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Intertidal shellfish monitoring in the northern North Island region, 2014–15

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EXECUTIVE SUMMARY

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In New Zealand's sheltered coastal environments, bivalve species targeted in recreational and customary fisheries include cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*), which both inhabit sedimentary habitats throughout the country. In the northern North Island region, cockles and pipi are the principal fisheries species in sheltered environments of beaches, harbours, and estuaries, where some populations are under considerable pressure from these non-commercial fishing activities. To monitor the northern cockle and pipi populations, the Ministry for Primary Industries (MPI) commissions regular population assessments in northern North Island, with survey sites distributed across the wider Auckland region, Northland, Waikato, and Bay of Plenty.

The present study documents the most recent bivalve survey in the northern North Island region, conducted in 2014–15. The sites included in this survey were (in alphabetical order) Aotea Harbour, Eastern Beach, Kawakawa Bay (West), Mangawhai Harbour, Mill Bay, Ngunguru Estuary, Otumoetai (Tauranga Harbour), Raglan Harbour, Ruakaka Estuary, Te Haumi Beach, Whangamata Harbour, and Whangapoua Harbour. At each site, the population survey focused on areas targeted by non-commercial fisheries to determine the abundance and population densities of cockles and pipi. The survey also involved the collection of sediment data (grain size and organic content) to provide broad-scale baseline information about some of the habitat characteristics that influence bivalve populations.

All of the 2014–15 survey sites contained cockle populations. Cockle population sizes and densities varied across sites, with total abundance estimates ranging from the smallest population of 16.66 million (CV: 9.56%) cockles at Mill Bay to the largest population of 109.56 million (CV: 4.95%) individuals at Raglan Harbour. Whangamata Harbour and Ngunguru Estuary also supported large cockle populations, with an estimated 104.53 million (CV: 6.59%) and 92.67 million (CV: 7.53%) cockles, respectively. Population densities were also variable, with relatively high density estimates at three sites, Ngunguru Estuary, Raglan Harbour, and Whangamata Harbour, ranging from 1372 cockles per m^2 at Whangamata Harbour to 1696 cockles per m^2 at Ngunguru Estuary. At the remaining sites, cockle densities were considerably lower, with the next highest estimate of 675 cockles per m^2 (CV: 8.77%) at Ruakaka Estuary. The lowest population density was 68 cockles per m^2 (CV: 16.59%) at Eastern Beach.

Most cockle populations were dominated by small and medium-sized cockles, with relatively low numbers and densities of large individuals ($\geq$30 mm shell length). Furthermore, time-series comparisons across surveys (starting in 1999–2000) documented a general decrease in the population of large cockles, with only Eastern Beach reflecting a notable increase in this size class in 2014–15. In contrast, recruits ($\leq$15 mm shell length) were abundant at the majority of sites, where they constituted a considerable proportion of the population (up to 53.82% at Ruakaka Estuary).

Pipi populations were present at 11 (of the total 12) sites in the 2014–15 survey, excluding Aotea Harbour, where only one individual was sampled. Most of the pipi populations were small, and abundances were only relatively high at three sites, Te Haumi Beach, Ruakaka Estuary, and Otumoetai (Tauranga Harbour), where pipi numbers ranged between an estimated total of 55.91 million (CV: 18.38%; Te Haumi Beach) and 92.59 million (CV: 5.59%; Otumoetai) individuals. The corresponding population densities at these sites were 438 pipi to 1207 pipi m^2 (at Te Haumi Beach and Otumoetai, respectively), compared with considerably lower densities at the remaining sites, including a maximum density of 90 pipi per m^2 (at Mill Bay).

There was a general scarcity of large pipi ($\geq$50 mm shell length) in the 2014–15 populations, and this size class was absent at five of the sites surveyed. The lack or low abundance of large pipi at these sites was consistent throughout the survey series, especially in recent surveys (i.e., since 2005–06). At the same time, recruits ($\leq$20 mm shell length) were present in all pipi populations in 2014–15, with up to

74.50% of individuals in this size class (at Eastern Beach).

At all sites, the sediment was characterised by a low organic content, which was less than 4%. The bulk of the sediment consisted of fine or medium sands (>125 to >250 µm grain size), with only a small proportion or no fines (silt and clay; <63 µm grain size). Only individual samples at Mangawhai Harbour, Ngunguru Estuary, Ruakaka Estuary, and Te Haumi Beach exceeded 10% in this grain size fraction, with the highest proportion of fines at 20.6% in one sample at Te Haumi Beach.

1. INTRODUCTION

Bivalve populations in coastal waters frequently include species that are important in recreational and customary fisheries. In New Zealand's sheltered coastal environments, these species include cockles (tuangi/tuaki, or littleneck clam, *Austrovenus stuchburyi*) and pipi (*Paphies australis*), which are both found in sedimentary habitats of beaches, harbours, and estuaries throughout the country.

Cockle populations frequently form high-density patches and extensive beds, which are predominantly in intertidal areas, but may extend into shallow subtidal sediments. Pipi often co-occur with cockles, but their distribution is more restricted as they prefer clean, coarse sands and strong tidal currents; their beds are usually close to mean low water and in subtidal sediments. Both species can dominate benthic assemblages, with populations reaching high densities in localised areas, e.g., beds exceeding 1000 individuals per square metre (Morton & Miller 1973, Hooker 1995).

In New Zealand, cockles and pipi are targeted in recreational and customary fisheries, and are valued as kai moana (traditional Māori food) (Hauraki Māori Trust Board 2003, Hartill et al. 2005). In the northern North Island region, they are the principal fisheries species in sheltered environments, and non-commercial fishing pressure has been identified as one of several potential stressors of bivalve populations in this region (Grant & Hay 2003). To monitor the northern bivalve populations, the Ministry for Primary Industries (MPI) has commissioned regular (generally annual) surveys since 1992. Initially, the selection of survey sites was limited to the wider Auckland metropolitan area, but the spatial extent of the monitoring programme was subsequently expanded to include sites throughout the Auckland Fisheries Management Area (FMA 1) (see information about the surveys in Appendix A).

The data collection at each site is focused on providing information about the abundance and population structure (size-frequency distribution) of cockle and pipi populations (most recently, Berkenbusch et al. 2015). These data include the proportion of large individuals, defined as $\geq$30 mm shell length for cockles and $\geq$50 mm shell length for pipi, and also juveniles that are considered to be recruits, defined by shell lengths $\leq$15 mm for cockles and $\leq$20 mm shell length for pipi. As the surveys are based on intertidal areas that have been identified as important for recreational and customary fisheries, they do not provide population estimates of the entire cockle and pipi populations at each site (Pawley & Ford 2007). Nevertheless, they allow present-day and longer-term assessments of the bivalve populations that are subject to non-commercial fishing pressure throughout FMA 1. This information is directly relevant to the management of the northern bivalve populations. Management measures have included seasonal and permanent closures, and reductions in bag limits at some sites.

For cockles, regular abundance surveys have also been carried out by other organisations and community groups in the northern North Island region (e.g., Whangateau Harbourcare). The Hauraki Gulf Forum coordinates an annual bivalve monitoring effort by community groups, schools, and local iwi on intertidal beaches in the Hauraki Gulf Marine Park area (e.g., Auckland Council 2013). Their survey effort involves some of the sites that are also part of the MPI monitoring programme, but the sampling design and some of the areas differ between the two survey series.

The present study continued the series of (generally) annual MPI surveys of infaunal bivalve abundance and population structure at selected sites in the northern North Island region. The overall objective of this project was "to determine the distribution, abundance and size frequency of selected intertidal shellfish" for the 2014–15 fishing year.

The survey sites included in this study were (in alphabetical order): Aotea Harbour, Eastern Beach, Kawakawa Bay (West), Mangawhai Harbour, Mill Bay, Ngunguru Estuary, Otumoetai (Tauranga Harbour), Raglan Harbour, Ruakaka Estuary, Te Haumi Beach, Whangamata Harbour, and Whangapoua Harbour (see Figure 1).

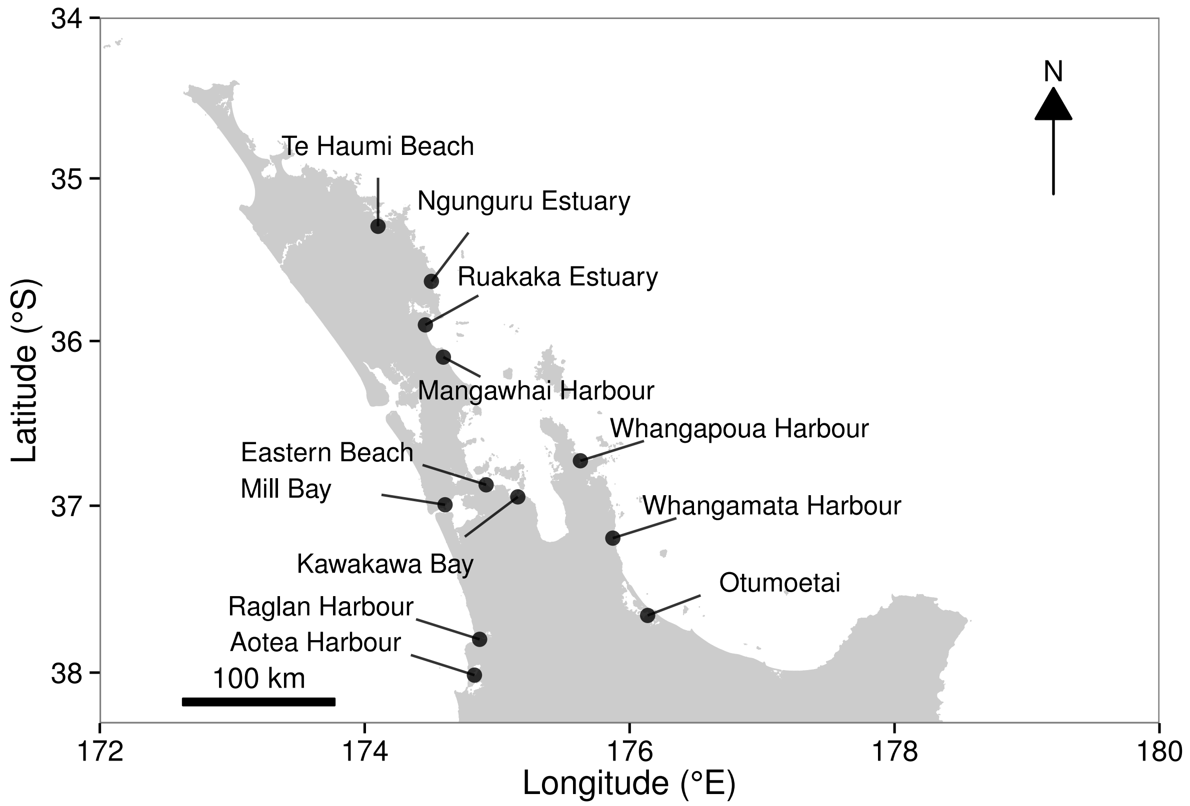


Figure 1: Sites included in the northern North Island intertidal bivalve surveys in 2014–15.

2. METHODS

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

2.1 Survey methods

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

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 either square, rectangle, or parallelogram shaped cells), with the size and shape of the grid cells reflecting the desired sampling density and the orientation of the stratum. The intersection of the grid with the boundary of the stratum was taken. For each phase, a sampling point was then allocated to each cell, with a probability proportional to the area of the cell over the maximum area of any of the cells in the grid. The position of the point within the cell was uniformly randomly allocated. With this procedure, not all the cells that were clipped by the boundary had sampling points allocated to them. The expected density of sampling points across the stratum was uniform. Points were pre-calculated for two phases before the sampling began. All phase-1 points were sampled, while sampling of phase-2 points was only carried out when the coefficient of variation (CV) of the total abundance estimate after sampling in the first phase exceeded the target CV of 20% for either cockle or pipi (for five sites in 2014–15).

2.2 Field sampling—bivalves

The field component of this study was carried out in January and February 2015. At each site, the intertidal sampling was conducted during periods of low tide (see sampling dates for the present and previous surveys in Appendix A, Tables A-1, A-2).

The sampling unit consisted of a pair of benthic cores of 15 cm diameter each that (combined) sampled a surface area of 0.035 m^2 (to 15 cm depth; see, for example, Morrison et al. 1999b, Pawley 2012). The sampling depth encompassed the maximum burrowing depths of the infaunal bivalves concerned, 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 pushed 15 cm into the sediment directly adjacent to each other. The cores were excavated, and all sediment from each core was sieved in the field on 5-mm mesh. All cockles and pipi retained on the sieve were counted and measured (length of the maximum dimension, to the nearest millimetre), before returning them to the benthos. The counts were conducted by using hand-held counters or by splitting the bivalves retained within each sieve into groups of ten.

For strata with population densities exceeding 2000 individuals per m^2, a subsample of 50 individuals was measured across both cores (see Pawley 2011). This subsample involved measuring the first 50 individuals that had been counted (and involved 9 and 3% of all samples for cockles and pipi in the 2014–15 survey, respectively).

2.3 Field sampling - sediment

Owing to the importance of sediment properties for infaunal bivalves, the present monitoring programme also included the collection of sediment samples to provide baseline information about sediment properties at the survey sites (see detailed information in Appendix B). Both cockles and pipi are sensitive to changes in the sediment regime and, for example, show discernible decreases in their abundances in response to increases in sediment mud content (silt and clay, <63 µm grain size), i.e., by terrestrial-derived clay (Anderson 2008).

This sampling involved the analysis of a subset of sediment cores (5 cm diameter, sampled to 10 cm depth) for sediment grain size and organic content that were collected across the spatial extent of existing bivalve beds, and also in directly adjacent areas. The subsequent grain size analysis of the sediment samples was based on wet sieving to ascertain the proportion of different size classes, ranging from sediment fines (silt and clay, <63 µm grain size) to different sand fractions of very fine to very coarse sands and gravel (i.e., 125 to 2000 µm grain size) (Eleftheriou & McIntyre 2005). Each sample was homogenised before processing it on a stack of sieves to determine the proportion in each sediment grain size fractions (i.e., >63, >125, >250, >500, and >2000 µm). Each sediment fraction retained on the sieves was subsequently dried to constant weight at 60°C before weighing it (accuracy ± 0.00001 g).

The sediment organic content of each sample was determined by loss on ignition (4 hours at 550°C) after drying the sample to constant weight at 60°C (Eleftheriou & McIntyre 2005).

2.4 Data analysis

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. The data analysis followed previous analyses as outlined in Pawley & Smith (2014). Results from the present survey were compared with previous surveys using the MPI beach database. Comparisons with previous surveys from 1999–2000 onwards were made for estimates of abundance and population density. Length-frequency distributions from the present survey were compared with the two preceding surveys.

As in recent previous surveys, the two cores within each grid cell were considered as 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 (in individuals per m^2) within the stratum. The total number $\hat{N}$ of bivalves at each site is then the sum of total abundance within each stratum, estimated by multiplying the density within each stratum by the stratum area A_k.

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

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

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

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

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

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

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

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

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

3. RESULTS

3.1 Aotea Harbour

Aotea Harbour is on the Waikato west coast. This harbour was included in two previous bivalve surveys, in 2005–06 and 2009–10 (see Appendix A, Tables A-1, A-2). Both of the preceding surveys, and the current study, only assessed the cockle population, as there are no pipi beds in Aotea Harbour. Although anecdotal evidence indicated the earlier presence of an extensive, high-density pipi bed immediately north of Aotea Harbour township, this area (referred to as stratum C in the 2009–10 survey) was void of pipi in the preceding survey. Reconnaissance for the present study confirmed the absence of pipi, and only a single individual of pipi was sampled in the current survey.

The first survey of Aotea Harbour in 2005–06 sampled cockles in two areas, strata A and B. Stratum B was a narrow, subtidal strip (sampled to 0.5 m depth) situated within the main channel, and only accessible by boat. The subsequent survey in 2009–10 included both of these strata, and also added another cockle stratum, stratum D, directly adjacent to stratum A on the landward side. The same survey also added stratum C, north of Aotea Harbour township, where the sampling focused on pipi (none were found). Both strata A and D were surveyed in 2014–15, but movement of the channel prevented sampling of stratum B, as its sampling points had become too deep (i.e., exceeding 0.5 m water depth at low tide). For this reason, the current assessment of the cockle population at Aotea Harbour was based on strata A and D only, involving a total of 82 sampling points (Table 1).

Sediment sampling involved cores within both strata and in adjacent areas (Figure 2, and see details in Appendix B, Table B-3). Both sediment organic content and grain size were similar across samples, with a low proportion of organic matter (0.9 to 1.5%) and no sediment fines (<63 µm grain size). The bulk of the sediment consisted of fine sand (>125 µm grain size), followed by very fine sand (>63 µm grain size). The proportion of coarse particles was small, although one sample in the northwestern area adjacent to the survey strata contained 20.5% of gravel (>2000 µm grain size).

