrush et al. 2005). At Cockle Bay, four samples exceeded this threshold, ranging between 20.9 and 69.4%, while two samples at Eastern Beach contained 15.4% and 42.1% of sediment fines, respectively. High proportions of sediment fines can lead to increased resuspension, affecting the feeding efficiency of suspension-feeding cockles.

In addition to potential sediment impacts through elevated resuspension, Cockle Bay also had extensive areas of consolidated clay across the sampling extent (see also Berkenbusch et al. 2022). This compaction was evident below a thin layer of surface sediment in parts of the bay (see illustration in Appendix D, Figure D-1). Sediment compaction or penetrability has been shown to affect environmental conditions in intertidal habitats (Gerwing et al. 2020), and is likely to impact on the burrowing ability and movement of cockles (and other infauna). The notion that cockles may be impacted by sediment compaction at Cockle Bay is supported by the reduction in their spatial distribution over time. For example, total cockle population estimates were similar in 2013–14 and 2022–23, but their spatial distribution was greatly restricted in the current assessment compared with their spatial extent in 2013–14 (see Berkenbusch et al. 2015).

Nine of the 2022–23 survey sites contained pipi populations, but population estimates were generally low. Only three sites, Hokianga Harbour, Otūmoetai, and Waiotahe Estuary, had density estimates that exceeded 100 individuals per square metre, and the estimate at the latter estuary had relatively high uncertainty (CV: 25.01%). Population estimates were low at Grahams Beach, and also had high uncertainty.

All of the current density estimates followed recent or ongoing declines in the pipi populations. These decreases may in part be explained by changes to the pipi beds that led to their shift into subtidal waters, inaccessible to the field sampling. Although a number of pipi beds had marked reductions in their spatial extent in the recent survey, part of these reductions was in areas remaining easily accessible in intertidal sampling. Examples include Otūmoetai (Tauranga Harbour), Whangapoua Harbour, Whangamatā Harbour, and Ōhiwa Harbour. At some sites, such as Pataua Estuary and Ōhiwa Harbour, significant movement of adjacent sandbanks led to the partial burial of previous pipi beds. At Ōhiwa Harbour, the movement of sand also affected a pipi bed in a side channel close to the harbour entrance. Between November 2022 and the field survey in March 2023, significant sand movement and changes to the tidal channel made the pipi bed inaccessible.

Similar to the cockle populations, the 2022–23 pipi populations were largely formed by medium-sized individuals, with varying recruitment and a general scarcity or only small densities of large individuals across sites. Large pipi contributed a notable proportion (over 15%) of individuals at three sites: Pataua Estuary, Whangamatā Harbour, and Whangapoua Harbour. The pipi population at Whangamatā Harbour was also characterised by strong recruitment, with 25.05% of pipi in the recruits size class. Recruitment was also strong at Hokianga Harbour (31.40% recruits); at Grahams Beach, 79.12% of the current pipi population were recruits. For these sites with strong recruitment, the small-sized individuals may potentially grow to larger sizes and boost the medium size class; however, the shift in population size composition may not subsequently lead to increases in population abundance and density. For example, length-frequency distributions in the current study indicated a shift from recruits and small pipi towards larger sizes at Pataua Estuary and Whangapoua Harbour, but this growth did not lead to increases in the population estimates (there were population declines at both sites). At the other sites, there was no clear evidence of recruits persisting and growing to medium-sized pipi across the three most recent surveys.

At Pataua Estuary, Northland Regional Council reported a pipi mortality event in July 2022 (M. Pomarède, pers. comm.). The die-off occurred in a small pipi bed in the estuary side channel, close to the harbour entrance; this bed was included in the current monitoring of the estuary. It is unknown what caused the mortality event, and if pipi in the main channel were also affected. Pipi in the latter area have been regularly surveyed, and substantial sediment movement through the fast-flowing estuary channel has affected their distribution and abundance across surveys (e.g., Berkenbusch et al. 2022). In 2022–23, there was a build-up of sandbanks in the western part of the pipi bed between November 2022 and February 2023 which led to the burial of pipi in this part of the bed. In comparison to the main estuary channel, the side channel is shallow and less dynamic, and a sandbank diminishes the tidal influence of the estuary entrance. Black shells of live pipi in this bed indicated anoxic conditions in the sediment (see Appendix D, Figure D-2). Localised and large-scale mortalities of pipi (and cockles) have also been reported from other northern survey sites, including previous observations of die-offs during field surveys (e.g., Berkenbusch et al. 2015, Berkenbusch & Neubauer 2018). Identified and suggested causes for these mortalities include adverse weather conditions (particularly unusually hot weather), parasites, bacteria, and a combination of these factors (e.g., cockle mortalities in Whangateau Harbour; Tricklebank et al. 2021).

Estuary-wide habitat degradation has been documented in 2017 at Waiotahe Estuary, in Bay of Plenty. Substantial contamination by faecal bacteria (*Escherichia coli*) from dairy farming led to health warnings and the closure of the estuary, and this contamination continues to affect resident bivalve populations (Bay of Plenty Regional Council 2021). Recorded adverse conditions in this estuary also include high total suspended solids and high turbidity. The deterioration of the estuary in 2017 led to substantial declines in the cockle and pipi populations between 2016–17 and 2022–23. These declines were caused by the loss of medium-sized and large individuals. The current cockle population consisted mostly of recruits, which may not become established, while the declining habitat quality also appeared to have a long-term impact on larger individuals.

The data collection for this assessment was conducted after flooding impacted the wider Auckland area in January 2023, and during a period when severe tropical cyclone Gabrielle profoundly affected extensive North Island areas in February 2023. Some of the severe flooding events occurred in the northern North Island regions included in the current field survey. At the time of the sampling, the bivalve habitats across these regions appeared to be unaffected by the flooding; e.g., there was no evidence of substantial sediment run-off following high rainfall. Nevertheless, there may be subsequent habitat impacts that were not immediately obvious at some of the survey sites.

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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
Aotea Harbour																					
Bowentown Beach																					
Cheltenham Beach																					
Clarks Beach																					
Cockle Bay																					
Cornwallis Wharf																					
Eastern Beach																					
Grahams Beach																					
Hokianga Harbour																					
Howick Harbour																					
Kawakawa Bay (West)																					
Little Waihi Estuary																					
Mangawhai Harbour																					
Marokopa Estuary																					
Marsden Bank																					
Mill Bay																					
Ngunguru Estuary																					
Ōhiwa Harbour																					
Okoromai Bay																					
Otūmoetai																					
Papamoa Beach																					
Pataua Estuary																					
Raglan Estuary																					
Ruakākā Estuary																					
Tairua Harbour																					
Te Haumi Beach																					
TeMata Bay																					
Umupuia Beach																					
Waikawau Beach																					
Waiotahe Estuary																					
Whangamatā Harbour																					
Whangapoua Harbour																					
Whangateau Harbour																					
Whitianga Harbour																					