Cockles were present in both strata, particularly in the lower part of stratum D (Figure 3). Based on the field sampling, the total population estimate was 34.99 million (CV: 14.26%) cockles in 2014–15, based on a similar sampling extent as in previous surveys (Table 2). The mean population density of all cockles was 356 individuals per m^2. Both the abundance and density estimates were substantial decreases from previous values, with the preceding estimates including 70.94 million (CV: 16.91%) individuals in 2009–10, at a population density of 887 cockles per m^2 (comparing similar sampling extents). Nevertheless, the total population size and density of cockles in the first survey at Aotea Harbour in 2005–06 were also low and similar to the current estimates, documenting fluctuation in the cockle population throughout the survey series.

While the population estimates for large cockles ($\geq$30 mm shell length) corresponded with fluctuations in the total cockle population, this size class was consistently small across surveys, with the lowest estimates in the current study (Tables 2 and 3). In 2014–15, there were 0.55 million (CV: 45.13%) large individuals at Aotea Harbour, and their corresponding mean density was 6 large cockles per m^2. Similarly, their current estimate of 0.74% large cockles within the total population signified a continuing decrease over time, for example, from 2.52% large cockles in the preceding survey. At the same time, small cockles (recruits, defined as $\leq$15 mm shell length) made up 24.91% of the cockle population in 2014–15 (compared with 33.29% in 2009–10).

The prevalence of small and medium-size cockles was reflected in the length-frequency distributions of the Aotea Harbour population (Figure 4). There were few cockles $\geq$30 mm shell length in the survey series, and the population was generally unimodal across surveys, with a modal size of 19-mm shell length in 2014–15.

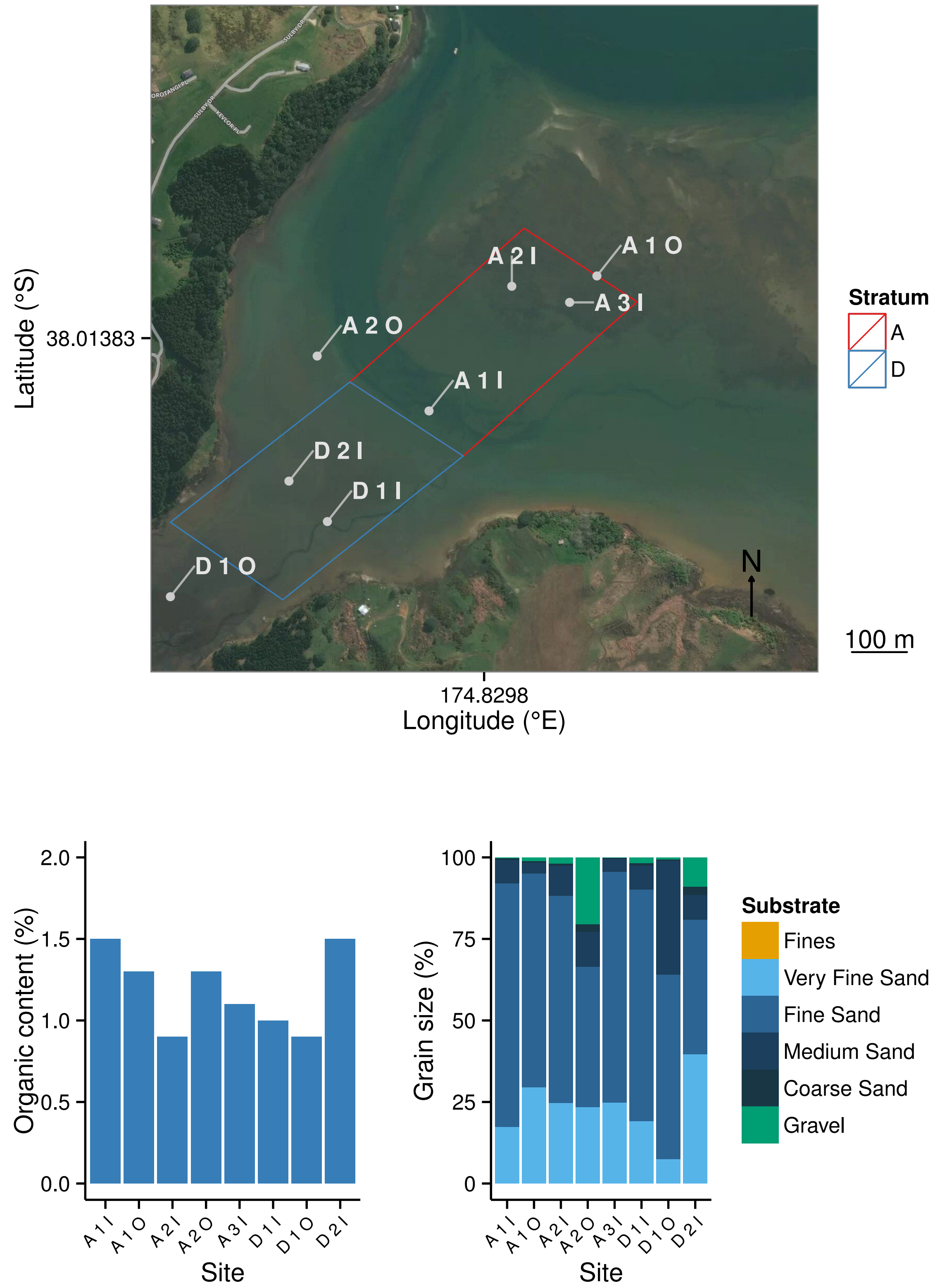


Figure 2: Sediment sample locations and characteristics at Aotea Harbour. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.2 Cockles at Aotea Harbour

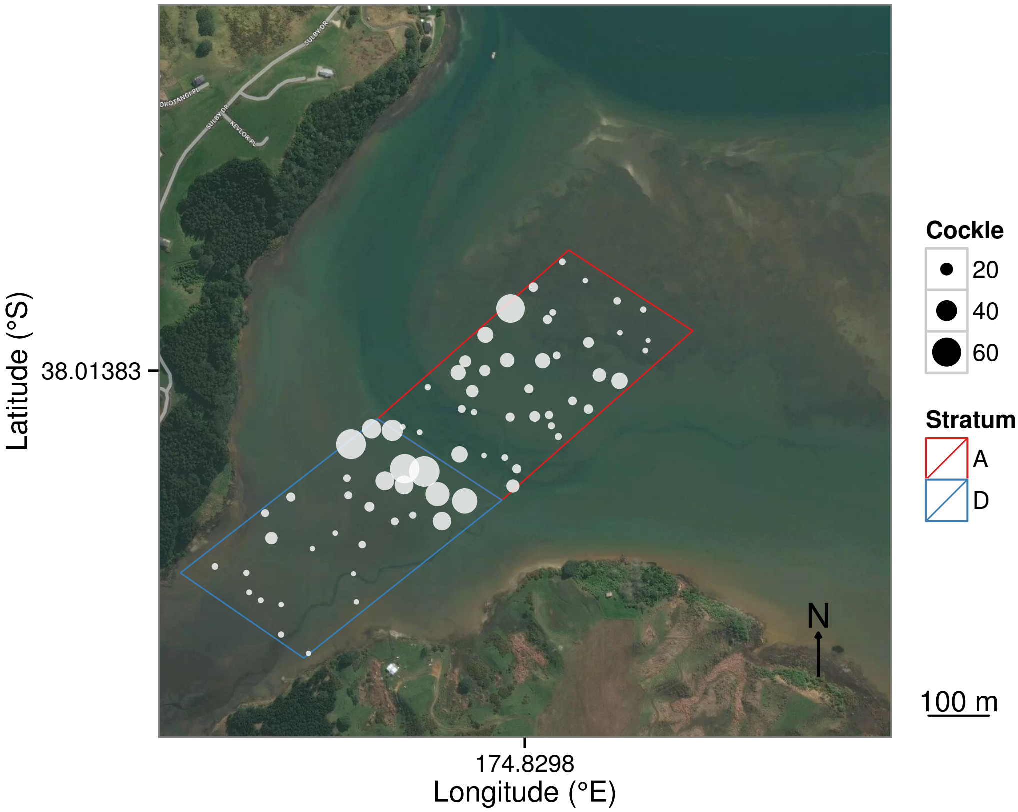


Figure 3: Map of sample strata and individual sample locations for cockles at Aotea Harbour, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 1: Estimates of cockle abundance at Aotea Harbour, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	9.8	41	511	34.99	356	14.26
D	9.6	41	584	39.21	407	21.86

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). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

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
2005–06*	8.0	30.24	378	4.99	1.18	15	17.18
2009–10	28.1	140.78	501	10.54	3.46	18	27.88
2009–10*	8.0	70.94	887	16.91	3.27	41	29.08
2014–15	19.5	74.20	381	13.37	0.55	3	45.13
2014–15*	9.8	34.99	356	14.26	0.55	6	45.13

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	21.70	22	6–36	9.60	3.91
2009–10	18.19	15	4–37	33.29	2.52
2014–15	18.40	19	6–32	24.91	0.74

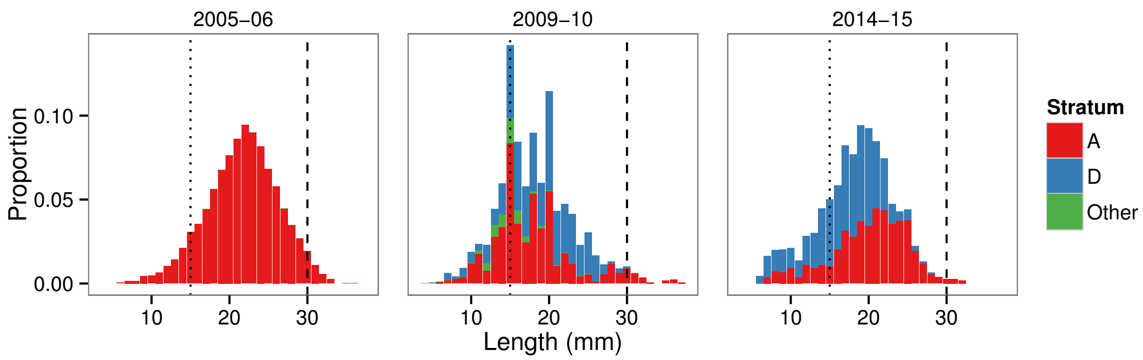


Figure 4: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Aotea Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.3 Eastern Beach

Eastern Beach is within the Auckland metropolitan area, on the eastern side of the city centre, in Hauraki Gulf. The survey site included the sandy beach along the residential area, with its northwestern and southeastern ends bounded by headlands and rocky platforms. This site was last surveyed in 2001–02, with one earlier recent survey in 1999–2000 (see Appendix A, Tables A-1, A-2). The beach has been closed to fishing since 1993 (Morrison et al. 1999a).

The 2014–15 sampling extent was consistent with the area surveyed in the two preceding assessments, and involved four strata across the beach (Figure 5). Strata A and B extended parallel along the upper and lower intertidal zones of the beach, respectively, while strata C and D were at either end of the previous strata. Strata C and D contained areas with rocky outcrops and platforms that had little sediment on top. Bivalves in the 2014–15 survey were assessed in a total of 276 sampling points, including 104 sampling points in phase 2 (Table 4).

The sediment at Eastern Beach was characterised by a low organic content that ranged between 1.3 and 2.1% (Figure 5, and see details in Appendix B, Table B-3). Similarly, there was a small proportion of fines across samples, with a maximum of 2.9% of sediment that was <63 µm grain size. Most samples were dominated by fine sand (>125 µm grain size), with a smaller proportion of very fine sand (>63 µm grain size). Three of the samples (at the southeastern end of the sampling extent) contained relatively high proportions of coarse particles, i.e., coarse sand (>500 µm) and gravel (>2000 µm grain size).

Cockles were predominantly sampled in strata A and B, with only few cockles sampled in strata C and D (Figure 6, Table 4). Across the entire sampling extent, the total population estimate for Eastern Beach was 28.16 million (CV: 16.59%) cockles in 2014–15 (Table 5). The corresponding mean population density was 68 cockles per m^2. Included in this population estimate were 12.84 million (CV: 26.54%) large cockles ($\geq$30 mm shell length). This size class had a mean density of 31 individuals per m^2. The 2014–15 population estimates reflected marked increases from the previous estimates in 2001–02; for example, the estimates for cockles in the large size class were 3.00 million (CV: 29.93%) individuals, at a mean density of 21 individuals per m^2 in 2001–02.

The increase in the number of large cockles was also reflected in their contribution to the total population (Table 6). In 2014–15, large cockles constituted about half of the population (45.61%), compared with 22.96% of large cockles in 2001–02. In contrast, there were very few recruits ($\leq$15 mm shell length) at Eastern Beach in 2014–15, with only 0.12% of cockles in this size class. In 1999–2000, this size class reflected 21.02% of the total population (which contained no large cockles), but the proportion of recruits declined markedly in the subsequent survey in 2001–02, when there were only 2.94% of cockles in this size class.

The increase in the proportion of large cockles (and decrease in recruits) across the three surveys was evident in the changes in the length-frequency distributions over time (Table 6, Figure 7). The mean cockle shell length increased from 17.05 mm in 1999–2000 to 28.87 mm in 2014–15. The large size class was absent in the earlier survey in 1999–2000, and the population was characterised by a strong, single mode at a relatively small size (with most cockles in stratum A). In the two subsequent surveys, including the current assessment, the length-frequency distributions shifted towards larger cockles, and there were few recruits present.

Most of the cockles in 2014–15 were in strata A and B, compared with the majority of cockles in stratum D in the preceding assessment in 2001–02, and stratum A in 1999–2000. The shift in the cockle population across strata could be related to unstable habitat at Eastern Beach, which seems to be affected by the movement of sand (Morrison et al. 1999a). Significant movement of sand from the northern to the southern end of Eastern Beach has also been documented recently (April 2014, and the year before; Smith (2014)), and it is possible that this erosion and subsequent remediation has impacted on the cockle population, particularly in strata A and D. Although a noted decline in large cockles in early surveys (i.e., before 1999) was attributed to potential changes in environmental conditions that affected adult survival, the current cockle population includes a substantial proportion of large individuals, indicating that recruiting juveniles persist to adult sizes.

The pipi survey at Eastern Beach extended across the same strata as the cockle survey (Figure 8, Table 7). There were only 24 pipi sampled across all four strata, including 21 pipi in stratum A. Most of the latter pipi were concentrated at the southeastern end of stratum A. The total population estimate at Eastern Beach was 0.34 million (CV: 49.71%) pipi in 2014–15, with a mean population density of <1 pipi per m^2; the low sample size resulted in a considerable CV (Table 8). As in the previous surveys, there were no large pipi ($\geq$50 mm shell length) in the Eastern Beach population.

In addition to the lack of large pipi, there were few individuals in the medium-size range, with recruits ($\leq$20 mm shell length) dominating the pipi population (Table 9, Figure 9). In 2014–15, 74.50% of the population consisted of small-size pipi. In the 1999–2000 survey, recruits made up a similarly high proportion of the population with 80.60% of recruits, evident in a strong cohort of small-sized individuals and few medium-size and large pipi. The following assessment in 2001–02 revealed a markedly smaller proportion of recruits (i.e., 31.13%), and a concomitant reduction in the size of this cohort, with a second cohort of medium-size pipi, resulting in a bimodal population. The corresponding population estimates in 2001–02 were comparatively high with a total of 6.18 million (CV: 31.96%) pipi, based on recruits and also medium-size and large individuals in the pipi population.

Although only few pipi were sampled in 2014–15, they were concentrated at the southern end of stratum A, on the upper shore. In previous surveys, the pipi population was primarily in stratum D, at the southern end of the beach. This shift in the pipi population at Eastern Beach could be related to a reduction in suitable habitat in stratum D, as erosion and remediation impacted on the sediment in this stratum; in 2014–15, it included areas of rocky outcrops and platforms that contained little sand. This reduction in suitable habitat may impact on the pipi population at Eastern Beach, in spite of the observed recruitment of small pipi in the present study.

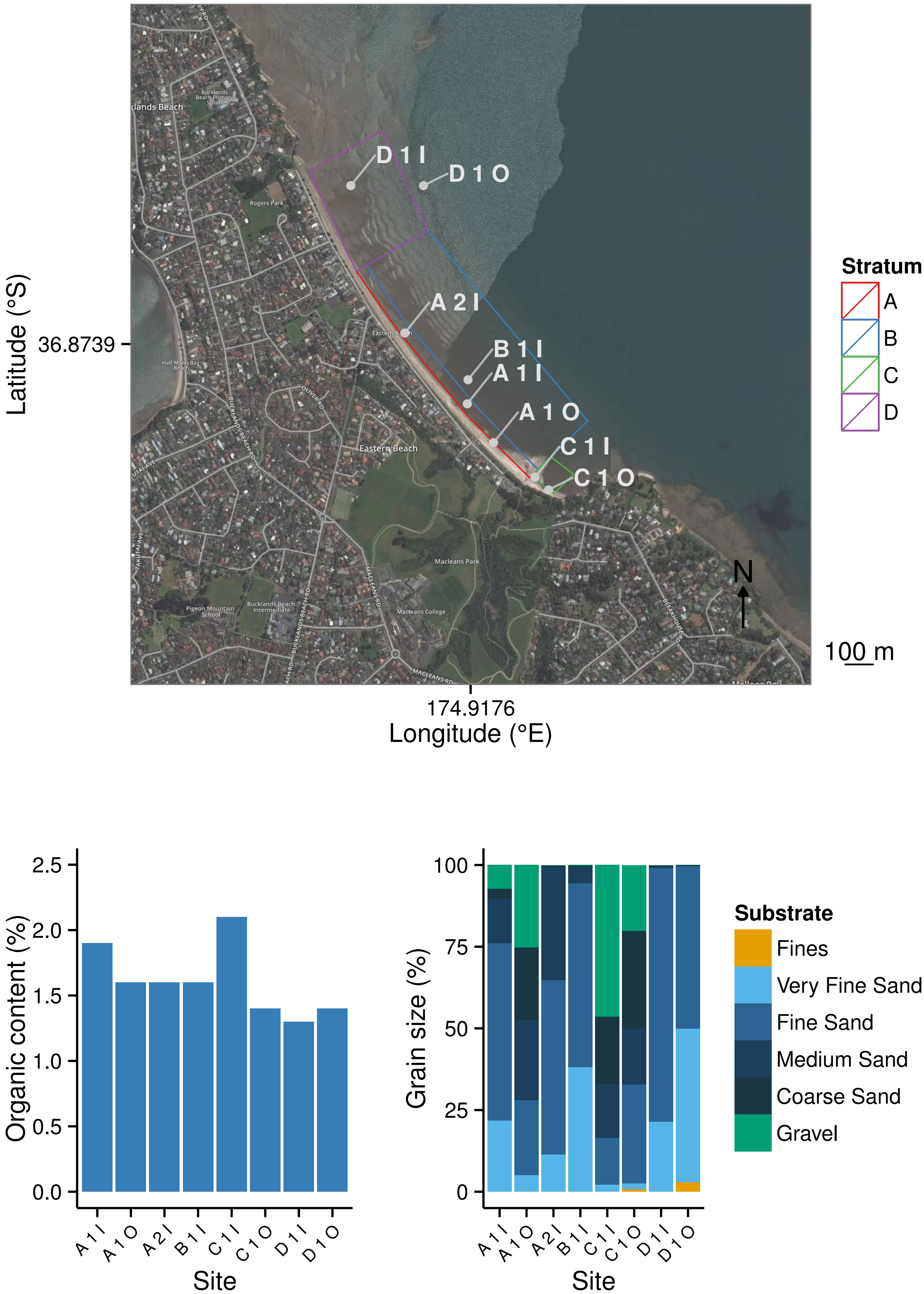


Figure 5: Sediment sample locations and characteristics at Eastern Beach. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.4 Cockles at Eastern Beach

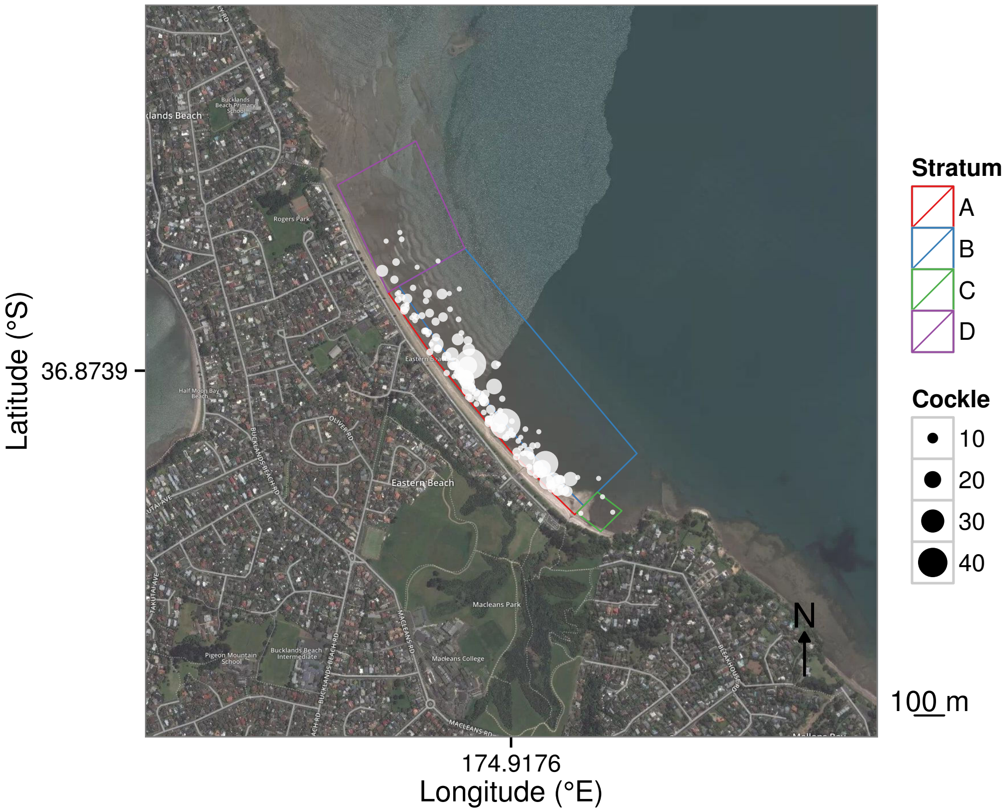


Figure 6: Map of sample strata and individual sample locations for cockles at Eastern Beach, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 4: Estimates of cockle abundance at Eastern Beach, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.2	103	588	6.83	163	11.13
B	24.6	104	285	19.23	78	23.39
C	1.0	22	3	0.04	4	54.92
D	11.7	47	29	2.06	18	48.69

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

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

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
1999–00	17.05	17	7–24	21.02	0.00
2001–02	25.52	24	7–38	2.94	22.96
2014–15	28.87	30	7–43	0.12	45.61

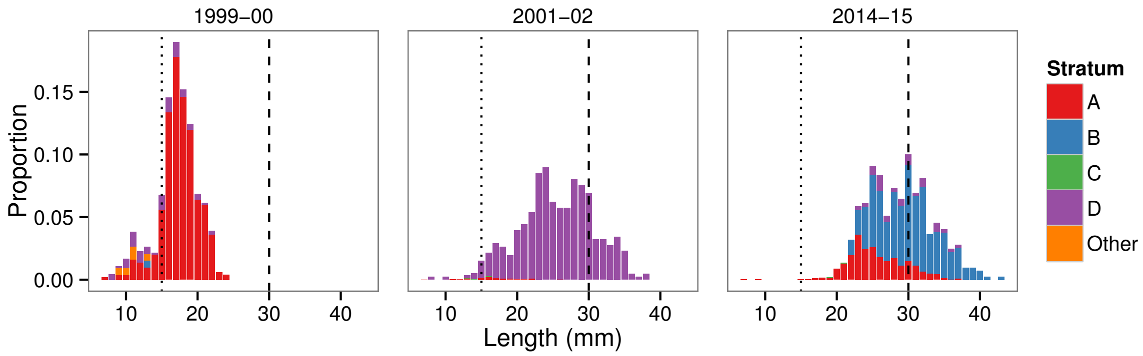


Figure 7: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Eastern Beach. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.5 Pipi at Eastern Beach

Figure 8: Map of sample strata and individual sample locations for pipi at Eastern Beach, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 7: Estimates of pipi abundance at Eastern Beach, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.2	103	21	0.24	6	62.16
B	24.6	104	0	0.00	0	
C	1.0	22	2	0.03	3	>100
D	11.7	47	1	0.07	<1	>100

Table 8: Estimates of pipi abundance at Eastern Beach for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	48.0	1.08	2	31.62	0.00	0	
2001–02	43.4	6.18	14	31.96	0.00	0	
2014–15	41.4	0.34	<1	49.71	0.00	0	

Table 9: Summary statistics of the length-frequency (LF) distribution of pipi at Eastern Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
1999–00	17.24	12	7–40	80.60	0.00
2001–02	28.30	34	7–49	31.13	0.00
2014–15	15.81	28	8–28	74.50	0.00

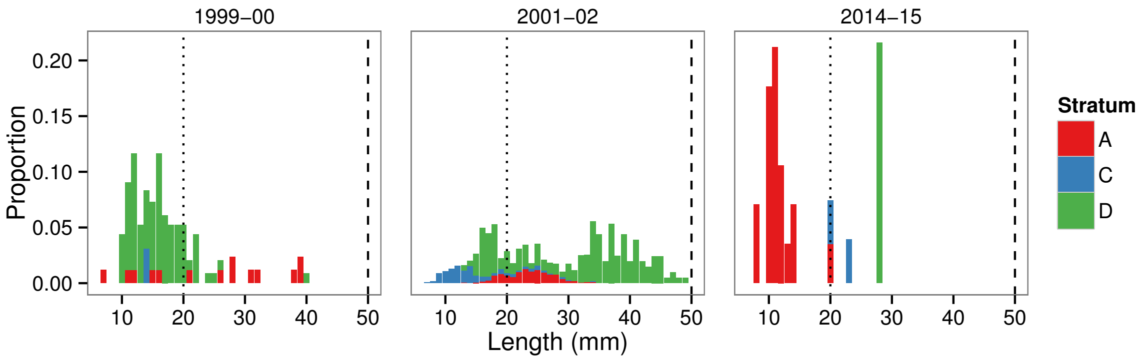


Figure 9: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Eastern Beach. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.6 Kawakawa Bay (West)

Kawakawa Bay (West) is in the wider Auckland metropolitan area, in Tamaki Strait within Hauraki Gulf. Cockles at this bay have been under considerable fishing pressure, with local residents expressing concerns about the potential impact of the high numbers of cockles taken.

This site was first included in the recent bivalve surveys in 2004–05, with one subsequent survey in 2006–07 (see Appendix A, Tables A-1, A-2). Earlier Ministry of Fisheries (now MPI) bivalve surveys also included Kawakawa Bay (West) in 1992–93 and 1993–94. This site is also part of the community monitoring coordinated by the Hauraki Gulf Forum, with annual surveys based on across-shore transects along the bay (e.g., Auckland Council 2013). The current study used the same sampling extent as the two recent MPI surveys, with five strata covering the entire bay (Figure 10). There were 218 sampling points in the 2014–15 survey, with 194 sampling points in phase 1, and 24 sampling points in phase 2 (Table 10).

Sediment samples at Kawakawa Bay (West) were low in organic content, with values ranging between 1.0 and 4% (Figure 10, and see details in Appendix B, Table B-3). The prevalent grain sizes were very fine (>63 µm) and fine (>125 µm) sands in half of the samples. The remaining samples were dominated by coarse sand and gravel (i.e., >500 µm and >2000 µm grain sizes, respectively), and these samples were primarily on the upper shore. Most of the samples contained no fines (<63 µm grain size), and only two samples included a small proportion of sediment in this grain size fraction.

Most cockles in the 2014–15 survey were in the eastern part of the bay, in strata E and D, with fewer cockles at the western end in stratum B (Figure 11, Table 10). Cockle numbers were low in stratum C, in the middle of the bay, and there were only few cockles in stratum A. Based on the sampling, the 2014–15 population estimate for this site was 74.44 million (CV: 9.69%) cockles, with a corresponding mean population density of 122 individuals per m^2 (Table 11). These estimates were slightly lower than values in the preceding surveys. For example, the previous assessment in 2006–07 estimated the total population at 86.39 million (CV: 10.54%) cockles, and the population density at 137 cockles per m^2.

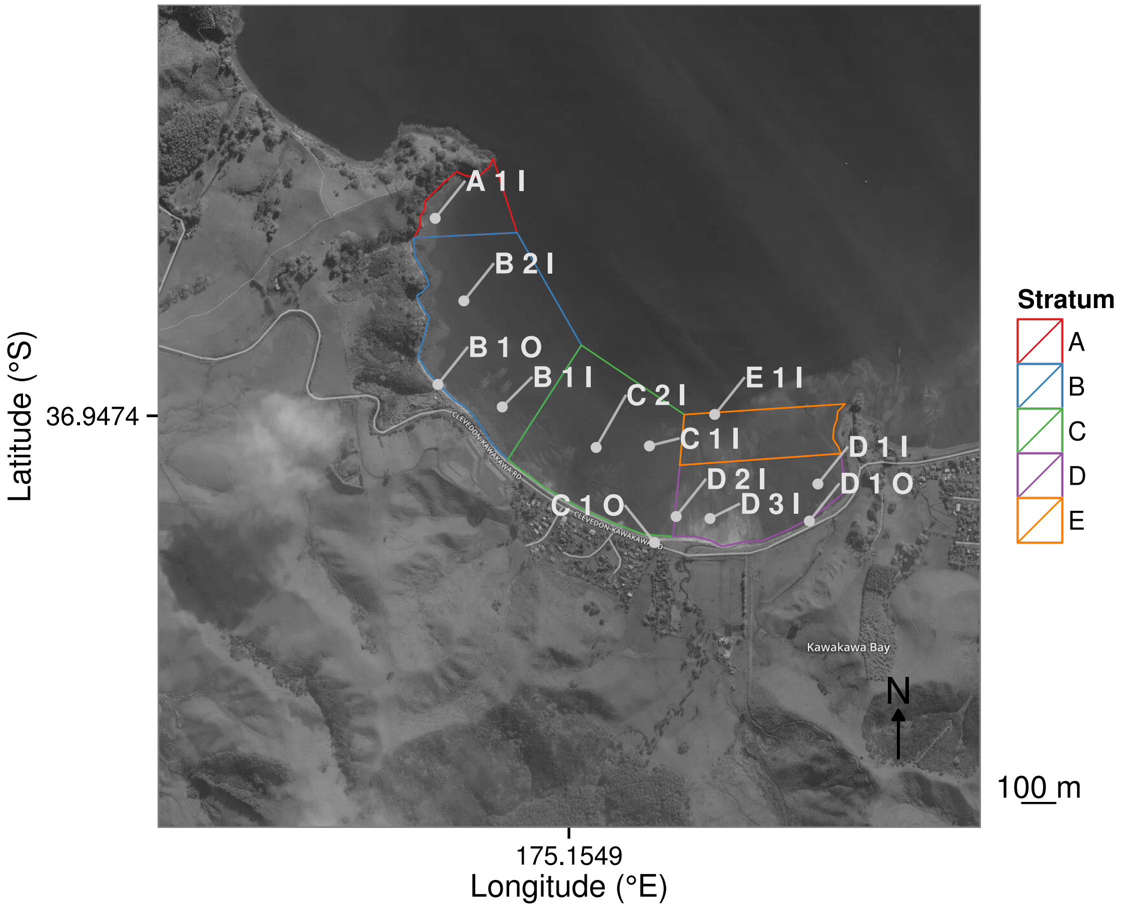
The cockle population included a number of large individuals (≥30 mm shell length), and there were 19.80 million (CV: 15.80%) individuals in this size class in 2014–15, with a corresponding mean density of 33 large cockles per m^2. This size class has consistently been part of the Kawakawa Bay (West) cockle population, and numbers have remained similar in the two recent surveys. In the preceding assessment in 2006–07, there were 21.23 million (CV: 22.75%) large cockles at this site, and their average density was 34 large cockles per m^2.

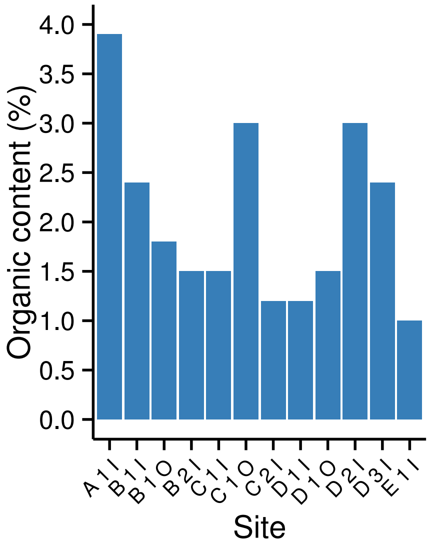
Considering the contribution of large individuals to the population, this size class made up about a quarter of the cockle population in the two most recent assessments at Kawakawa Bay (West): large cockles constituted 24.58% and 26.64% of the total population in 2006–07 and 2014–15, respectively (Table 12). At the same time, the proportion of recruits (≤15 mm shell length) was relatively low, although it showed an increase from 8.48% in 2006–07 to 18.04% in 2014–15.

The length-frequency distributions illustrate the range of cockle sizes at this beach (Figure 12). Although the population remained unimodal throughout the survey series, there was a marked increase in the number of recruits and small individuals in the most recent survey. Nevertheless, the mean shell length was similar across the three surveys, with a mean cockle size of 24.05 mm (range: 6–46 mm) shell length in 2014–15.