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–2000, including the present survey in 2022–23. 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
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
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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
Mangawhai Harbour	1999–00	23 Mar–30 Jun	9.40	AKI1999-01
	2000–01	29 Jan–31 Jan	8.40	AKI2000-01
	2001–02	15 Mar–14 Apr	8.40	AKI2001-01
	2002–03	1 Jan–31 Jan	8.40	AKI2002-01
	2003–04	1 Jan–31 Jan	8.40	AKI2003-01
	2010–11	24 Mar–15 Apr	9.00	AKI2010-01
	2014–15	21 Jan–22 Jan	8.55	AKI2014-01
	2016–17	11 Feb–16 Feb	8.59	AKI2016-01
	2018–19	18 Jan–19 Jan	7.23	AKI2018-01
	2021–22	1 Feb–2 Feb	7.17	AKI2018-01
Marokopa Estuary	2005–06	18 Feb–20 Feb	2.35	AKI2005-01
	2010–11	16 May	2.35	AKI2010-01
	2015–16	12 Feb–13 Feb	2.58	AKI2015-01
Marsden Bank	2009–10	13 Nov	11.51	IPA2009-12
	2012–13	12 Dec	6.31	AKI2012-01
	2013–14	2 Feb	15.43	AKI2013-01
	2017–18	4 Feb–5 Feb	0.85	AKI2017-01
	2021–22	5 Feb	0.87	AKI2021-01
Mill Bay	1999–00	4 May–30 Jun	4.60	AKI1999-01
	2000–01	20 Feb–23 Feb	4.80	AKI2000-01
	2001–02	20 Mar–22 Apr	4.50	AKI2001-01
	2003–04	26 Jan–28 Jan	4.50	AKI2003-01
	2004–05	24 Dec–24 Jan	4.50	AKI2004-01
	2005–06	20 Dec–24 Dec	4.50	AKI2005-01
	2009–10	13 May	4.95	AKI2009-01
	2014–15	26 Feb	4.88	AKI2014-01
	2017–18	30 Jan–31 Jan	4.86	AKI2017-01
	2018–19	26 Jan	4.86	AKI2018-01
	2021–22	16 Feb	4.84	AKI2021-01
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
	2014–15	23 Jan–24 Jan	5.46	AKI2014-01
	2016–17	13 Feb–15 Feb	6.28	AKI2016-01
	2018–19	22 Feb	6.47	AKI2018-01
	2021–22	3 Feb	6.35	AKI2018-01
Ōhiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
	2015–16	9 Feb–10 Feb	4.58	AKI2015-01
	2018–19	1 Feb–2 Feb	2.54	AKI2018-01
	2020–21	16 Feb–19 Feb	2.65	AKI2018-01
	2022–23	15 Mar–16 Mar	1.87	AKI2021-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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	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 Estuary	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
	2017–18	29 Jan	7.24	AKI2017-01
	2019–20	8 Feb	7.38	AKI2018-01
	2021–22	30 Jan	7.32	AKI2021-01
Ruakākā Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
	2014–15	25 Jan–26 Jan	6.51	AKI2014-01
	2016–17	14 Feb	5.61	AKI2016-01
	2018–19	23 Feb	3.93	AKI2018-01
	2021–22	5 Feb–6 Feb	4.09	AKI2018-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
	2015–16	6 Feb–7 Feb	8.17	AKI2015-01
	2017–18	20 Feb–22 Feb	6.48	AKI2017-01
	2019–20	23 Feb	6.12	AKI2018-01
	2021–22	23 Feb	5.95	AKI2021-01
Te Haumi Beach	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01
	2012–13	13 Dec	12.06	AKI2012-01
	2014–15	24 Jan–26 Jan	12.78	AKI2014-01
	2016–17	12 Feb	12.77	AKI2016-01
	2018–19	21 Feb–24 Feb	11.91	AKI2018-01
	2021–22	4 Feb	10.64	AKI2018-01
Te Mata Bay	2020–21	14 Feb–20 Feb	0.97	AKI2018-01
	2021–22	24 Feb–26 Feb	0.68	AKI2021-01
Umupuia Beach	1999–00	1 Apr–12 Apr	25.00	AKI1999-01
	2000–01	15 Feb–16 Feb	36.00	AKI2000-01
	2001–02	28 Mar–12 Apr	36.00	AKI2001-01
	2002–03	28 Dec–2 Jan	36.00	AKI2002-01
	2003–04	25 Mar–28 Mar	36.00	AKI2003-01
	2004–05	22 Jan–23 Jan	36.00	AKI2004-01
	2005–06	28 Jan–29 Jan	36.00	AKI2005-01
	2006–07	18 Apr	36.00	AKI2006-01
	2009–10	15 Feb	36.00	AKI2009-01
	2010–11	4 May	36.00	AKI2010-01
	2012–13	13 Mar	36.00	AKI2012-01
	2013–14	30 Mar–1 Apr	33.86	AKI2013-01
	2015–16	18 Jan–19 Jan	33.90	AKI2015-01
	2017–18	28 Jan	33.43	AKI2017-01
	2019–20	14 Feb	33.43	AKI2018-01
	2021–22	18 Feb	32.72	AKI2021-01
Waikawau Beach	1999–00	20 May–30 Jun	2.90	AKI1999-01
	2000–01	24 Feb–15 May	2.70	AKI2000-01
	2004–05	18 Jan–10 Mar	3.10	AKI2004-01
	2005–06	15 Feb–27 Feb	3.10	AKI2005-01
	2013–14	21 Mar		AKI2013-01
Waiotahe Estuary	2002–03	7 Feb–10 Feb	8.50	AKI2002-01
	2003–04	21 Jan–24 Jan	8.50	AKI2003-01
	2004–05	21 Jan–25 Jan	9.50	AKI2004-01
	2005–06	10 Feb–12 Feb	9.50	AKI2005-01
	2009–10	4 Mar	9.50	AKI2009-01
	2013–14	17 Mar–20 Mar	11.23	AKI2013-01
	2016–17	22 Feb	11.98	AKI2016-01
	2019–20	26 Feb–27 Feb	11.98	AKI2018-01
	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

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (ha)	Project
	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 Harbour	2002–03	30 Mar–6 Apr	1.66	AKI2002-01
	2003–04	1 Feb–3 Feb	5.20	AKI2003-01
	2004–05	8 Mar–10 Mar	5.20	AKI2004-01
	2005–06	8 Mar–10 Mar	5.20	AKI2005-01
	2010–11	21 Apr	5.20	AKI2010-01
	2014–15	24 Feb–25 Feb	6.32	AKI2014-01
	2016–17	25 Feb–26 Feb	6.32	AKI2016-01
	2018–19	27 Jan–28 Jan	5.28	AKI2018-01
	2020–21	12 Feb–13 Feb	5.27	AKI2018-01
	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
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 2022–23 as part of the northern North Island bivalve surveys. Position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediment grain size fractions are defined as fines (silt and clay) ≤63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm.

						Sediment grain size fraction (%)					
Survey site	Stratum	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Aotea Harbour	A	1	-38.01757	174.82538	1.4	11.2	13.7	56.9	14.1	3.7	0.4
	A	2	-38.01756	174.82607	1.9	20.5	20.4	46.2	10.8	2.1	0.0
	A	3	-38.01723	174.82623	1.7	15.8	11.2	44.6	22.9	4.0	1.5
	A	4	-38.01714	174.82685	1.9	19.4	25.1	44.5	8.3	2.3	0.4
	A	5	-38.01671	174.82455	1.2	4.0	8.0	60.5	23.0	4.1	0.4
	A	6	-38.01661	174.82420	1.5	14.5	15.0	51.7	16.1	2.5	0.2
	A	7	-38.01646	174.82577	1.6	16.7	16.5	47.6	17.4	1.9	0.0
	A	8	-38.01627	174.82487	1.4	13.8	11.9	52.5	18.8	2.9	0.0
	A	9	-38.01626	174.82621	1.5	13.2	28.6	48.9	7.6	1.7	0.0
	A	10	-38.01603	174.82531	1.8	17.6	17.1	50.2	13.2	1.9	0.0
	A	11	-38.01590	174.82758	1.2	8.5	11.0	60.0	18.9	1.6	0.0
	A	12	-38.01345	174.83247	1.4	8.7	20.3	67.8	3.1	0.1	0.0
	B	1	-38.01661	174.82766	2.5	20.7	24.3	45.5	6.7	2.0	0.8
	B	2	-38.01651	174.82679	1.0	7.5	16.3	64.9	10.0	1.3	0.0
	B	3	-38.01608	174.82736	1.0	6.3	12.7	67.7	12.8	0.6	0.0
	B	4	-38.01556	174.82658	1.3	5.6	16.8	65.4	11.1	1.2	0.0
	B	5	-38.01538	174.82648	1.3	11.1	17.7	59.9	10.8	0.5	0.0
	B	6	-38.01484	174.82883	2.0	8.0	12.8	64.4	11.7	3.1	0.0
	B	7	-38.01431	174.83138	3.8	24.8	49.9	22.5	2.1	0.7	0.0
	B	8	-38.01417	174.82955	2.2	12.8	42.2	40.8	3.7	0.5	0.0
	B	9	-38.01376	174.83061	1.4	12.6	20.7	61.9	4.4	0.5	0.0
	B	10	-38.01310	174.83091	1.5	9.9	24.0	61.5	4.2	0.4	0.0
	B	11	-38.01308	174.83176	1.6	13.1	19.2	62.1	5.3	0.3	0.0
	B	12	-38.01282	174.83091	1.6	9.6	24.5	62.5	2.8	0.5	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Cockle Bay	A	1	-36.90116	174.95473	1.6	3.2	22.3	51.3	15.2	8.0	0.0
	A	2	-36.90094	174.95534	1.7	2.0	28.1	54.6	9.8	4.4	1.3
	A	3	-36.89869	174.95507	1.1	1.8	28.8	64.8	4.3	0.4	0.0
	A	4	-36.89845	174.95507	1.6	3.8	27.0	62.0	6.3	0.8	0.0
	A	5	-36.89816	174.95626	1.4	28.2	19.6	47.9	3.4	1.0	0.0
	A	6	-36.89781	174.95559	1.4	2.2	25.8	68.0	3.2	0.8	0.0
	B	1	-36.89782	174.95361	1.3	2.6	29.9	63.0	3.6	0.9	0.0
	B	2	-36.89768	174.95400	1.4	3.5	37.1	55.6	2.8	0.9	0.0
	B	3	-36.89752	174.95305	1.5	2.2	38.9	54.2	4.5	0.3	0.0
	B	4	-36.89747	174.95483	1.2	2.1	23.2	70.5	4.1	0.1	0.0
	B	5	-36.89745	174.95351	1.6	4.2	35.5	55.7	4.0	0.5	0.0
	B	6	-36.89722	174.95462	1.1	1.9	17.6	75.0	5.3	0.1	0.0
	C	1	-36.90051	174.95550	1.8	4.3	29.4	60.6	3.5	1.9	0.3
	C	2	-36.90017	174.95538	1.2	3.5	29.8	60.1	4.7	1.5	0.4
	C	3	-36.89997	174.95168	1.5	3.2	43.4	37.4	11.5	4.4	0.0
	C	4	-36.89992	174.95217	1.4	3.1	29.5	44.7	16.2	6.5	0.0
	C	5	-36.89989	174.95178	1.5	3.3	29.3	45.6	15.9	5.9	0.0
	C	6	-36.89961	174.95250	1.8	5.1	36.0	46.7	8.1	4.1	0.0
	D	1	-36.90009	174.95392	3.4	49.1	27.2	19.4	3.1	1.2	0.0
	D	2	-36.89934	174.95151	2.0	7.1	18.1	36.6	25.2	12.4	0.6
	D	3	-36.89921	174.95228	5.7	69.5	13.1	12.8	3.3	1.4	0.0
	D	4	-36.89895	174.95372	1.3	2.6	27.8	58.4	7.9	3.3	0.0
	D	5	-36.89882	174.95342	1.3	2.6	43.5	44.1	5.8	4.0	0.0
	D	6	-36.89851	174.95306	2.3	20.9	33.6	37.9	4.1	3.4	0.0
Eastern Beach	A	1	-36.87727	174.91972	1.6	2.9	18.3	68.8	7.3	2.8	0.0
	A	2	-36.87694	174.91960	1.2	1.5	26.7	70.2	1.6	0.0	0.0
	A	3	-36.87651	174.92054	1.0	0.8	12.7	86.2	0.3	0.0	0.0
	A	4	-36.87507	174.91857	1.0	2.4	19.6	77.4	0.6	0.0	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	A	5	-36.87480	174.91699	1.4	2.4	40.4	55.2	1.9	0.0	0.0
	A	6	-36.87406	174.91678	1.1	0.7	19.0	79.4	0.8	0.0	0.0
	A	7	-36.87388	174.91775	1.0	1.4	14.3	83.9	0.5	0.0	0.0
	A	8	-36.87305	174.91631	2.2	15.4	25.9	57.0	0.7	0.7	0.2
	A	9	-36.87270	174.91420	2.0	2.0	43.5	49.5	5.0	0.0	0.0
	A	10	-36.87227	174.91420	1.6	1.8	36.4	56.7	5.0	0.1	0.0
	A	11	-36.87133	174.91367	1.3	1.1	25.2	71.4	2.3	0.0	0.0
	A	12	-36.87129	174.91344	1.5	1.3	21.0	65.5	11.0	1.2	0.0
	B	1	-36.86934	174.91321	1.1	0.5	17.7	81.2	0.5	0.2	0.0
	B	2	-36.86918	174.91304	1.1	1.1	19.4	78.4	0.7	0.4	0.0
	B	3	-36.86917	174.91188	2.1	3.4	34.6	61.4	0.6	0.0	0.0
	B	4	-36.86908	174.91255	1.1	1.1	19.4	79.0	0.3	0.1	0.0
	B	5	-36.86898	174.91322	1.0	1.9	12.7	84.4	0.4	0.6	0.0
	B	6	-36.86866	174.91307	0.8	0.7	12.3	86.7	0.2	0.1	0.0
	B	7	-36.86852	174.91143	4.0	5.0	36.4	49.1	4.2	5.2	0.0
	B	8	-36.86852	174.91313	0.8	1.2	10.3	88.0	0.3	0.2	0.0
	B	9	-36.86837	174.91200	2.5	42.1	20.9	35.6	1.1	0.3	0.0
	B	10	-36.86829	174.91286	0.8	1.6	9.4	88.8	0.1	0.1	0.0
	B	11	-36.86822	174.91232	1.5	5.2	21.6	70.4	2.2	0.6	0.0
	B	12	-36.86803	174.91211	1.5	0.9	7.1	90.9	0.6	0.5	0.0
Grahams Beach	A	1	-37.05737	174.66746	0.8	1.4	0.3	13.1	43.4	39.9	1.9
	A	2	-37.05721	174.66679	0.7	0.0	0.1	2.0	53.4	43.8	0.7
	A	3	-37.05684	174.66731	0.8	0.4	0.1	3.5	51.6	44.0	0.4
	A	4	-37.05671	174.66820	1.0	0.2	0.2	9.0	54.3	35.8	0.6
	A	5	-37.05207	174.66642	1.1	0.0	1.8	39.0	45.4	13.8	0.0
	A	6	-37.05181	174.66628	1.3	0.0	2.0	43.5	41.6	12.9	0.0
	A	7	-37.05055	174.66554	1.3	0.6	2.0	51.6	38.2	7.7	0.0
	A	8	-37.05018	174.66517	1.3	0.5	2.1	47.6	43.0	6.6	0.4