Pipi were not as widely distributed as cockles at Kawakawa Bay (West), but were restricted to the eastern part of the bay, particularly stratum D (Figure 13, Table 13). Within this stratum, the highest pipi densities were in the upper intertidal area, close to shore. The total population estimate at this beach was 6.17 million (CV: 19.19%) pipi. This estimate was a considerable increase from the previous surveys, such as the preceding assessment in 2006–07, when the pipi population was 0.13 million (CV: 100.00%) individuals. Similarly, the mean population density increased from <1 individual per m^2 in 2006–07 to 10 pipi per m^2 in the current study (Table 14).

Although there was an increase in the total population, there were no large pipi ($\geq$50 mm shell length) in Kawakawa Bay (West) in 2014–15. The lack of large pipi was consistent with their absence in the other recent population assessments (Table 15, Figure 14). Furthermore, the pipi population was dominated by recruits ($\leq$20 mm shell length) in the current survey, with 51.57% of individuals in the total population in this size class, and a mean shell length of 21.44 mm. In the previous survey in 2006–07, the pipi population consisted exclusively of recruits (100.00% of the total population), and the population overall was considerably smaller than in the current study. In comparison, the pipi population in 2014–15 was larger, and included individuals across a range of sizes, such as medium-size pipi, although there was no single strong mode or cohort, and large-size individuals were lacking.





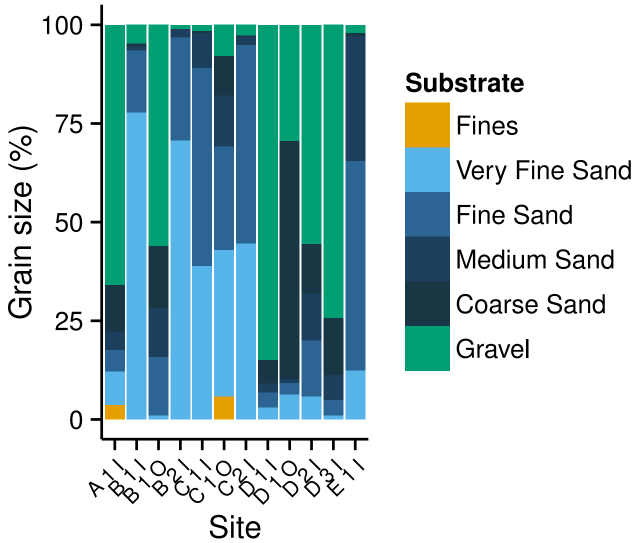


Figure 10: Sediment sample locations and characteristics at Kawakawa Bay. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.7 Cockles at Kawakawa Bay (West)

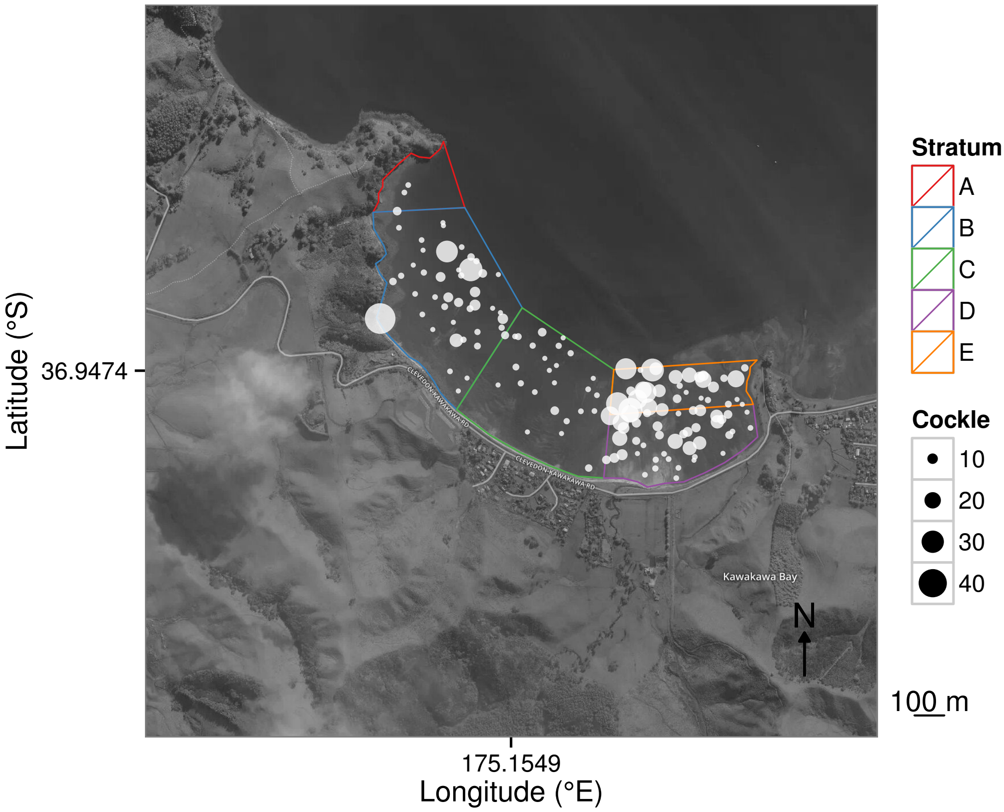


Figure 11: Map of sample strata and individual sample locations for cockles at Kawakawa Bay, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 10: Estimates of cockle abundance at Kawakawa Bay, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.3	19	4	0.26	6	68.72
B	21.1	70	260	22.39	106	24.21
C	18.2	45	69	7.97	44	18.72
D	10.5	52	331	19.10	182	14.18
E	6.8	32	408	24.72	364	14.61

Table 11: Estimates of cockle abundance at Kawakawa 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 $\geq$ 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

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	24.79	27	5–38	4.27	15.15
2006–07	25.12	25	2–48	8.48	24.58
2014–15	24.05	26	6–46	18.04	26.64

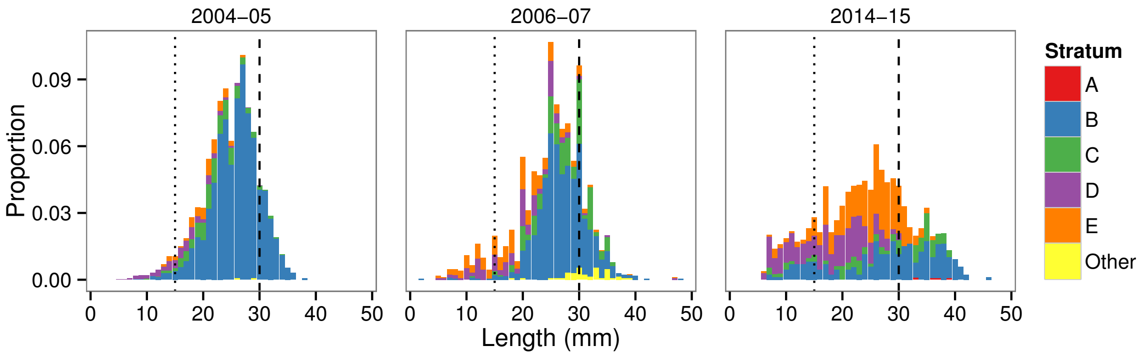


Figure 12: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Kawakawa Bay. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.8 Pipi at Kawakawa Bay (West)

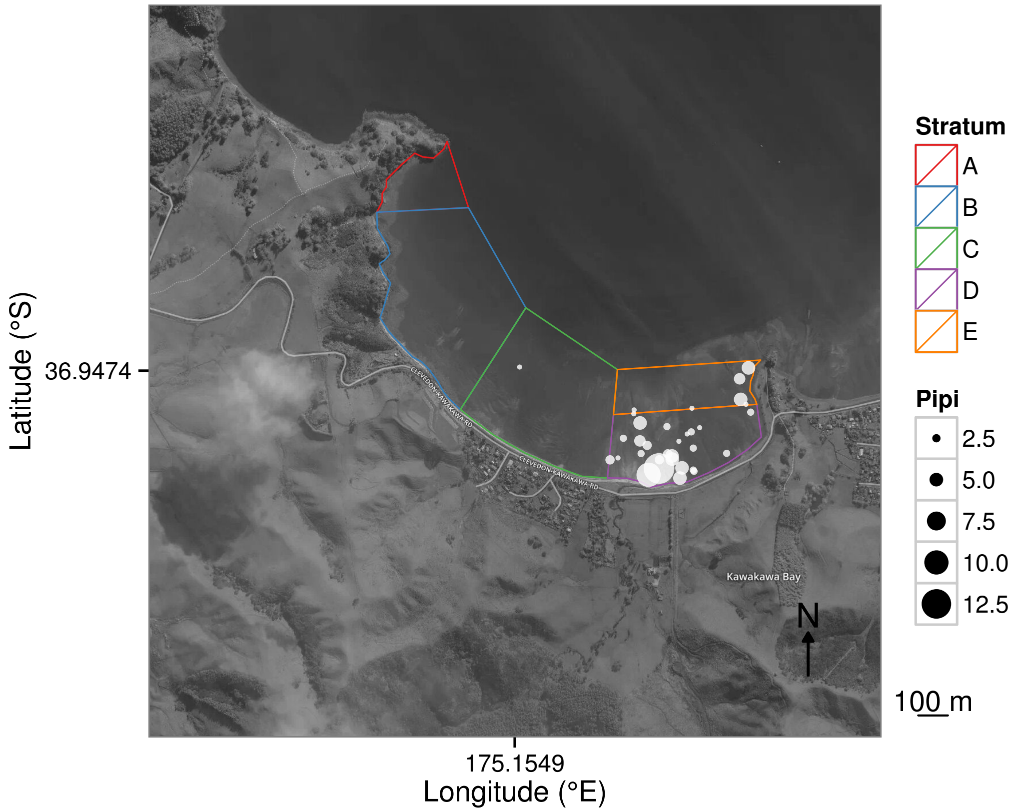


Figure 13: Map of sample strata and individual sample locations for pipi at Kawakawa Bay, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 13: Estimates of pipi abundance at Kawakawa Bay, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.3	19	0	0.00	0	
B	21.1	70	0	0.00	0	
C	18.2	45	1	0.12	<1	>100
D	10.5	52	87	5.02	48	21.45
E	6.8	32	17	1.03	15	46.28

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2004–05	60.4	1.04	2	14.88	0.00	0	
2006–07	62.9	0.13	<1	100.00	0.00	0	
2014–15	60.9	6.17	10	19.19	0.00	0	

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	22.39	24	10–42	37.21	0.00
2006–07	19.00	18	18–20	100.00	0.00
2014–15	21.44	19	10–40	51.57	0.00

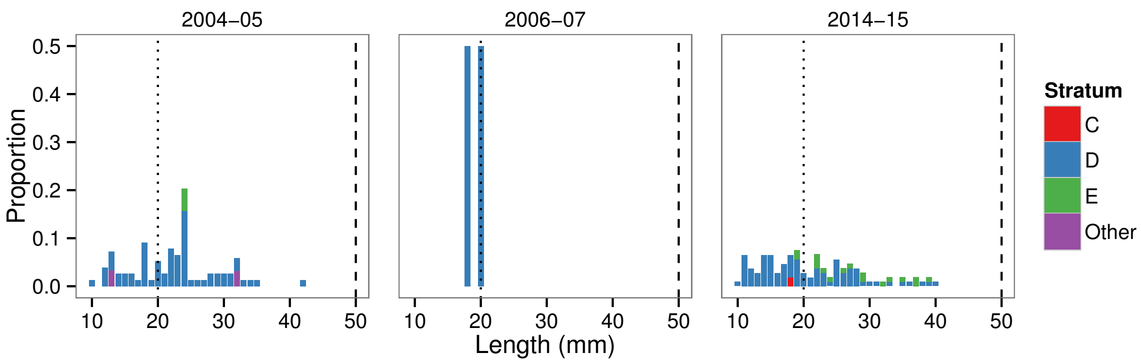


Figure 14: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Kawakawa Bay. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.9 Mangawhai Harbour

Mangawhai Harbour is in the eastern Northland region. This site has been regularly included in the bivalve surveys since 1999–2000, with six assessments preceding the current study (see Appendix A, Tables A-1, A-2). The most recent previous bivalve survey at this site was in 2010–11. The surveys in this series have focused on specific areas within the lower harbour, and the current assessment followed this sampling approach. Specifically, the sampling extent consisted of five strata, with an additional stratum F added in 2014–15 as this area contained a pipi bed (Figure 15). The adjoining strata A to C were on the western side of the main channel at the harbour entrance, while stratum D was south of these strata, on an intertidal sandflat, adjacent to a side channel. The remaining strata E and F were further south and upstream, on the eastern side of the main channel. Cockles and pipi were targeted in a total of 186 sampling points across these strata (Table 16).

The sediment organic content at Mangawhai Harbour was consistently low at less than 1% (Figure 15, and see details in Appendix B, Table B-3). The sediment grain size was also similar across samples, and characterised by fine (>125 µm grainsize) and medium (>250 µm grain size) sands. There was only a small proportion of fines (<63 µm grain size) in most samples, although the silt content exceeded 12.0% in two of the samples (within stratum A and adjacent to stratum D, respectively).

Cockles in Mangawhai Harbour were mostly in stratum A, close to the harbour entrance, followed by stratum D (Figure 16, Table 16). These strata contained the highest numbers and densities of cockles at this site. There were considerably fewer cockles in stratum B, and the remaining strata contained only small numbers of cockles. Across all strata (but excluding stratum F), the population estimates for cockles in Mangawhai Harbour in 2014–15 were 52.66 million (CV: 7.59%) individuals for the total population, and the mean density was 637 cockles per m^2 (Table 17). These estimates were consistent with previous survey findings, based on a comparable sampling extent throughout the survey series (with some variation in the size of the strata primarily targeting pipi). Although there has been some variation in the population size and density, the cockle population at Mangawhai Harbour has been relatively stable in recent years (i.e., since 2002–03 about 46 to 62 million individuals).

In contrast, the number of large cockles (≥30 mm shell length) markedly declined (i.e., by an order of magnitude) in recent surveys, from 20.46 million (CV: 15.95%) large cockles in 2002–2003 to 2.05 million (CV: 15.95%) individuals in this size class in 2014–15. This continued decrease was also reflected in the declining population densities of large cockles, which dropped from 256 million large individuals per m^2 in 2002–2003 to 25 million large cockles per m^2 in 2014–15.

The decrease in the number of large cockles within the Mangawhai Harbour population was also evident in the reduction in mean shell length and their declining contribution to the total population (Table 18). The mean shell length in 2014–15 was 19.68 mm, compared with a mean shell length of 25.68 mm in 2003–04. The proportion of large cockles decreased from 34.33% in 2003–04 to 3.89% in the current study. The decline in large cockles was accompanied by an increase in the proportion of recruits (≤15 mm shell length) from 13.75% in 2003–04 to 25.45% in 2014–15.

The length-frequency distributions across the three surveys illustrated the increase in the number of small cockles in the current survey (Figure 17). Although the cockle population consistently included individuals that were of medium size, the 2014-15 survey had a strong cohort of recruits, resulting in a bimodal population. At the same time, there was a decline in cockles that were at or above 30-mm shell length. Overall, medium-size cockles continued to dominate the population at Mangawhai Harbour, but there was a discernible lack of large cockles in the current study compared with the two previous surveys.

Pipi were sampled across the same strata as cockles at Mangawhai Harbour, and were present in all strata (Figure 18, Table 19). Their numbers were highest in the southern part of the sampling extent, in strata F and E, whereas there were few pipi in strata C and D. Across all strata, the total pipi population in 2014–15 was estimated at 6.00 million (CV: 21.28%) individuals (Table 20). The corresponding population density was 70 pipi per m^2. These estimates incorporated sampling points from stratum F, which was added to the sampling extent as it contained a pipi bed along the eastern side of the main channel. Without stratum F, the population estimates for the 2014–15 survey were 4.73 million (CV: 25.58%) pipi, at a mean density of 57 pipi per m^2.

The total population contained few large pipi ($\geq$50 mm shell length), and the inclusion of stratum F made little difference to the population estimates for this size class. There was a total of 0.03 million (CV: 72.74%) large pipi when including stratum F in the estimate, or 0.02 million (CV: 82.45%) large pipi without this stratum. The corresponding population density was <1 pipi per m^2 (with or without stratum F). Although population estimates for this size class have been consistently low since 2001–02, when the number of large pipi dropped from 1.26 million (CV: 9.35%) the previous year to 0.51 million (CV: 9.55%) individuals, the number and densities of large pipi continued to decrease, and the current estimate is the lowest value to date.

The low population estimates for large pipi highlight the prevalence of small individuals at Mangawhai Harbour (Table 21, Figure 19). In the current survey, recruits ($\leq$20 mm shell length) made up 37.53% of the total population compared with 0.47% of large pipi ($\geq$50 mm shell length). While the proportion of recruits remained similar across surveys, the proportion of large pipi underwent a notable decrease, corresponding with the decline in the overall number of large pipi. This size class constituted 37.14% of the total population in 2003–04, but only 1.82% in 2010–11. The current estimate reflected a further drop in the proportion of large pipi in the Mangawhai Harbour population.

This population shift towards small-sized pipi was also documented in the length-frequency distributions (Figure 19). Previously, the Mangawhai Harbour population consisted of two strong cohorts, representing small-size and also large pipi (including individuals exceeding 60 mm shell length) in 2003–04. Since then, it showed a substantial shift towards smaller sizes in the subsequent surveys. Although there was a range of shell lengths in 2010–11 and 2014–15, the population consisted predominantly of small- and medium-size pipi, with a concomitant reduction in mean shell length from 35.35 mm in 2003–04 to 25.27 mm in the current study.

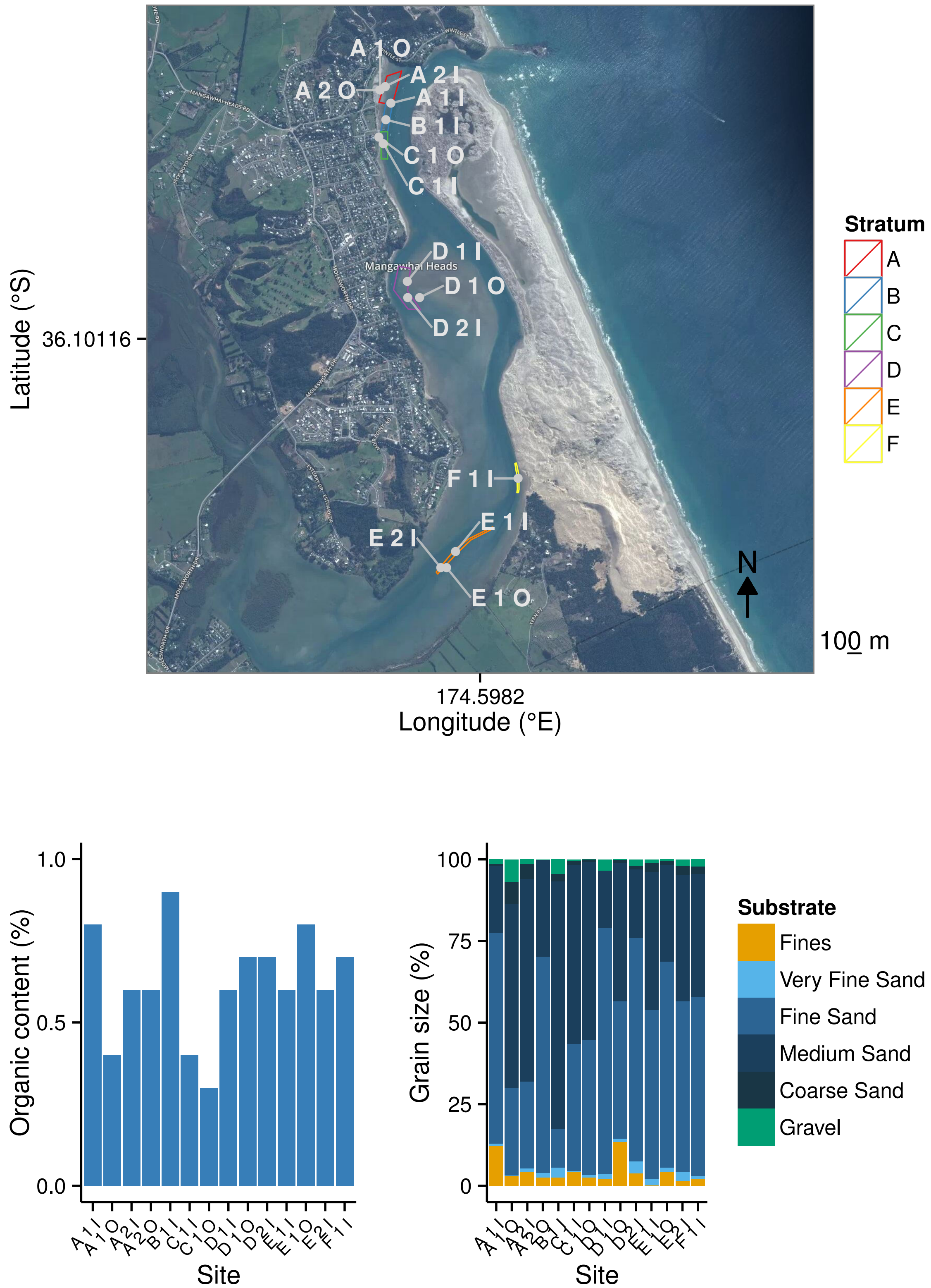


Figure 15: Sediment sample locations and characteristics at Mangawhai Harbour. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.10 Cockles at Mangawhai Harbour

Figure 16: Map of sample strata and individual sample locations for cockles at Mangawhai Harbour, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 16: Estimates of cockle abundance at Mangawhai Harbour, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	2.2	55	2 910	33.66	1 512	9.65
B	1.0	20	236	3.39	337	40.62
C	1.0	18	20	0.31	32	51.90
D	3.0	47	786	14.17	478	13.09
E	1.1	26	94	1.13	103	22.66
F	0.3	20	17	0.07	24	40.28

Table 17: Estimates of cockle abundance at Mangawhai Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	9.4	98.71	1 050	4.54	28.56	304	7.17
2000–01	8.4	76.61	912	4.35	45.27	539	4.35
2001–02	8.4	28.54	340	5.80	8.75	104	7.48
2002–03	8.4	46.14	549	5.46	20.46	256	6.47
2003–04	8.4	50.77	604	4.71	17.43	207	6.24
2010–11	9.0	61.78	686	9.15	8.28	92	17.41
2014–15	8.6	52.73	617	7.58	2.05	24	15.95
2014–15*	8.3	52.66	637	7.59	2.05	25	15.95

Table 18: Summary statistics of the length-frequency (LF) distribution of cockles at Mangawhai Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2003–04	25.68	28	5–44	13.75	34.33
2010–11	21.62	20	5–39	19.17	13.40
2014–15	19.68	25	4–37	25.45	3.89

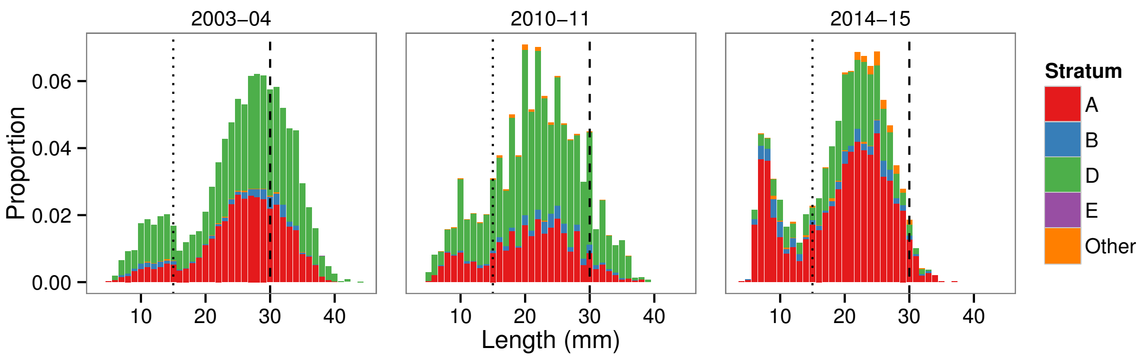


Figure 17: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mangawhai Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.11 Pipi at Mangawhai Harbour

Figure 18: Map of sample strata and individual sample locations for pipi at Mangawhai Harbour, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 19: Estimates of pipi abundance at Mangawhai Harbour, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	2.2	55	99	1.15	51	19.31
B	1.0	20	99	1.42	141	78.34
C	1.0	18	2	0.03	3	68.60
D	3.0	47	6	0.11	4	45.31
E	1.1	26	169	2.03	186	20.59
F	0.3	20	311	1.27	444	32.08

Table 20: Estimates of pipi abundance at Mangawhai Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	9.4	4.78	51	15.88	1.54	16	15.23
2000–01	8.4	1.96	23	9.81	1.26	17	9.35
2001–02	8.4	0.78	9	9.56	0.51	7	9.55
2002–03	8.4	1.44	17	11.63	0.37	6	9.27
2003–04	8.4	1.18	14	11.00	0.44	7	9.65
2010–11	9.0	4.21	47	19.57	0.08	<1	33.76
2014–15	8.6	6.00	70	21.28	0.03	<1	72.74
2014–15*	8.3	4.73	57	25.58	0.02	<1	82.45

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2003–04	35.35	14	9–71	36.54	37.14
2010–11	26.26	12	6–57	36.48	1.82
2014–15	25.27	11	8–53	37.53	0.47

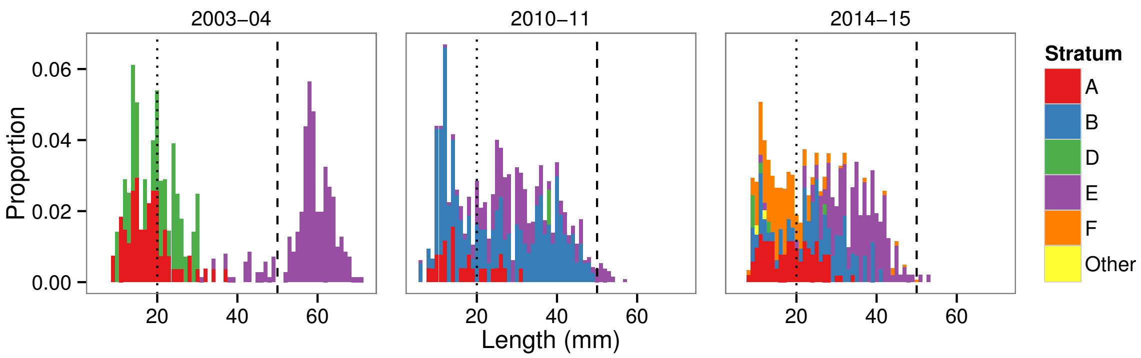


Figure 19: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mangawhai Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.12 Mill Bay

Mill Bay is in northwestern Manukau Harbour, in the Waitakere Ranges. This bay has been regularly surveyed since 1999–2000, with seven bivalve assessments preceding the current study (see Appendix A, Tables A-1, A-2). Throughout this survey series, the sampling extent has covered a similar area, with earlier surveys dividing it into several different strata; more recent assessments (i.e., since 1999-2000) were based on a single stratum only. The current field sampling followed this latter approach, and population estimates for cockles and pipi were based on a single stratum within the bay, stratum A (Figure 20). Stratum A extended from the upper intertidal area to the mean low water level, with rocky platforms and boulders in the adjacent northeastern and southwestern areas bordering the stratum. The lower intertidal area of stratum A contained a seagrass bed. Within this stratum, bivalves were surveyed in 117 sampling points (Table 22).

The sediment at Mill Bay was low in organic content (1.3 to 3.0%), with some variation in the sediment grain size distribution across samples (Figure 20, and see details in Appendix B, Table B-3). There were no fines (<63 µm grain size) in the samples, and fine (>125 µm grain size) and medium (>250 µm grain size) sands consistently made up a large proportion of the sediment. All of the samples contained at least 10% of coarse sand (>500 µm grain size), and some uppershore samples also included a notable proportion of gravel (>2000 µm grain size), ranging from 12.2 to 33.5%.

This site supported an abundant cockle population in 2014–15, and cockle numbers were highest in the middle part of stratum A (Figure 21, Table 22). The total population estimate for this site was 16.66 million (CV: 9.56%) cockles, with a mean density of 342 cockles per m^2 (Table 23). Included in this total estimate were 0.07 million (CV: 42.43%) large cockles (≥30 mm shell length), with their mean density at 1 individual per m^2. The current population estimates were the highest values in the survey series, and signified an increase from the previous survey in 2009–10, when there were 11.31 million (CV: 8.92%) cockles at a population density of 229 cockles per m^2.

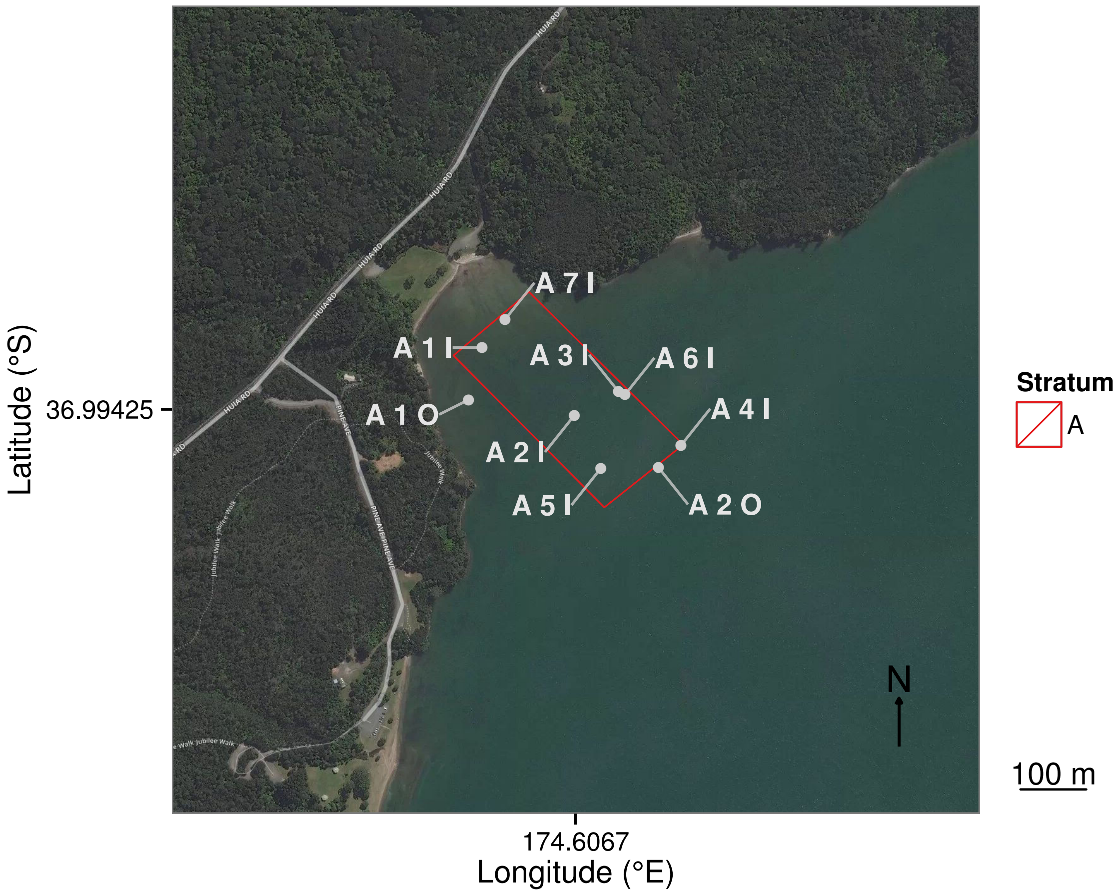
The estimate for large cockles, however, reflected a continuing decreasing trend in their number and density in recent years. Since 2001–02, the number of cockles in the large size class has been less than 0.4 million individuals, with densities ranging between 4 and 8 cockles per m^2. In 2014–15, the small number of large cockles was less than half the number of individuals in this size class in the preceding survey in 2009–10. This decrease in the number of large individuals was also reflected in their small contribution to the total population in 2014–15, which was 0.43% (Table 24).

In addition to the reduction in the population of large cockles, there was a decrease in the proportion of recruits (≤15 mm shell length) in 2014–15. This size class constituted 62.92% of the total population in 2009–10, but only 24.37% in 2014–15. At the same time, the mean size increased from 14.41 mm to 19.42 mm shell length, and the modal size increased from 10 mm to 22 mm shell length. These increases in shell length were owing to the strong cohort of medium-sized cockles in the current study (Figure 22). While there was a large cohort of recruits in the previous survey, and a relatively small second cohort of medium-sized cockles, the latter cohort was substantially stronger in the current study, with a smaller cohort of recruits. The number of large cockles, however, was consistently low across the length-frequency distributions, confirming the lack of this size class at Mill Bay.

The pipi population at Mill Bay was largely in the middle and upper area of stratum A, with no pipi in the lower intertidal area (which contained seagrass) (Figure 23, Table 25). The population estimates for pipi at this site were 4.41 million (CV: 14.32%) individuals in 2014–15, and the corresponding density was 90 pipi per m^2 (Table 26). Comparing population estimates across surveys, the current values were lower than those in the preceding survey in 2009–10, although both the two recent surveys had markedly higher estimates than previous assessments. The only exception was a relatively high population estimate in 2000–01.

Although the total pipi population showed an increase in recent assessments, it continued to lack large pipi (≥50 mm shell length), and there were no individuals in this size class in 2014–15. This finding was consistent with the absence or low numbers of large pipi at Mill Bay throughout the survey series.