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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	-37.05558	174.66792	0.8	0.7	0.2	9.9	48.4	40.2	0.5
	B	2	-37.05436	174.66678	1.0	1.0	0.9	15.5	63.9	18.7	0.0
	B	3	-37.05359	174.66608	2.0	1.6	1.0	25.7	57.1	14.6	0.1
	B	4	-37.05280	174.66672	1.0	0.5	1.8	33.8	46.1	17.9	0.0
	B	5	-37.04857	174.66274	2.0	7.8	1.9	34.0	47.4	7.5	1.3
	B	6	-37.04816	174.66340	1.3	0.5	3.1	56.9	34.9	4.6	0.0
	B	7	-37.04736	174.66106	0.9	0.2	0.1	7.3	51.6	39.9	1.0
	B	8	-37.04686	174.66085	0.9	0.2	0.1	12.9	62.9	23.9	0.0
	C	1	-37.05253	174.66510	1.0	0.5	0.8	14.6	75.1	9.0	0.0
	C	2	-37.05210	174.66538	1.4	0.2	0.9	24.6	70.2	4.0	0.2
	C	3	-37.05127	174.66329	0.8	0.0	0.0	1.3	49.6	47.9	1.2
	C	4	-37.05068	174.66411	1.0	1.2	1.1	16.6	66.6	14.4	0.0
	C	5	-37.05045	174.66349	0.7	0.0	0.2	5.0	64.6	29.9	0.4
	C	6	-37.05017	174.66452	1.0	0.8	2.7	49.7	44.9	1.9	0.0
	C	7	-37.04861	174.66239	1.1	0.0	0.5	17.7	67.4	14.0	0.4
	C	8	-37.04859	174.66147	1.0	0.0	0.2	18.1	71.5	9.5	0.7
Hokianga Harbour	B	1	-35.49585	173.40277	2.8	2.1	2.7	22.7	16.5	12.9	43.2
	B	2	-35.49584	173.40272	2.3	3.5	5.0	28.8	21.3	11.2	30.2
	B	3	-35.49579	173.40277	2.8	1.7	4.4	23.4	19.4	10.7	40.4
	B	4	-35.49578	173.40272	2.0	1.9	3.9	30.2	25.3	9.3	29.6
	B	5	-35.49574	173.40247	2.3	2.3	2.6	21.4	17.2	13.2	43.4
	B	6	-35.49569	173.40284	2.2	3.3	3.6	28.3	38.4	13.1	13.2
	B	7	-35.49567	173.40256	2.1	1.8	1.8	12.8	11.6	11.9	60.0
	B	8	-35.49567	173.40267	2.4	2.7	2.8	18.3	26.9	14.1	35.2
	B	9	-35.49564	173.40247	1.8	1.2	2.4	17.9	14.8	11.0	52.7
	B	10	-35.49560	173.40263	2.0	2.1	3.9	35.4	33.1	13.2	12.2
	B	11	-35.49558	173.40258	1.5	3.7	2.5	21.7	41.1	16.0	15.0
	B	12	-35.49558	173.40271	3.3	10.2	4.6	17.3	31.2	8.6	28.1