Nevertheless, length-frequency distributions showed an increase in mean and modal sizes of pipi, which were 24.78 mm and 29 mm shell length, respectively (Table 27, Figure 24). The increase in sizes from recruits ($\leq$20 mm shell length) to medium-size pipi resulted in a decrease in the proportion of recruits in the population, from over 60% in the two preceding surveys to 32.06% in 2014–15. The high number of medium-size pipi in 2014–15 was evident in the biomodal population that consisted of two similar-size cohorts of recruits and medium-size pipi. In earlier surveys, the population was dominated by recruits, particularly in 2009–10, when it contained a considerable number of pipi at about 10–15 mm shell length.



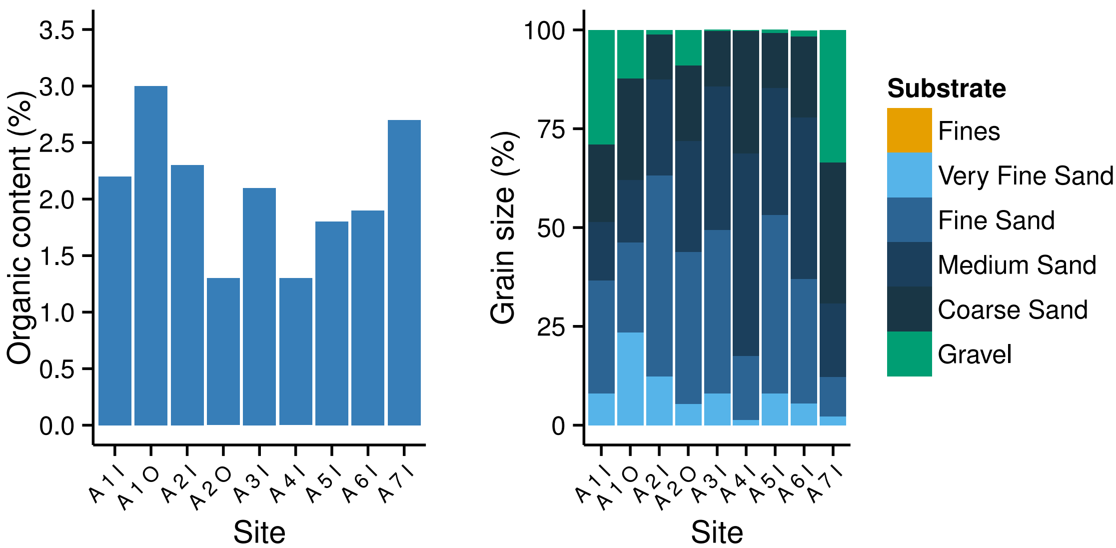


Figure 20: Sediment sample locations and characteristics at Mill Bay. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.13 Cockles at Mill Bay

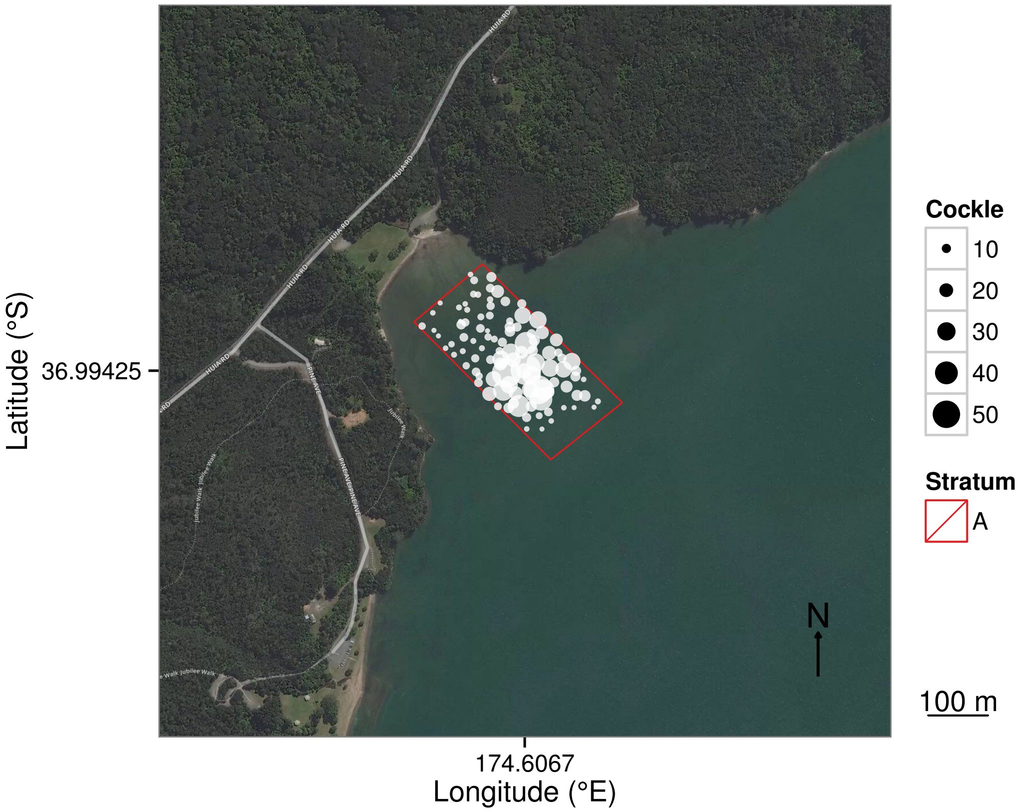


Figure 21: Map of sample strata and individual sample locations for cockles at Mill Bay, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 22: Estimates of cockle abundance at Mill Bay, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.9	117	1 399	16.66	342	9.56

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	4.6	4.91	107	7.87	0.74	16	12.06
2000–01	4.8	10.24	213	6.32	1.23	26	9.50
2001–02	4.5	5.21	116	6.89	0.38	8	13.26
2003–04	4.5	5.33	118	7.69	0.32	7	14.64
2004–05	4.5	4.23	94	7.30	0.30	7	14.45
2005–06	4.5	6.72	149	6.66	0.39	9	11.89
2009–10	5.0	11.31	229	8.92	0.18	4	31.80
2014–15	4.9	16.66	342	9.56	0.07	1	42.43

Table 24: Summary statistics of the length-frequency (LF) distribution of cockles at Mill Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	20.40	25	6–34	25.60	5.84
2009–10	14.41	10	4–34	62.92	1.59
2014–15	19.42	22	4–32	24.37	0.43

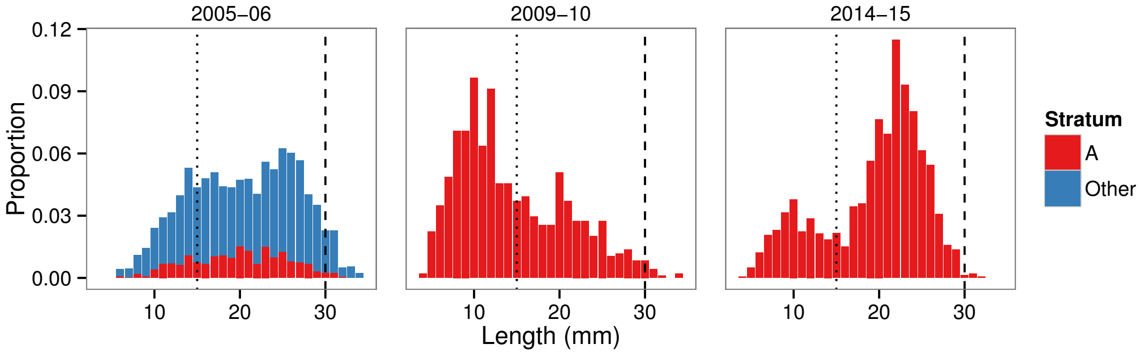


Figure 22: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Mill Bay. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.14 Pipi at Mill Bay

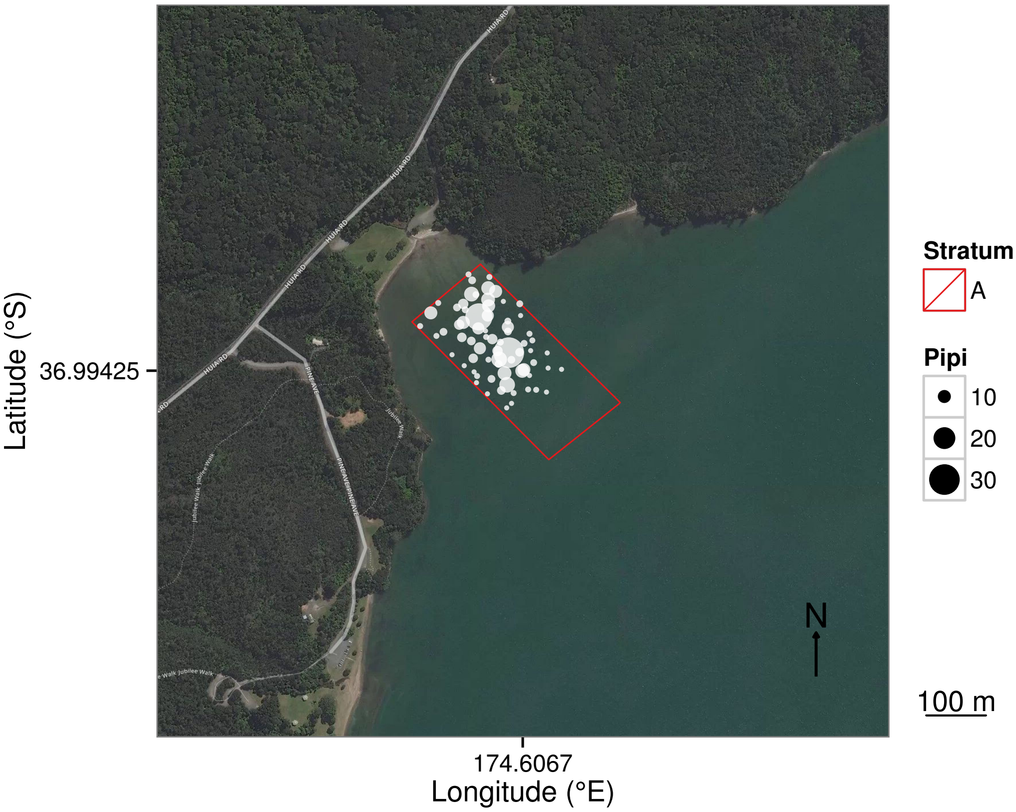


Figure 23: Map of sample strata and individual sample locations for pipi at Mill Bay, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 25: Estimates of pipi abundance at Mill Bay, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.9	117	370	4.41	90	14.32

Table 26: Estimates of pipi abundance at Mill Bay for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

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

Table 27: Summary statistics of the length-frequency (LF) distribution of pipi at Mill Bay. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2005–06	19.73	20	6–51	61.63	0.39
2009–10	17.59	12	5–49	68.79	0.00
2014–15	24.78	29	7–42	32.06	0.00

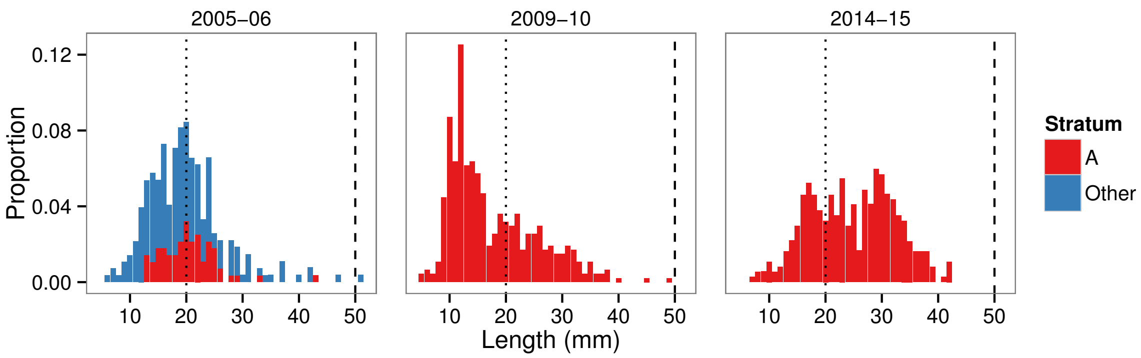


Figure 24: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Mill Bay. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.15 Ngunguru Estuary

Ngunguru Estuary is in eastern Northland, just north of Whangarei. There have been three previous bivalve surveys at this site recently, most recently in 2010–11 (see Appendix A, Tables A-1, A-2). Field sampling in the current survey focused on the same strata as previous assessments, but included one additional intertidal sandflat area, stratum E, that contained a cockle bed (Figure 25). As stratum E is in the middle of the main channel, it required crossing of the channel. Similarly, strata B and C were also only accessible across the main channel. There were 140 sampling points for cockles and pipi in the current study (Table 28).

Sediment sampling in Ngunguru Estuary revealed a low organic content of 1.2 to 2.5% across samples at the site (Figure 25, and see details in Appendix B, Table B-3). Sediment grain size was dominated by fine (>125 µm grain size) sand, with no or only a small proportion of fines (<63 µm grain size) in the samples. There was one exception, with one sample in stratum B containing over 14% fines. In addition, two of the samples included over 10% gravel (>2000 µm grain size) in their grain size distribution, although the proportion of larger-size grains was generally low.

Cockles were present in strata A, C, and E, with the highest number of cockles in additional stratum E, followed by stratum C (Figure 26, Table 28). Based on the same strata as previous surveys (i.e., excluding stratum E), the population estimates for 2014–15 were 14.78 million (CV: 13.01%) individuals for the total population, and the mean density was 814 cockles per m^2 (Table 29). The estimated number of large cockles (≥30 mm shell length) within the population was small, with 0.06 million (CV: 35.13%) individuals and an estimated density of 4 large cockles per m^2.

These estimates were lower than those in the preceding study in 2010–11, but both recent surveys documented considerably higher abundance and density estimates for the total cockle population at this site than the earlier assessments in 2003–04 and 2004–05. For example, between 2004–05 and 2010–11, the cockle population increased from 9.79 million (CV: 7.77%) to 19.55 million (CV: 10.72%) cockles, and the population density almost doubled from 544 to 1086 individuals per m^2.

In spite of the overall population increase, the number and density of large cockles showed a marked decline over the same period. There were 0.34 million (CV: 18.85%) cockles in this size class in 2004–05, compared with 0.07 million (CV: 35.49%) large cockles in 2010–11. The corresponding densities showed a similar decrease between 2004–05 and 2010–11, from 25 large cockles per m^2 to 5 large cockles per m^2. Although the population of large cockles has been relatively small throughout the survey series, the 2010–11 and 2014–15 estimates highlight a marked reduction in the abundance and density of large cockles in recent years.

The newly-added stratum E supported a substantial cockle bed, and including this stratum in the current estimates resulted in a total abundance of 92.67 million (CV: 7.53%) cockles, with a corresponding mean density of 1696 cockles per m^2. There were a number of large cockles in this stratum, and the estimate for this size class was 0.38 million (CV: 32.11%) large individuals and a corresponding density of 8 cockles per m^2.

Considering the length-frequency distributions across the three most recent surveys, the cockle population was unimodal, with a mean shell length of 19.07 mm and a modal size of 20 mm in 2014–15 (Table 30, Figure 27). Recruits (≤15 mm shell length) and large cockles only made up small parts of the populations (18.71 and 0.41%, respectively), and this pattern was consistent throughout recent assessments.

Pipi at Ngunguru Estuary were mostly in stratum B, in the middle of the channel, with few individuals throughout the remaining strata (Figure 28, Table 31). The total population at this site was small, with an estimated 0.54 million (CV: 44.85%) pipi (excluding stratum E) (Table 32). The mean population density was 30 individuals per m^2, and the small number of pipi sampled and their patchy distribution led to a high CV. There were no large individuals (≥50 mm shell length) in the population in 2014–15, and the absence of large pipi was a marked change from previous surveys.

Although the total population and the number of large individuals showed a decrease across the three preceding assessments (i.e., between 2003–04 and 2004–05), the population estimate for large pipi in 2010–11 was 0.25 million (CV: 19.25%) individuals at a density of 14 pipi per m^2. The corresponding estimate for the total population was 0.73 million (CV: 16.60%) pipi in 2010–11, compared with the current estimate of 0.54 million pipi. These data imply that the reduction in the total pipi population may be attributed to the recent decrease in the number of large pipi.

This suggestion was supported by the length-frequency distributions of the pipi population over time (Table 33, Figure 29). For example, between 2010–11 and 2014–15, the mean size and range decreased from 42.10 mm and 8–49 mm shell length to 34.31 mm and 8–49 mm shell length, respectively, and large-size pipi made up 38.86% of the population in the 2010–11 assessment. Although the latter size class and medium-size pipi dominated the Ngunguru Estuary population in previous surveys, this cohort only included medium-size pipi in 2014–15. At the same time, there was a second cohort of recruits ($\leq$20 mm shell length) in the present study, and this size class contributed 14.84% of individuals to the total population.