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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
	B	13	-35.49557	173.40275	2.5	12.2	8.5	22.2	37.5	11.1	8.6
	B	14	-35.49557	173.40247	1.6	1.9	3.2	32.4	39.6	11.3	11.6
	B	15	-35.49555	173.40259	1.6	2.3	3.1	29.9	34.2	9.4	21.1
	B	16	-35.49553	173.40283	1.8	1.8	1.3	16.7	28.1	10.2	41.9
	B	17	-35.49552	173.40268	3.2	4.6	4.0	31.6	43.0	8.4	8.4
	B	18	-35.49548	173.40243	1.7	4.0	4.4	30.7	34.9	11.6	14.4
	B	19	-35.49544	173.40268	3.4	16.3	7.4	25.4	36.1	6.3	8.5
	B	20	-35.49544	173.40245	1.8	4.4	4.9	27.7	32.6	10.4	20.1
	B	21	-35.49542	173.40270	4.1	23.7	7.1	22.5	32.0	7.9	6.8
	B	22	-35.49538	173.40264	1.7	5.2	3.2	23.5	44.2	11.5	12.4
	B	23	-35.49534	173.40252	2.0	5.8	4.3	26.2	32.1	8.1	23.5
	B	24	-35.49527	173.40243	2.9	8.6	3.5	20.7	32.4	10.3	24.5
Kawakawa Bay	A	1	-36.94936	175.15511	2.3	8.6	62.6	21.3	4.8	2.6	0.1
	A	2	-36.94881	175.15415	2.7	14.8	63.4	17.2	3.1	1.3	0.2
	A	3	-36.94877	175.15567	2.2	10.5	71.3	16.6	1.2	0.5	0.0
	A	4	-36.94857	175.16288	1.3	7.8	25.5	27.2	8.3	16.1	15.1
	A	5	-36.94849	175.16286	1.6	7.9	31.5	34.5	8.0	13.9	4.2
	A	6	-36.94759	175.16344	2.0	8.8	12.5	44.9	26.7	4.6	2.5
	A	7	-36.94673	175.15120	3.0	22.6	53.3	9.7	3.8	2.9	7.8
	A	8	-36.94425	175.15008	3.4	7.1	7.2	2.9	6.3	9.0	67.5
	A	9	-36.94307	175.15188	1.7	3.4	54.0	41.3	1.3	0.1	0.0
	B	1	-36.94883	175.15934	1.7	6.0	12.0	39.4	28.3	10.5	3.8
	B	2	-36.94881	175.15363	2.0	7.5	63.3	27.4	1.5	0.2	0.0
	B	3	-36.94874	175.16242	2.0	6.1	20.9	17.0	6.8	10.8	38.4
	B	4	-36.94844	175.15810	1.3	1.4	31.7	52.9	13.3	0.6	0.0
	B	5	-36.94699	175.15319	1.9	7.7	64.1	26.0	1.4	0.6	0.3
	B	6	-36.94613	175.15096	2.8	13.4	68.0	16.9	1.2	0.4	0.0
	B	7	-36.94490	175.15025	1.9	4.9	71.6	21.0	2.4	0.1	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	8	-36.94450	175.15309	1.5	3.4	49.9	46.0	0.6	0.1	0.0
	B	9	-36.94400	175.15296	1.6	3.0	46.4	50.0	0.5	0.1	0.0
	B	10	-36.94291	175.15018	3.3	18.4	60.8	15.1	4.9	0.6	0.2
	B	11	-36.94172	175.15064	1.1	3.0	29.8	66.8	0.4	0.0	0.0
	C	1	-36.94234	175.15131	1.9	7.0	72.4	18.4	1.6	0.7	0.0
	C	2	-36.94212	175.15251	1.8	2.8	61.8	34.3	1.0	0.1	0.0
	C	3	-36.94202	175.15186	1.9	4.4	66.2	25.0	1.7	0.5	2.4
	C	4	-36.94162	175.15082	3.2	22.2	61.7	7.3	1.0	1.5	6.4
Ōhiwa Harbour	A	1	-38.00999	177.13951	2.5	11.9	23.1	62.1	2.3	0.6	0.0
	A	2	-38.00960	177.13949	3.9	11.9	24.8	60.0	2.3	0.9	0.0
	A	3	-38.00893	177.13955	1.9	1.2	7.5	90.3	1.0	0.0	0.0
	A	4	-38.00877	177.13937	2.0	2.5	13.8	82.6	0.8	0.3	0.0
	A	5	-38.00857	177.13953	1.7	1.0	5.6	92.0	1.3	0.1	0.0
	A	6	-38.00829	177.13931	1.9	4.3	11.6	82.5	1.3	0.3	0.0
	A	7	-38.00815	177.13929	1.8	1.1	10.5	87.4	0.9	0.1	0.0
	A	8	-38.00783	177.13935	1.8	3.1	3.4	87.2	5.4	0.9	0.0
	A	9	-38.00769	177.13912	1.9	3.3	8.6	85.9	1.6	0.6	0.0
	A	10	-38.00745	177.13912	1.8	3.5	7.3	87.2	1.6	0.3	0.0
	A	11	-38.00696	177.13917	1.7	3.0	6.0	83.3	6.6	1.0	0.0
	A	12	-38.00669	177.13907	1.9	2.7	6.4	83.7	6.3	0.9	0.0
	B	1	-38.01475	177.13802	2.4	6.9	14.2	77.0	1.6	0.3	0.0
	B	2	-38.01456	177.13803	1.8	2.7	7.0	88.4	1.9	0.1	0.0
	B	3	-38.01455	177.13816	2.5	9.1	19.2	69.8	1.6	0.3	0.0
	B	4	-38.01441	177.13816	1.8	7.2	11.7	79.5	1.4	0.2	0.0
	B	5	-38.01428	177.13837	1.9	3.6	7.8	86.9	1.6	0.1	0.0
	B	6	-38.01409	177.13842	1.8	7.2	8.6	81.1	2.7	0.4	0.0
	B	7	-38.01404	177.13839	2.3	8.7	13.6	75.2	2.2	0.2	0.0
	B	8	-38.01378	177.13866	2.1	8.1	15.5	74.6	1.6	0.2	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	9	-38.01372	177.13866	2.9	17.1	29.7	50.6	1.9	0.8	0.0
	B	10	-38.01362	177.13894	2.6	15.0	25.5	57.7	1.3	0.4	0.0
	B	11	-38.01361	177.13884	2.6	8.6	13.1	75.9	1.9	0.5	0.0
	B	12	-38.01355	177.13887	1.8	3.0	7.7	87.8	1.4	0.0	0.1
Okoromai Bay	A	1	-36.61206	174.81073	1.5	1.0	20.7	76.8	1.4	0.1	0.0
	A	2	-36.61175	174.80815	2.2	3.1	35.6	58.8	2.4	0.1	0.0
	A	3	-36.61160	174.80866	2.1	3.5	38.2	56.2	1.8	0.2	0.0
	A	4	-36.61151	174.81036	1.6	2.1	33.5	64.0	0.3	0.1	0.0
	A	5	-36.61137	174.80964	1.8	4.2	35.1	59.8	0.8	0.2	0.0
	A	6	-36.61116	174.80817	2.2	3.0	37.1	56.8	2.9	0.1	0.0
	B	1	-36.61236	174.80829	2.2	3.0	25.2	63.7	8.0	0.1	0.0
	B	2	-36.61215	174.80775	1.9	0.0	27.5	67.6	4.7	0.2	0.0
	B	3	-36.61208	174.80823	1.9	2.0	37.1	58.5	2.4	0.1	0.0
	B	4	-36.61208	174.80867	2.0	2.9	29.0	62.4	5.0	0.7	0.0
	B	5	-36.61089	174.81185	2.0	4.2	42.6	52.0	0.8	0.3	0.0
	B	6	-36.61012	174.81128	1.9	4.4	46.0	47.3	2.0	0.3	0.0
	C	1	-36.60975	174.81079	1.9	4.1	54.1	40.7	0.9	0.2	0.0
	C	2	-36.60929	174.80901	2.0	4.5	54.2	40.4	0.8	0.1	0.0
	C	3	-36.60914	174.80874	2.0	4.7	59.8	34.2	1.1	0.0	0.0
	C	4	-36.60884	174.81122	2.1	7.4	58.1	32.8	1.1	0.6	0.0
	C	5	-36.60858	174.80817	2.5	9.6	77.6	11.9	0.8	0.1	0.0
	C	6	-36.60842	174.81054	2.0	7.6	63.5	25.5	1.4	1.0	1.0
	D	1	-36.60836	174.81165	2.2	7.9	41.0	28.5	12.9	9.5	0.1
	D	2	-36.60835	174.81117	3.0	8.9	57.1	27.2	4.6	2.2	0.0
	D	3	-36.60822	174.81096	2.9	10.6	63.3	22.5	2.2	1.4	0.0
	D	4	-36.60806	174.81071	1.7	7.3	81.6	10.9	0.2	0.1	0.0
	D	5	-36.60803	174.81168	2.9	6.9	15.9	36.9	16.4	21.9	2.1
	D	6	-36.60762	174.81187	3.0	10.7	14.3	29.7	13.8	25.7	5.8

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Otūmoetai	A	1	-37.66454	176.15170	1.2	0.6	4.9	61.4	25.6	7.4	0.0
	A	2	-37.66452	176.15179	1.3	0.8	6.2	65.3	20.7	6.9	0.0
	A	3	-37.66449	176.15070	0.9	1.0	4.8	49.3	24.6	20.0	0.3
	A	4	-37.66446	176.15092	1.4	1.0	6.1	64.2	18.1	10.6	0.0
	A	5	-37.66443	176.15004	1.3	1.8	7.2	48.0	20.3	22.7	0.0
	A	6	-37.66439	176.15090	1.6	1.3	7.4	69.5	16.0	5.4	0.3
	A	7	-37.66429	176.15219	1.5	1.8	6.7	56.6	19.9	14.8	0.1
	A	8	-37.66427	176.15199	1.9	2.1	7.8	64.7	17.6	7.7	0.0
	A	9	-37.66422	176.15028	1.5	1.5	8.4	70.8	15.0	4.3	0.0
	A	10	-37.66422	176.15197	1.8	2.6	8.3	67.2	17.1	4.7	0.0
	A	11	-37.66421	176.15220	1.5	2.5	6.3	66.4	19.7	5.1	0.0
	A	12	-37.66418	176.15089	1.8	2.9	9.2	67.5	15.9	4.2	0.4
	B	1	-37.66416	176.15128	1.5	1.7	8.3	73.9	13.4	2.7	0.0
	B	2	-37.66410	176.15075	1.6	1.6	10.2	73.8	12.2	2.2	0.0
	B	3	-37.66405	176.15023	1.8	3.1	8.5	71.2	15.5	1.6	0.0
	B	4	-37.66402	176.15128	1.8	1.7	9.6	75.7	11.5	1.5	0.0
	B	5	-37.66402	176.15040	1.8	2.3	9.9	72.1	14.0	1.7	0.0
	B	6	-37.66395	176.15152	1.9	2.9	9.6	74.0	12.3	1.2	0.0
	B	7	-37.66390	176.15089	1.9	2.9	10.6	74.2	11.3	1.0	0.0
	B	8	-37.66388	176.15147	2.0	2.3	10.0	74.4	12.1	1.1	0.0
	B	9	-37.66378	176.15063	1.8	2.2	10.3	70.4	15.1	2.0	0.0
	B	10	-37.66377	176.15094	1.9	2.4	9.3	69.6	16.7	2.0	0.0
	B	11	-37.66375	176.15020	1.8	2.5	11.3	69.7	14.5	1.9	0.1
	B	12	-37.66375	176.15139	1.8	2.2	8.9	75.1	12.6	1.2	0.0
Pataua Estuary	A	1	-35.71896	174.51573	1.2	0.4	4.2	24.9	21.7	19.8	29.0
	A	2	-35.71798	174.51704	1.9	2.5	13.2	57.5	19.0	7.4	0.5
	A	3	-35.71795	174.51642	1.6	1.8	10.2	56.2	22.9	8.7	0.2
	A	4	-35.71779	174.51520	2.1	3.7	13.9	77.3	3.6	1.3	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
	A	5	-35.71762	174.51586	1.5	2.1	8.1	83.7	5.1	0.9	0.0
	A	6	-35.71742	174.51691	1.0	0.6	3.6	48.8	21.0	22.6	3.3
	A	7	-35.71732	174.51838	1.4	0.5	4.4	30.6	24.1	21.5	18.9
	A	8	-35.71715	174.51915	1.4	0.9	8.5	55.8	23.1	10.1	1.7
	A	9	-35.71696	174.51773	1.9	4.0	10.7	65.3	14.2	5.9	0.0
	A	10	-35.71683	174.51589	1.5	1.5	6.4	52.7	25.4	13.9	0.1
	A	11	-35.71649	174.51805	2.4	6.0	11.5	73.1	5.2	3.3	0.8
	A	12	-35.71647	174.51810	1.3	0.7	7.7	51.1	28.4	10.9	1.2
	B	1	-35.72126	174.51205	2.4	2.8	19.2	46.3	12.9	18.4	0.4
	B	2	-35.72103	174.51360	1.6	1.7	9.4	58.2	16.5	14.3	0.0
	B	3	-35.72026	174.51091	1.8	2.6	14.2	56.6	14.6	11.7	0.2
	B	4	-35.71949	174.51288	2.3	4.5	20.3	73.6	1.3	0.3	0.0
	B	5	-35.71937	174.51147	1.7	2.9	6.2	32.4	29.4	26.0	3.1
	B	6	-35.71935	174.51331	1.1	0.2	3.9	28.7	29.1	37.9	0.2
	B	7	-35.71905	174.51185	3.5	5.7	21.0	70.0	2.5	0.8	0.0
	B	8	-35.71889	174.51098	1.0	0.2	3.9	25.4	31.1	36.3	3.1
	B	9	-35.71880	174.51299	2.2	2.0	16.5	65.8	8.4	7.3	0.0
	B	10	-35.71827	174.51344	1.9	3.6	16.8	58.8	9.1	11.7	0.0
	B	11	-35.71775	174.51251	1.4	1.3	10.9	64.6	14.2	8.4	0.5
	B	12	-35.71729	174.51217	1.1	1.3	7.7	33.9	23.6	32.2	1.2
Waiotahe Estuary	A	1	-37.99411	177.20003	1.9	14.7	10.2	71.2	3.4	0.5	0.0
	A	2	-37.99382	177.19990	2.0	13.5	12.6	71.5	2.3	0.2	0.0
	A	3	-37.99311	177.19883	2.2	13.9	9.1	62.7	11.9	2.2	0.1
	A	4	-37.99300	177.19978	1.8	3.3	6.6	79.2	9.2	1.7	0.1
	A	5	-37.99250	177.19805	1.9	6.0	9.0	72.4	10.9	1.6	0.1
	A	6	-37.99224	177.19949	2.7	10.0	11.8	69.1	7.9	1.1	0.0
	A	7	-37.99197	177.19580	1.7	2.9	10.3	60.8	21.9	4.1	0.1
	A	8	-37.99148	177.19955	1.3	1.3	1.2	78.6	18.7	0.1	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	B	1	-37.99303	177.20314	1.4	0.5	1.5	90.0	7.9	0.0	0.0
	B	2	-37.99298	177.20147	1.4	1.3	0.7	79.4	17.4	1.2	0.0
	B	3	-37.99288	177.20373	1.3	0.0	1.6	86.5	11.9	0.1	0.0
	B	4	-37.99284	177.20188	1.8	0.0	2.0	81.5	14.5	1.5	0.5
	B	5	-37.99271	177.20221	1.4	0.6	1.2	84.8	13.2	0.3	0.0
	B	6	-37.99262	177.20282	1.4	0.3	0.3	53.4	45.6	0.5	0.0
	B	7	-37.99255	177.20251	1.4	0.3	2.3	87.7	9.5	0.3	0.0
	B	8	-37.99236	177.20472	1.1	0.8	3.6	90.5	5.1	0.0	0.0
	B	9	-37.99231	177.20285	1.6	0.8	2.7	89.3	7.2	0.1	0.0
	C	1	-37.99279	177.20403	1.3	0.5	0.6	67.6	31.2	0.1	0.0
	C	2	-37.99270	177.20417	1.3	0.3	1.6	75.4	22.6	0.1	0.0
	C	3	-37.99244	177.20507	1.6	1.3	2.2	60.7	12.5	1.0	22.3
	C	4	-37.99238	177.20353	1.5	0.0	0.4	75.4	24.1	0.1	0.0
	C	5	-37.99211	177.20510	1.5	0.3	0.1	47.8	51.2	0.6	0.0
	C	6	-37.99206	177.20562	1.3	0.0	0.1	16.3	79.0	4.7	0.0
	C	7	-37.99200	177.20467	1.2	0.6	0.6	60.7	37.7	0.4	0.0
Whangamatā Harbour	A	1	-37.19753	175.87460	1.6	0.0	6.0	75.6	17.3	1.2	0.0
	A	2	-37.19738	175.87481	1.5	0.9	3.9	66.7	25.5	1.9	1.1
	A	3	-37.19557	175.87367	1.7	0.0	1.7	42.7	28.0	26.3	1.3
	A	4	-37.19548	175.87392	2.9	1.9	1.9	62.3	30.9	3.0	0.0
	A	5	-37.19431	175.87331	2.4	0.7	2.2	66.9	29.6	0.7	0.0
	A	6	-37.19386	175.87276	2.3	0.7	2.7	80.1	16.1	0.3	0.0
	A	7	-37.19328	175.87185	2.0	2.4	4.9	38.4	13.5	34.3	6.4
	A	8	-37.19320	175.87118	2.6	2.3	6.0	39.0	13.2	30.3	9.1
	A	9	-37.19319	175.87129	3.1	1.1	6.0	46.8	20.2	21.4	4.6
	A	10	-37.19310	175.87134	2.5	0.0	3.3	28.0	27.5	36.6	4.7
	A	11	-37.19281	175.87025	2.0	1.8	7.1	48.5	20.3	20.6	1.6
	A	12	-37.19256	175.86972	3.3	8.6	7.7	47.2	14.6	19.9	2.1

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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
	B	1	-37.19648	175.87462	2.2	2.5	4.8	71.7	18.9	2.2	0.0
	B	2	-37.19636	175.87360	2.0	2.4	5.0	64.5	25.6	2.5	0.0
	B	3	-37.19627	175.87314	2.0	2.7	5.5	63.7	25.9	2.1	0.0
	B	4	-37.19613	175.87393	1.8	1.3	3.7	62.7	26.5	5.7	0.2
	B	5	-37.19610	175.87229	1.9	5.7	4.3	49.7	30.8	6.8	2.8
	B	6	-37.19584	175.87229	1.7	4.2	4.2	35.4	30.7	18.8	6.6
	B	7	-37.19385	175.87193	3.2	3.7	7.8	80.9	7.1	0.6	0.0
	B	8	-37.19369	175.87129	2.4	3.2	9.5	65.6	14.0	7.5	0.2
	B	9	-37.19355	175.87143	2.0	0.9	6.4	49.9	18.5	23.6	0.7
	B	10	-37.19333	175.87069	8.1	19.3	16.1	42.5	12.1	8.4	1.5
	B	11	-37.19291	175.87014	3.0	7.7	13.8	66.4	7.3	4.9	0.0
	B	12	-37.19268	175.86986	3.7	6.5	7.4	48.7	14.3	19.6	3.4
Whangapoua Harbour	A	1	-36.73867	175.64956	1.2	2.4	1.6	48.6	43.4	4.0	0.0
	A	2	-36.73866	175.64972	0.8	0.7	0.8	38.2	53.8	6.6	0.0
	A	3	-36.73857	175.64936	0.9	1.4	0.7	33.9	56.9	7.0	0.0
	A	4	-36.73850	175.64930	1.0	0.8	0.8	38.8	52.5	7.2	0.0
	A	5	-36.73846	175.64900	1.3	1.5	2.0	48.8	43.4	4.3	0.0
	A	6	-36.73841	175.64824	1.3	2.9	4.1	53.7	33.9	5.4	0.0
	A	7	-36.73839	175.64867	1.3	0.7	1.5	49.7	44.6	3.6	0.0
	A	8	-36.73836	175.64842	1.4	2.2	2.9	48.1	42.8	4.0	0.0
	B	1	-36.73468	175.64075	1.2	1.5	7.8	68.6	20.5	1.7	0.0
	B	2	-36.73459	175.63927	1.2	1.3	9.4	71.3	15.6	2.4	0.0
	B	3	-36.73439	175.63996	2.0	2.1	8.4	73.4	13.8	2.3	0.0
	B	4	-36.73425	175.63985	2.1	1.7	7.6	73.6	15.3	1.7	0.0
	B	5	-36.73397	175.63800	1.6	1.2	14.0	82.5	1.5	0.8	0.0
	B	6	-36.73386	175.63911	1.5	1.2	9.3	75.0	13.3	1.3	0.0
	B	7	-36.73353	175.63832	1.5	0.5	13.4	79.1	6.3	0.7	0.0
	B	8	-36.73348	175.63831	2.2	3.4	11.6	80.0	4.8	0.2	0.0

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Table B-1 – *Continued from previous page*