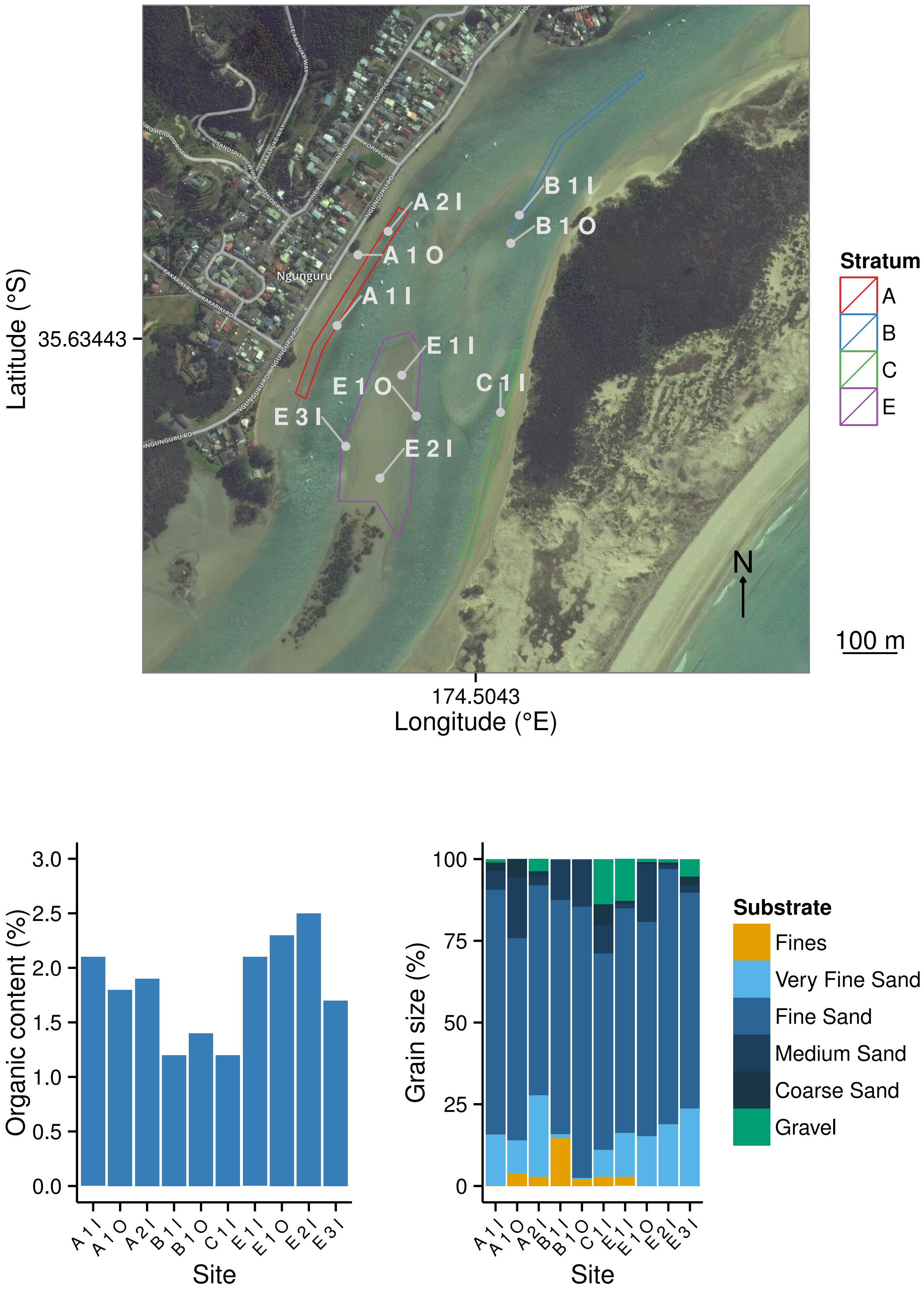


Figure 25: Sediment sample locations and characteristics at Ngunguru Estuary. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.16 Cockles at Ngunguru Estuary

Figure 26: Map of sample strata and individual sample locations for cockles at Ngunguru Estuary, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 28: Estimates of cockle abundance at Ngunguru Estuary, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.8	38	1 427	8.55	1 073	15.93
B	0.4	13	0	0.00	0	
C	0.6	29	1 080	6.23	1 064	21.79
E	3.6	60	4 485	77.89	2 136	8.62

Table 29: Estimates of cockle abundance at Ngunguru Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	8.63	508	6.71	0.64	38	11.70
2004–05	1.8	9.79	544	7.77	0.34	25	18.85
2010–11	1.8	19.55	1 086	10.72	0.07	5	35.49
2014–15	5.5	92.67	1 696	7.53	0.38	8	32.11
2014–15*	1.8	14.78	814	13.01	0.06	4	35.13

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	21.32	23	5–41	13.40	3.52
2010–11	17.46	20	5–32	33.21	0.38
2014–15	19.07	20	4–34	18.71	0.41

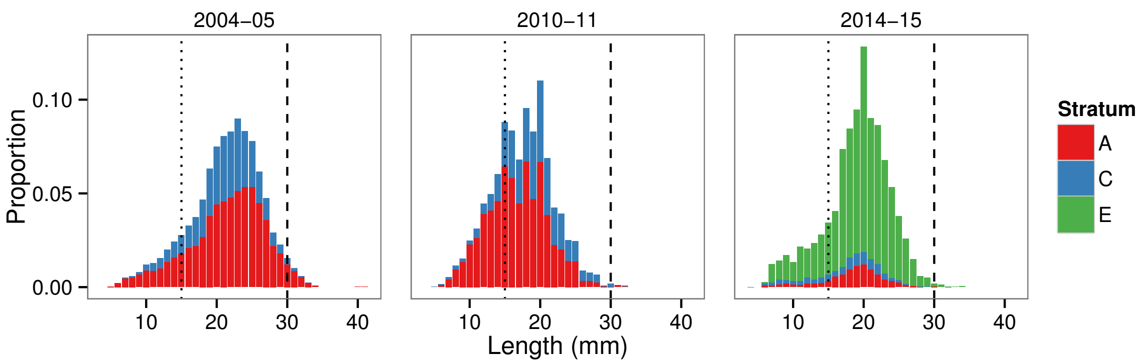


Figure 27: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ngunguru Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.17 Pipi at Ngunguru Estuary

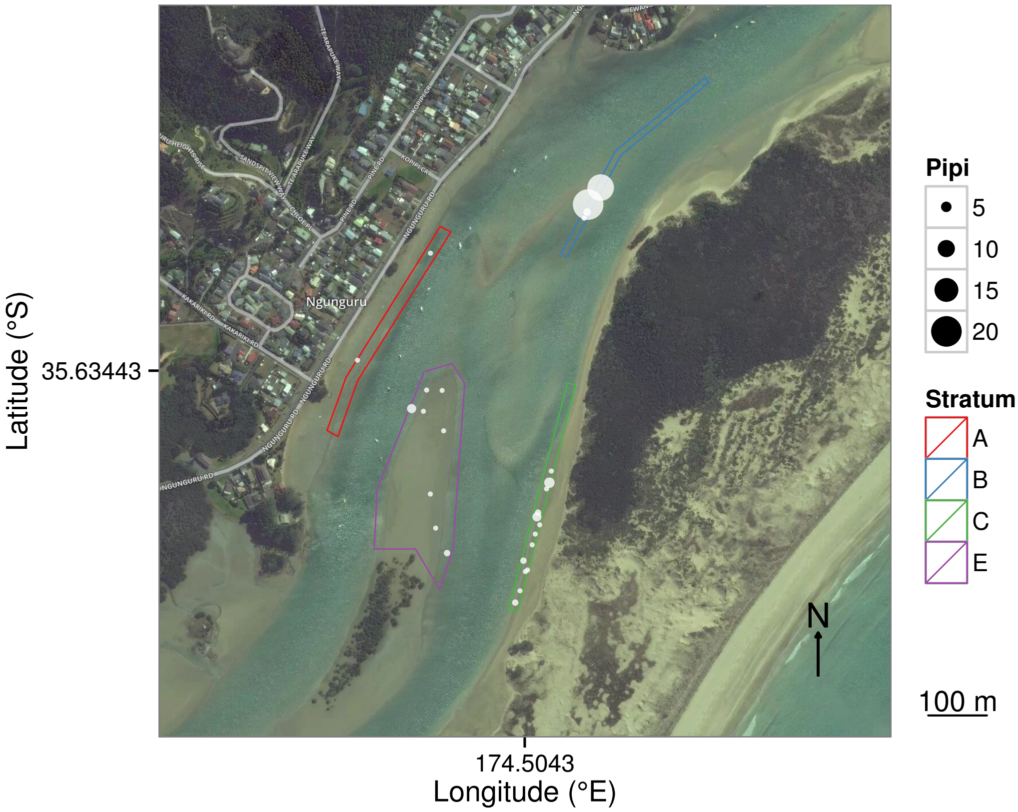


Figure 28: Map of sample strata and individual sample locations for pipi at Ngunguru Estuary, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 31: Estimates of pipi abundance at Ngunguru Estuary, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.8	38	2	0.01	2	69.75
B	0.4	13	41	0.39	90	60.59
C	0.6	29	23	0.13	23	28.93
E	3.6	60	12	0.21	6	40.82

Table 32: Estimates of pipi abundance at Ngunguru Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2003–04	1.7	1.87	110	8.73	0.87	51	9.04
2004–05	1.8	2.23	124	5.37	0.95	53	7.83
2010–11	1.8	0.73	40	16.60	0.25	14	19.25
2014–15	5.5	0.74	14	34.26	0.00	0	
2014–15*	1.8	0.54	30	44.85	0.00	0	

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	47.79	45	10–68	1.47	42.62
2010–11	42.10	50	7–67	7.65	38.86
2014–15	34.31	40	8–49	14.84	0.00

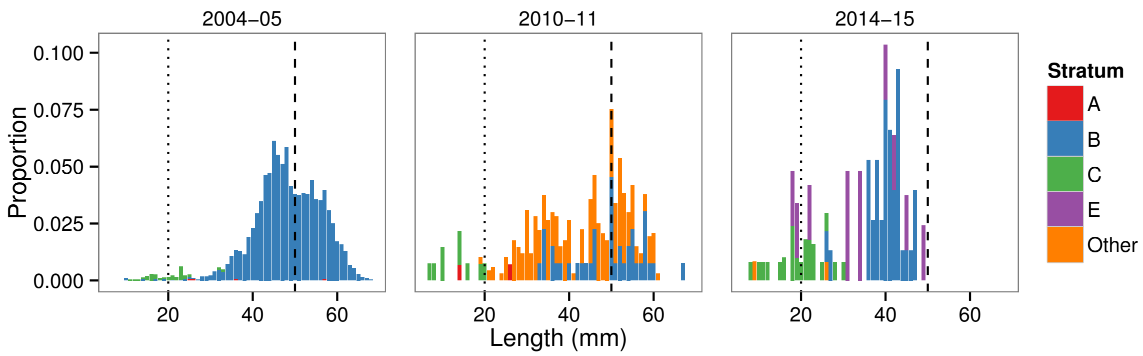


Figure 29: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ngunguru Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.18 Otumoetai (Tauranga Harbour)

Otumoetai is a survey site within Tauranga Harbour, located directly across the main harbour entrance. This site has been included in five previous bivalve assessments since 1999–2000, and was most recently sampled in 2009–10 before the current study (see Appendix A, Tables A-1, A-2). The 2014–15 survey used the same sampling extent as previous assessments, based on two separate areas that contained pipi and cockle beds, respectively (Figure 30). Sampling for pipi was focused on a western area off Tilby Point, where it extended alongside and into the side channel; this area was split into strata A and B. An additional stratum E at the southwestern end of stratum A was included in the 2014–15 survey to incorporate the extension of the pipi bed toward the headland. Sampling for cockles was focused on an area southeast of the pipi strata, and included two strata C and D on the intertidal sandflat next to the boat club. Cockles and pipi were assessed across all strata, based on a total of 142 sampling points (Table 34).

Sediment samples were taken across the entire sampling extent and in adjacent areas. The sediment was generally low in organic content, with 1.1 to 2.6% of organic matter in the samples (Figure 30, and see details in Appendix B, Table B-3). Most of the sediment consisted of sand, with a low proportion of fines (<63 µm grain size) that varied between 0.2 and 7.0%. The prevalent sand fractions were fine and medium sands (>125 µm and >250 µm grain size), with coarse sand (>500 µm grain size) making up a smaller proportion of the sediment. The proportion of gravel (>2000 µm grain size) was generally low, with maximum values of 8.0 and 6.9% in the samples.

Cockles were distributed throughout all strata, including the subtidal strata A, B, and E in the side channel (Figure 31, Table 34). They were most abundant in in the intertidal stratum C, but there were few cockles in the adjacent stratum D. Stratum C also supported the highest density of cockles with 1420 individuals per m^2, followed by the second highest estimate of 722 cockles per m^2 in stratum E.

The estimate for the total cockle population in 2014–15 (excluding data from stratum E) was 20.02 million (CV: 7.49%) cockles in 2014–15, compared with the preceding population estimate of 14.73 million (CV: 10.85%) cockles in 2009–10 (Table 35). The increase in population size was also evident in the corresponding density estimates, which increased from 263 cockles per m^2 in the previous survey to a mean density of 379 cockles per m^2 in the current assessment.

Based on the high number of cockles in stratum E, the population estimate was markedly higher when including data from this stratum: the estimated total abundance was 37.28 million (CV: 7.20%) individuals, with a mean density of 486 cockles per m^2. Overall, the current estimates were markedly higher than the preceding population estimates, even when excluding data from stratum E. Throughout the survey series, there was an overall increase in cockle abundance and density over time, from a relatively small population in 2006–07 to the current population size.

In spite of this increase in the total cockle population, the number and density of large cockles ($\geq$30 mm shell length) declined, with consistently low abundance and density estimates for this size class. In 2014–15, the cockle population included 0.02 million (CV: >100%) large individuals, which occurred at a density of <1 cockle per m^2.

Length-frequency distributions confirmed the prominence of small-sized cockles at Otumoetai, which was persistent throughout recent surveys (Table 36, Figure 32): almost half (40.90% to 47.56%) of the population consisted of recruits ($\leq$15 mm shell length), whereas large cockles only constituted between 0.05% and 1.62% of the population, with the lowest value in current study. The mean and modal sizes of the cockle population corresponded with the prevalence of small-sized individuals, and the current population consisted of a single cohort with a modal size of 17-mm shell length.

The pipi population at Otumoetai was almost exclusively in the channel strata (A, B, and E), with only three individuals in stratum C (Figure 33, Table 37). Numbers and densities were similarly high across strata A, B, and E. Excluding stratum E, the population estimates were 64.02 million (CV: 5.59%) pipi at a mean density of 1207 pipi per m^2 (Table 38). When including stratum E in the estimates, the total population size was 92.59 million (CV: 5.59%) pipi in 2014–15; the corresponding population density was 1207 pipi per m^2.

Across the survey series, the pipi population has been relatively constant, although the current estimates reflected a discernible increase in the size and density of the population, even without data from stratum E. In contrast to the marked increase in the the total population, however, the population size and density of large pipi ($\geq$50 mm shell length) decreased from previous estimates. The 2014–15 estimates for this size class were the lowest in the survey series, with an abundance of 0.47 million (CV: 29.21%) large pipi and a density of 11 pipi per m^2 (excluding data from stratum E). Adding data from stratum E made little difference to the estimates for large pipi, although it slightly decreased their population density to 7 pipi per m^2.

The proportion of large pipi in the total population has been consistently low across surveys, with their current proportion of 0.50% reflecting the lowest value since 2006–07 (Table 39). At the same time, the proportion of recruits ($\leq$20 mm shell length) increased markedly, from 0.49% of the total pipi population in 2009–10 to 15.80% in 2014–15. The overall decrease in pipi sizes was also illustrated in marked declines in shell lengths, with current mean and modal sizes at 26.62 mm and 24 mm shell length, respectively, compared with mean and modal shell lengths of 39.75 mm and 45 mm in 2009–10.

The decrease in the proportion of large pipi and the concomitant increase in the proportion of recruits were evident in the length-frequency distributions (Figure 34). Although the population remained unimodal, there was a notable shift in size-frequencies from a population characterised by medium-size pipi and including large individuals and few recruits in 2006–07 and 2009–10 to a population dominated by small pipi that were just over 20-mm shell length in the current assessment.