Survey site	Stratum	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
	C	1	-36.72605	175.61632	1.6	1.8	9.5	81.7	5.3	1.6	0.1
	C	2	-36.72574	175.61637	2.7	4.2	14.6	76.6	2.9	1.7	0.0
	C	3	-36.72564	175.61634	2.4	3.0	15.0	78.5	3.0	0.5	0.0
	C	4	-36.72559	175.61640	2.4	6.1	14.7	75.2	3.0	1.0	0.0
	C	5	-36.72547	175.61641	2.6	2.7	14.7	77.7	3.8	1.1	0.0
	C	6	-36.72547	175.61647	1.9	2.2	12.4	80.0	3.8	1.5	0.0
	C	7	-36.72546	175.61654	1.9	2.6	9.7	82.8	3.6	1.3	0.0
	C	8	-36.72508	175.61670	1.3	1.3	7.1	81.0	9.4	1.2	0.0

APPENDIX C: Geostatistical model predictions

C.1 Aotea Harbour

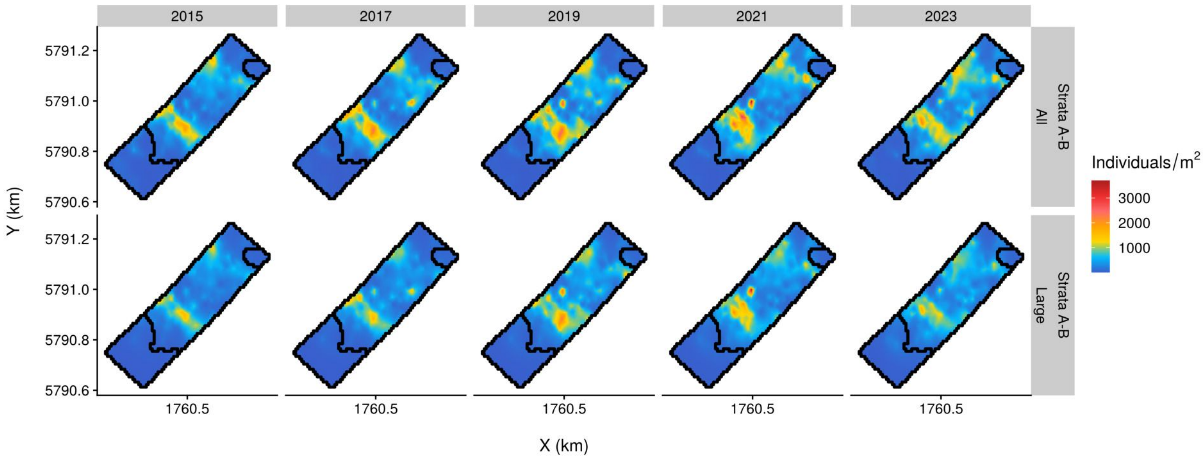

Figure C-1: Predicted cockle densities from the spatio-temporal model for Aotea Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.2 Cockle Bay

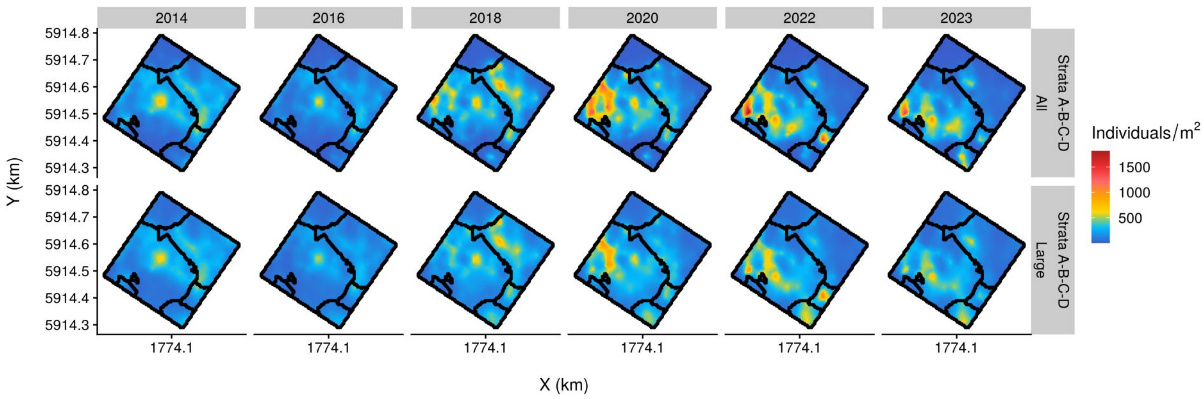

Figure C-2: Predicted cockle densities from the spatio-temporal model for Cockle Bay. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.3 Eastern Beach

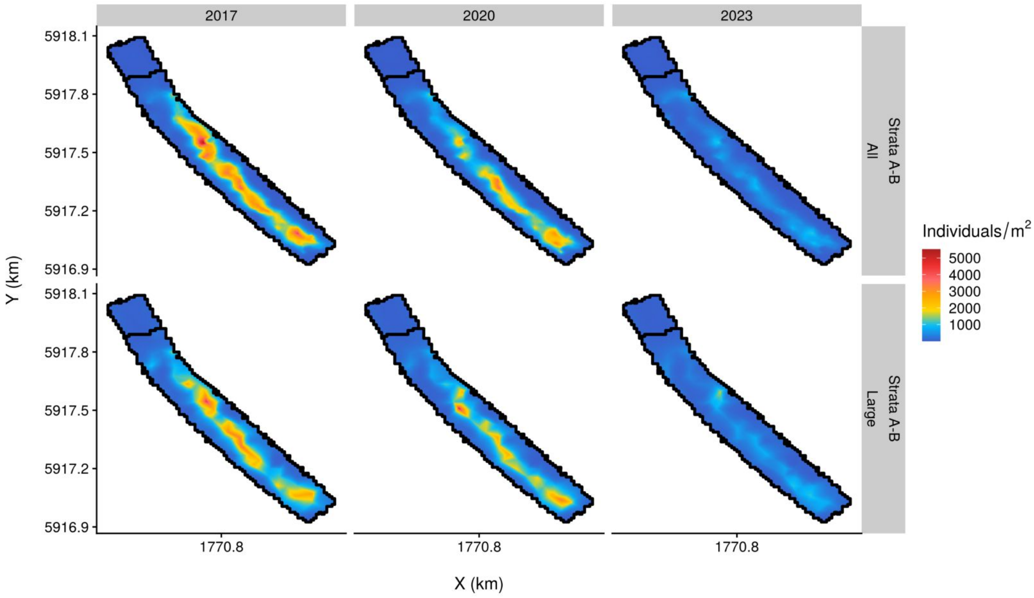

Figure C-3: Predicted cockle densities from the spatio-temporal model for Eastern Beach. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.4 Grahams Beach

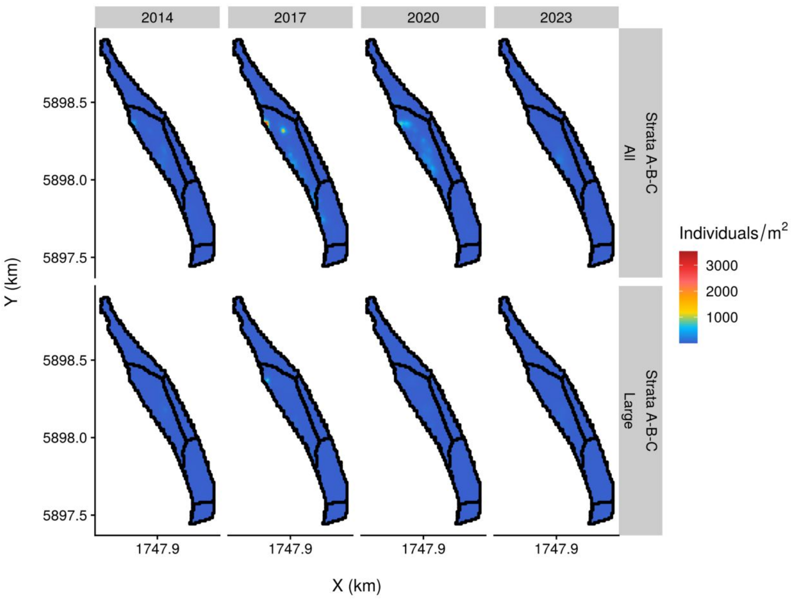

Figure C-4: Predicted cockle densities from the spatio-temporal model for Grahams Beach. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.5 Hokianga Harbour

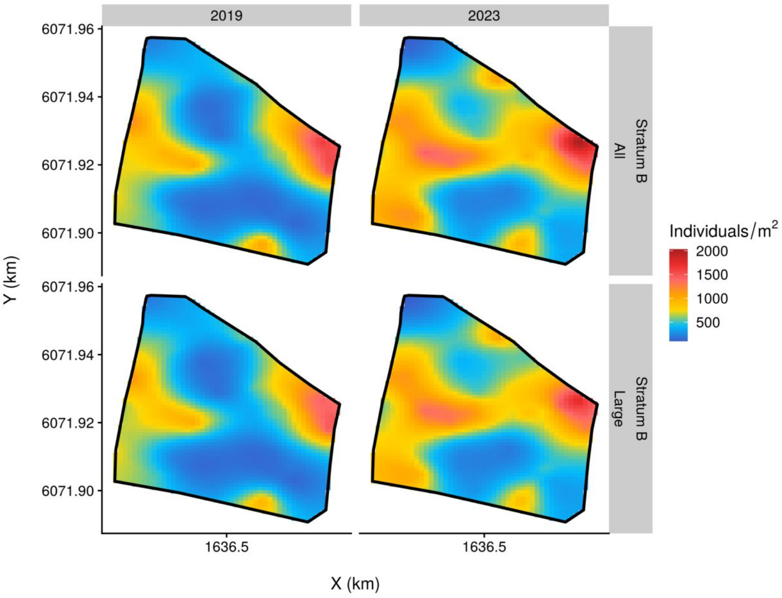

Figure C-5: Predicted cockle densities from the spatio-temporal model for Hokianga Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.6 Kawakawa Bay (West)

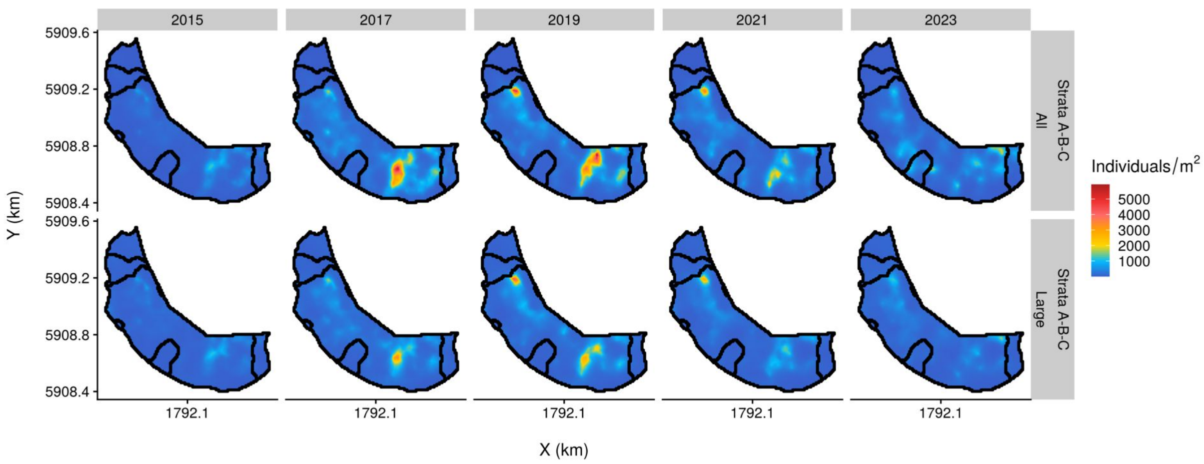

Figure C-6: Predicted cockle densities from the spatio-temporal model for Kawakawa Bay (West). Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.7 Ōhiwa Harbour

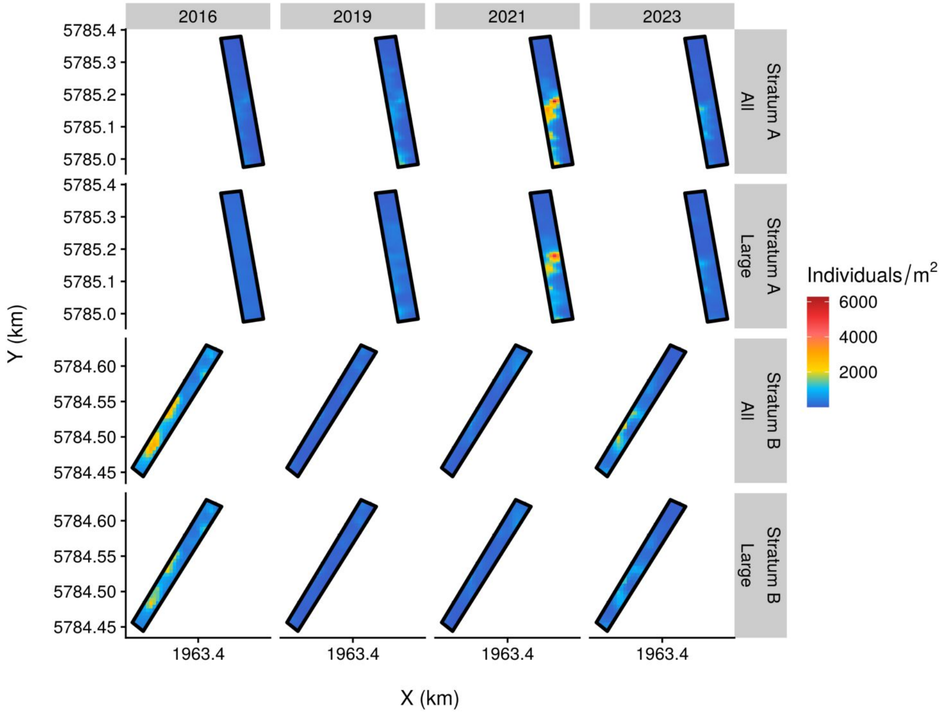

Figure C-7: Predicted cockle densities from the spatio-temporal model for Ōhiwa Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.8 Okoromai Bay

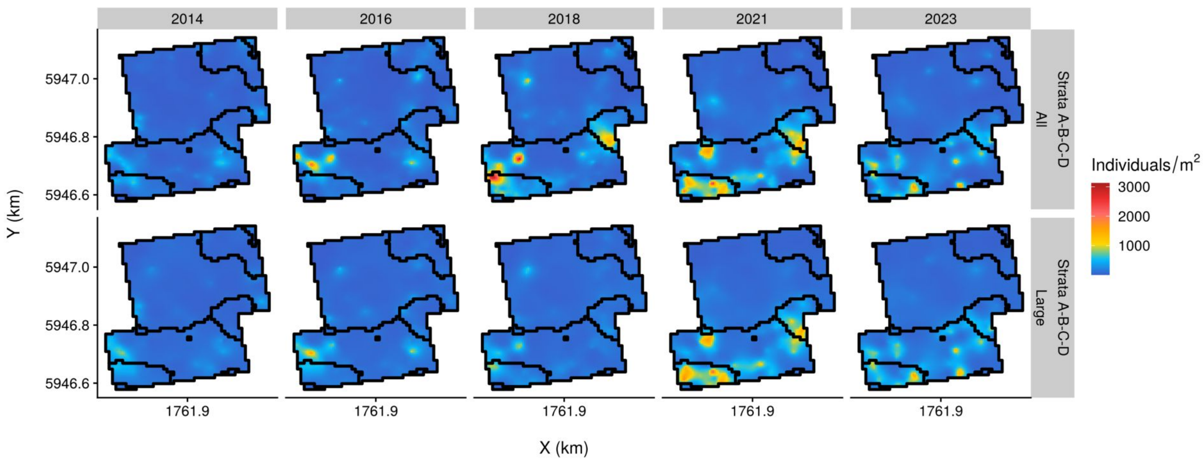

Figure C-8: Predicted cockle densities from the spatio-temporal model for Okoromai Bay. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.9 Otūmoetai (Tauranga Harbour)

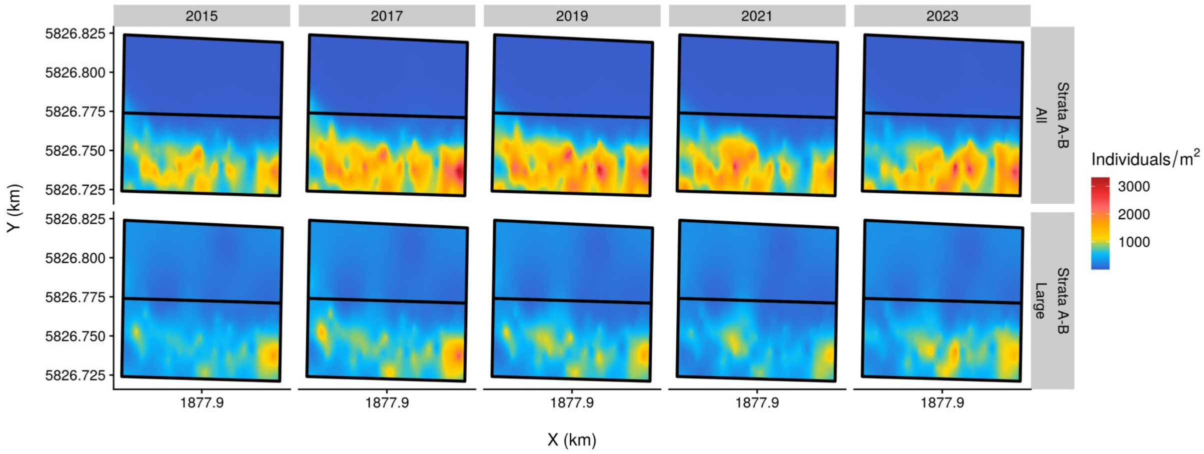

Figure C-9: Predicted cockle densities from the spatio-temporal model for Otūmoetai (Tauranga Harbour). Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.10 Pataua Estuary

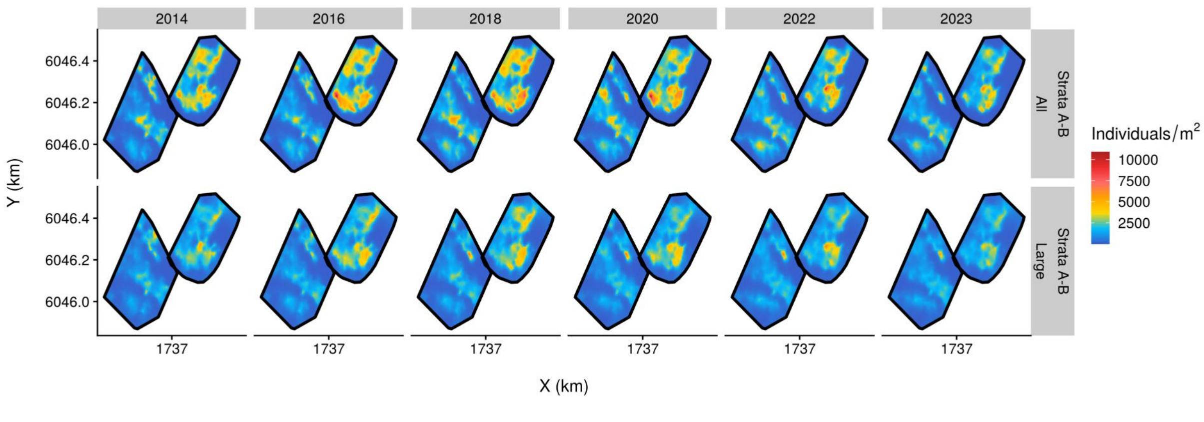

Figure C-10: Predicted cockle densities from the spatio-temporal model for Pataua Estuary. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.11 Waiotahe Estuary

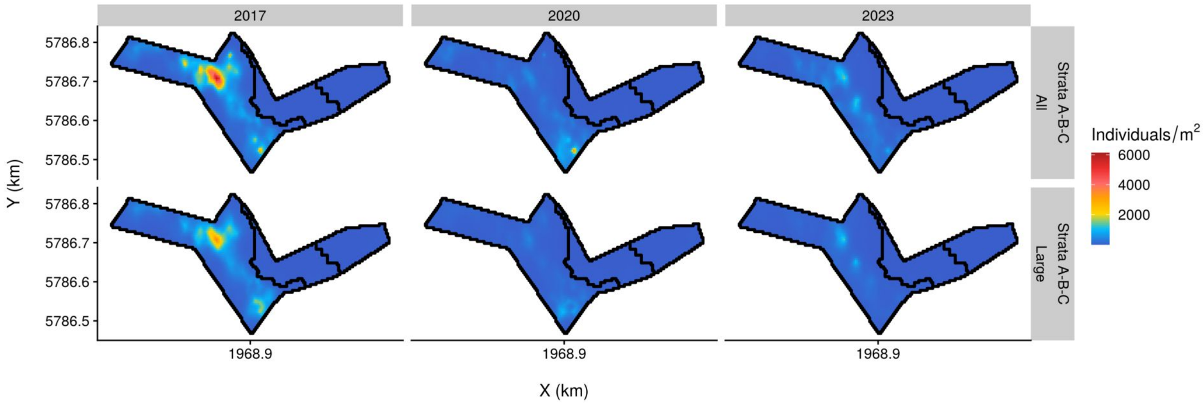

Figure C-11: Predicted cockle densities from the spatio-temporal model for Waiotahe Estuary. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.12 Whangamatā Harbour

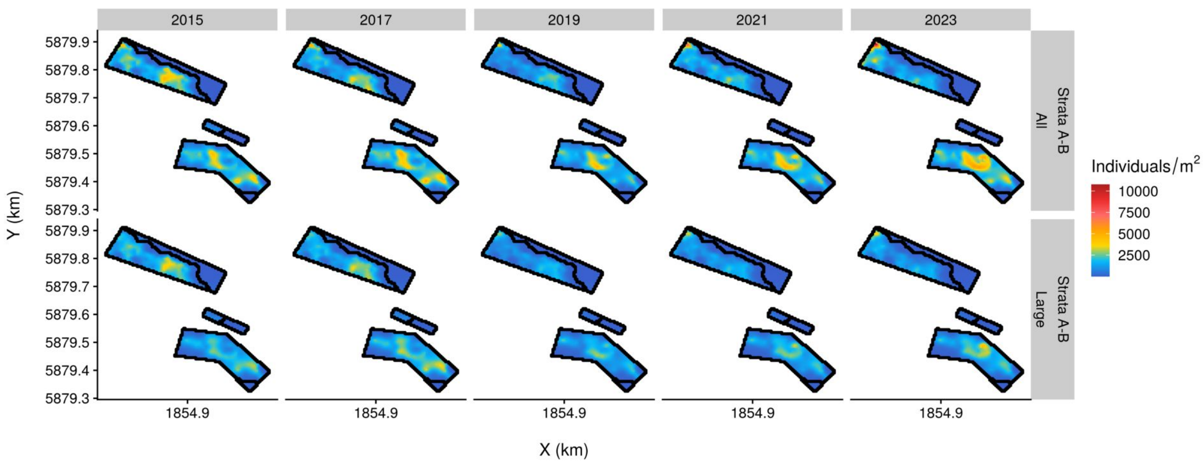

Figure C-12: Predicted cockle densities from the spatio-temporal model for Whangamatā Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

C.13 Whangapoua Harbour

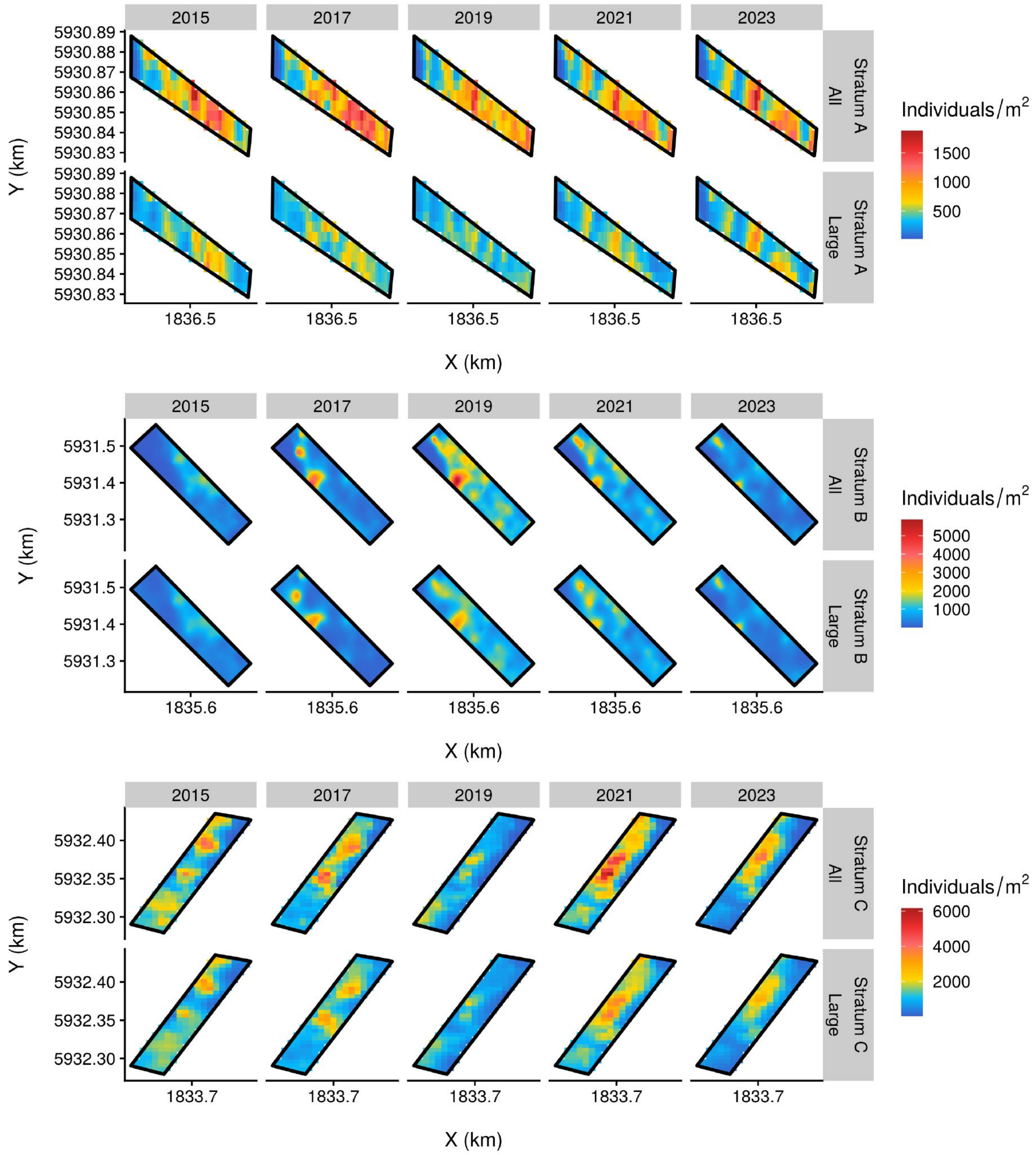

Figure C-13: Predicted cockle densities from the spatio-temporal model for Whangapoua Harbour. Predictions are shown for all and for large cockles (≥30 mm shell length) for each year the site was surveyed (since 2013–14, when high-resolution spatial data became available). Fishing years are indicated by the end year, e.g., 2023 refers to the 2022–23 fishing year.

APPENDIX D: Supplementary images

D.1 Cockle Bay: sediment surface

Figure D-1: Consolidated sediment habitat at Cockle Bay, February 2023. View across the sediment surface, with light-coloured clay showing beneath a thin layer of sandy sediment (left); sediment imprint from coring, revealing blueish clay immediately below the sandy surface (right). Diameter of core: 15 cm.

D.2 Pataua Estuary: pipi shells

Figure D-2: Sampled pipi at Pataua Estuary, February 2023, with blackened shells indicating anoxic sediment. Size of underlying mesh: 5 mm.