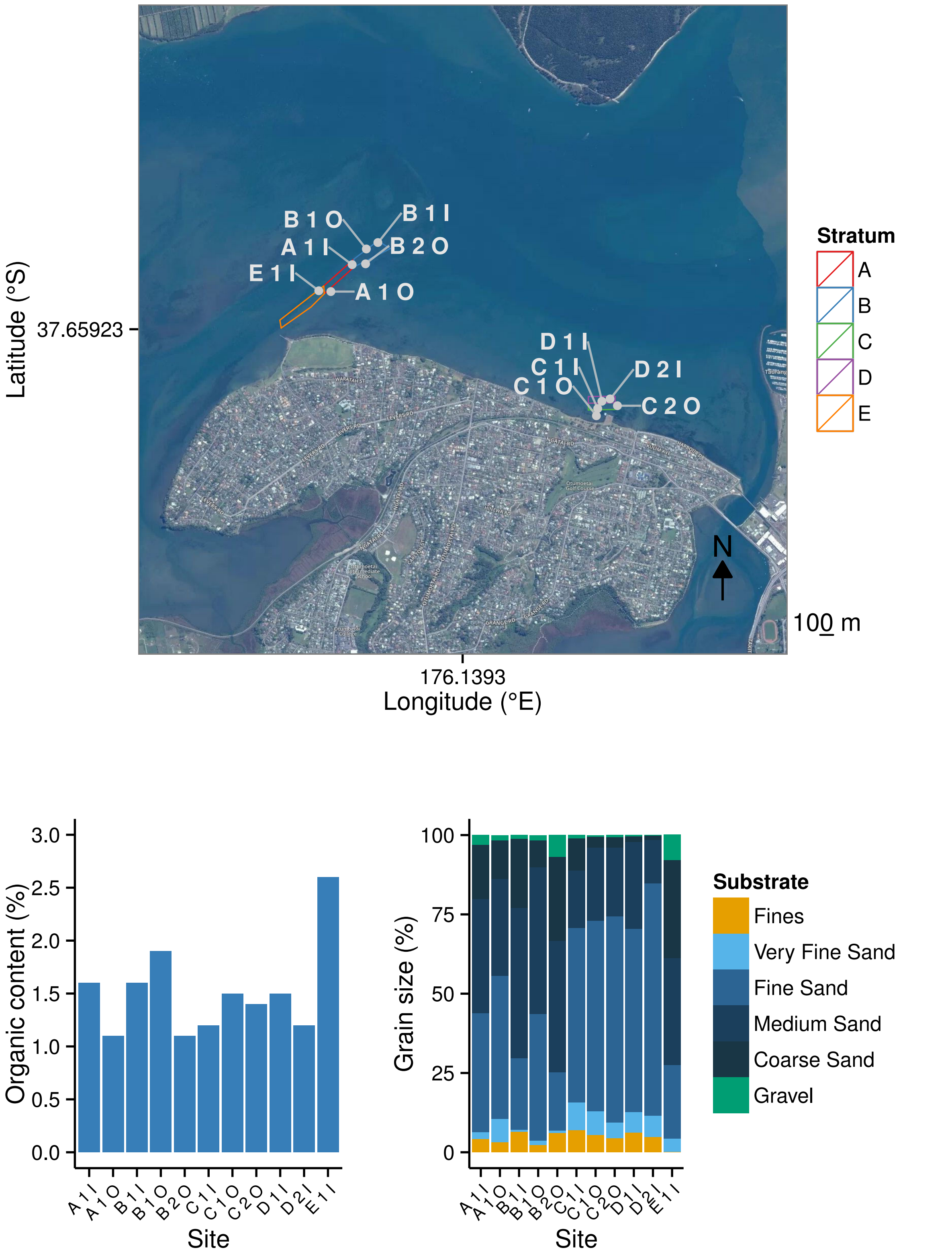


Figure 30: Sediment sample locations and characteristics at Otumoetai. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.19 Cockles at Otumoetai (Tauranga Harbour)

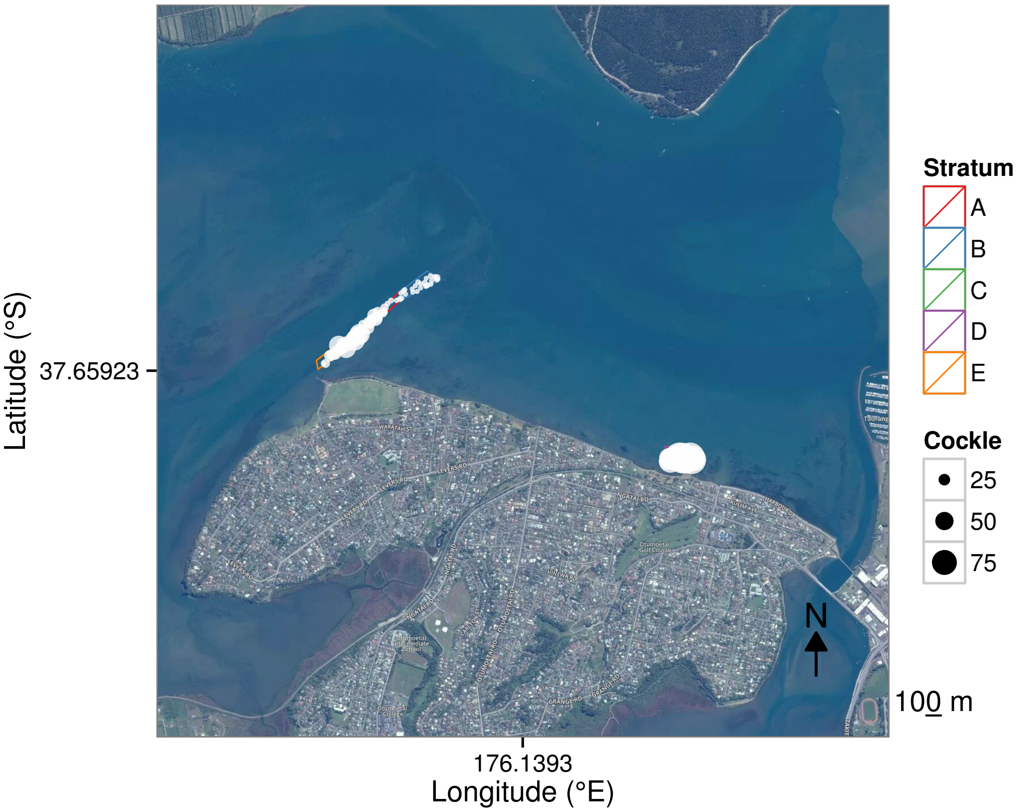


Figure 31: Map of sample strata and individual sample locations for cockles at Otumoetai, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 34: Estimates of cockle abundance at Otumoetai, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	1.4	22	270	4.77	351	19.24
B	1.9	31	51	0.91	47	21.01
C	1.0	31	1 541	14.20	1 420	8.21
D	1.0	32	15	0.13	13	71.03
E	2.4	26	657	17.27	722	12.89

Table 35: Estimates of cockle abundance at Otumoetai for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

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
2014–15*	5.3	20.02	379	7.49	0.02	<1	>100

Table 36: Summary statistics of the length-frequency (LF) distribution of cockles at Otumoetai. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	16.53	20	4–32	40.90	0.38
2009–10	16.28	15	4–39	45.13	1.62
2014–15	15.73	17	5–32	47.56	0.05

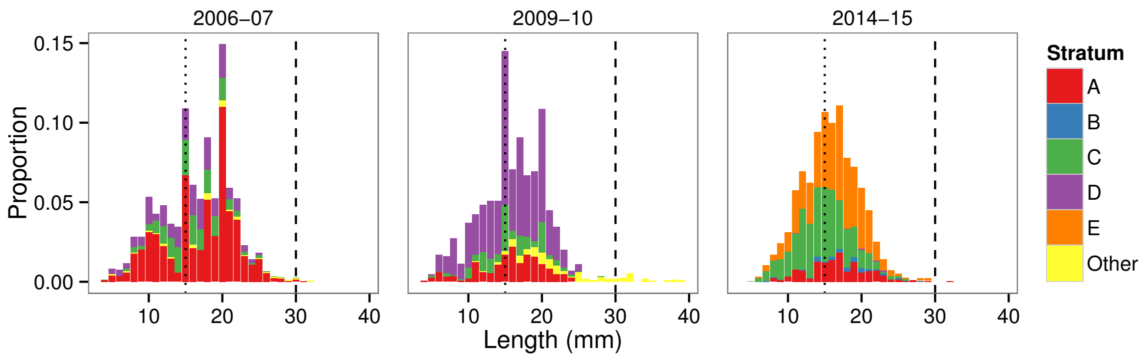


Figure 32: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Otumoetai. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.20 Pipi at Otumoetai (Tauranga Harbour)

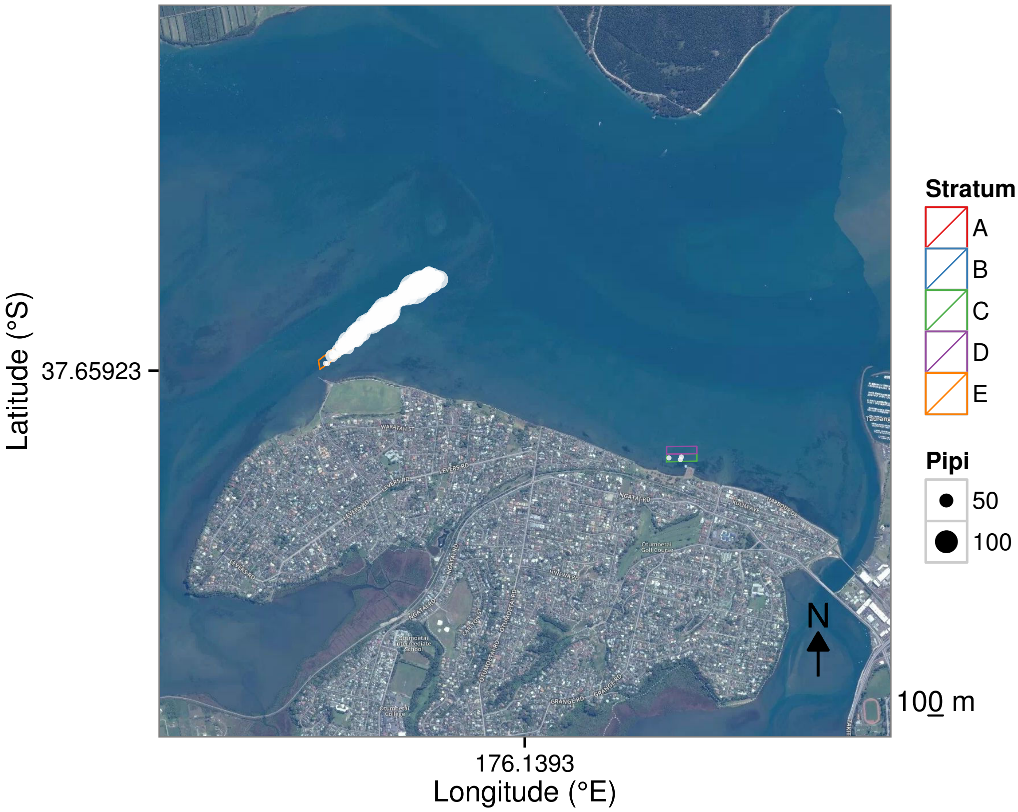


Figure 33: Map of sample strata and individual sample locations for pipi at Otumoetai, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 37: Estimates of pipi abundance at Otumoetai, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	1.4	22	1 520	26.87	1 974	8.51
B	1.9	31	2 083	37.12	1 920	7.34
C	1.0	31	3	0.03	3	55.78
D	1.0	32	0	0.00	0	
E	2.4	26	1 087	28.57	1 195	13.14

Table 38: **Estimates of pipi abundance at Otumoetai for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.**

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	5.6	24.76	442	3.30	9.17	255	3.56
2002–03	5.6	20.37	364	3.63	2.06	57	7.56
2005–06	4.6	34.26	745	2.76	1.62	45	7.11
2006–07	4.6	23.63	514	6.61	1.02	28	17.46
2009–10	5.6	17.35	310	7.23	0.63	18	27.44
2014–15	7.7	92.59	1 207	5.59	0.47	7	29.21
2014–15*	5.3	64.02	1 213	5.56	0.47	11	29.21

Table 39: Summary statistics of the length-frequency (LF) distribution of pipi at Otumoetai. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	32.42	30	9–61	1.72	4.30
2009–10	39.75	45	12–75	0.49	7.35
2014–15	26.62	24	9–55	15.80	0.50

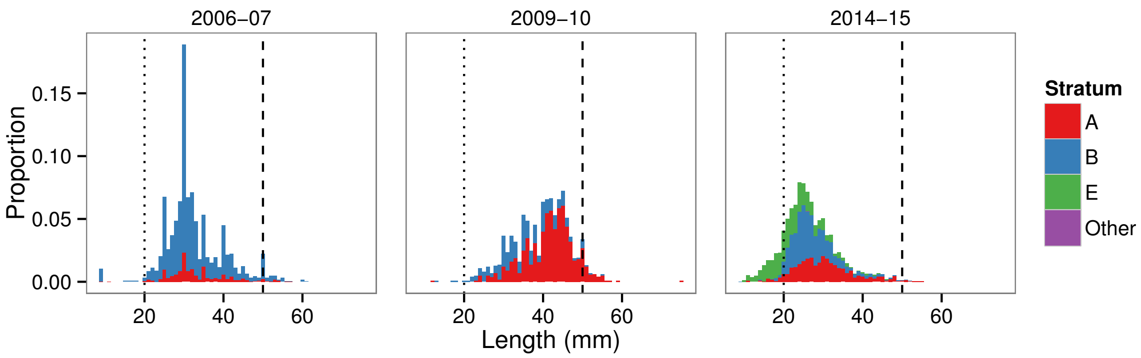


Figure 34: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Otumoetai. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.21 Raglan Harbour

Raglan Harbour is in the Waikato region, directly north of Aotea Harbour on the west coast. There have been six previous bivalve assessments at this site since 1999–2000, with the most recent study in 2012–13 preceding the current survey (see Appendix A, Tables A-1, A-2). As in previous assessments, the 2014–15 sampling extent at Raglan Harbour was split into three strata in two separate areas, with adjoining strata A and C in a side-arm of the harbour, and stratum D on an intertidal sandflat in the main part of it (Figure 35). Both areas were directly adjacent to and easily accessible from Raglan township. Across the entire sampling extent, cockles and pipi were surveyed in a total of 226 sampling points, with 135 sampling points allocated to phase 1, and another 91 sampling points in phase 2 (Table 40).

Sediment samples were taken within and adjacent to the survey strata, and revealed a low organic content that varied between 1.4 and 3.6% (Figure 35, and see details in Appendix B, Table B-3). There were no fine particles (<63 µm grain size) in the samples, and the sediment grain size was predominantly fine (>125 µm grain size) sand. The proportion of coarse particles was generally low, although two samples contained over 14% gravel (>2000 µm grain size).

Cockles were present in all strata, and were relatively evenly distributed within each stratum (Figure 36, Table 40). Stratum A contained the highest number of cockles, with fewer cockles in stratum D, and markedly lower numbers in stratum C. The total estimate for the cockle population at Raglan Harbour was 109.56 million (CV: 4.95%) individuals in 2014–15 (Table 41). This estimate was lower than the value in 2012–13, when the total population was estimated at 129.04 million (CV: 6.84%) cockles, although the latter estimate was based on a larger sampling extent. Nevertheless, the population densities were similar between the two most recent surveys, with 1513 cockles per m^2 in 2014–15 compared with 1566 cockles per m^2 in 2012–13.

For cockles in the large size class (≥30 mm shell length), there was a more pronounced decrease in population size and density: the estimated 2.44 million (CV: 15.20%) large cockles in 2014–15 represented only about a third of the size of the large cockle population in 2012–13 (i.e., 6.08 million cockles, CV: 19.74%). Similarly, the mean density of large cockles declined from 74 cockles per m^2 to 34 cockles per m^2 in the same period, and the current estimate was the lowest value in the reporting period.

In contrast, the length-frequency distributions remained relatively similar over time, with small changes in mean and modal sizes (Table 42, Figure 37). The mean shell length in the present study was 21.61 mm, and the population was unimodal, with a strong cohort around the 22-mm size mode. Both the proportions of recruits (≤20 mm shell length) and of large pipi in the population remained relatively similar between surveys, but showed a small decrease in 2014–15.

The pipi population at Raglan Harbour was concentrated in stratum C, with fewer pipi in the other strata (Figure 38, Table 43). Stratum C was in the channel of the side-arm to the main part of the harbour, with the entire pipi bed located in the subtidal part of this channel. In contrast to the cockle population, pipi showed an increase in their population estimates, with an estimated total of 2.35 million (CV: 15.53%) pipi in 2014–15 (Table 44). The mean population density was 32 individuals per m^2. Included in these estimates were an estimated 0.14 million (CV: 40.45%) large pipi (≥50 mm shell length), and their population density was 2 pipi per m^2. Although the total population estimate showed some variation in recent surveys, the number of large pipi and their population density have been relatively consistent over the same period.

The contribution of large pipi to the total population, however, decreased in the two recent surveys, and only 6.09% of individuals in 2014–15 were within the large size class. In 2009–10, this proportion was 24.33% (Table 45, Figure 39). There was also a smaller proportion of recruits in the current assessment, comprising of 5.83% of all individuals in 2014–15.

In the current and the preceding assessment, the pipi population was generally unimodal and included a number of large individuals. There were few small-size pipi, with the majority of the population in the medium size range, and a mean size of 37.49 mm shell length.

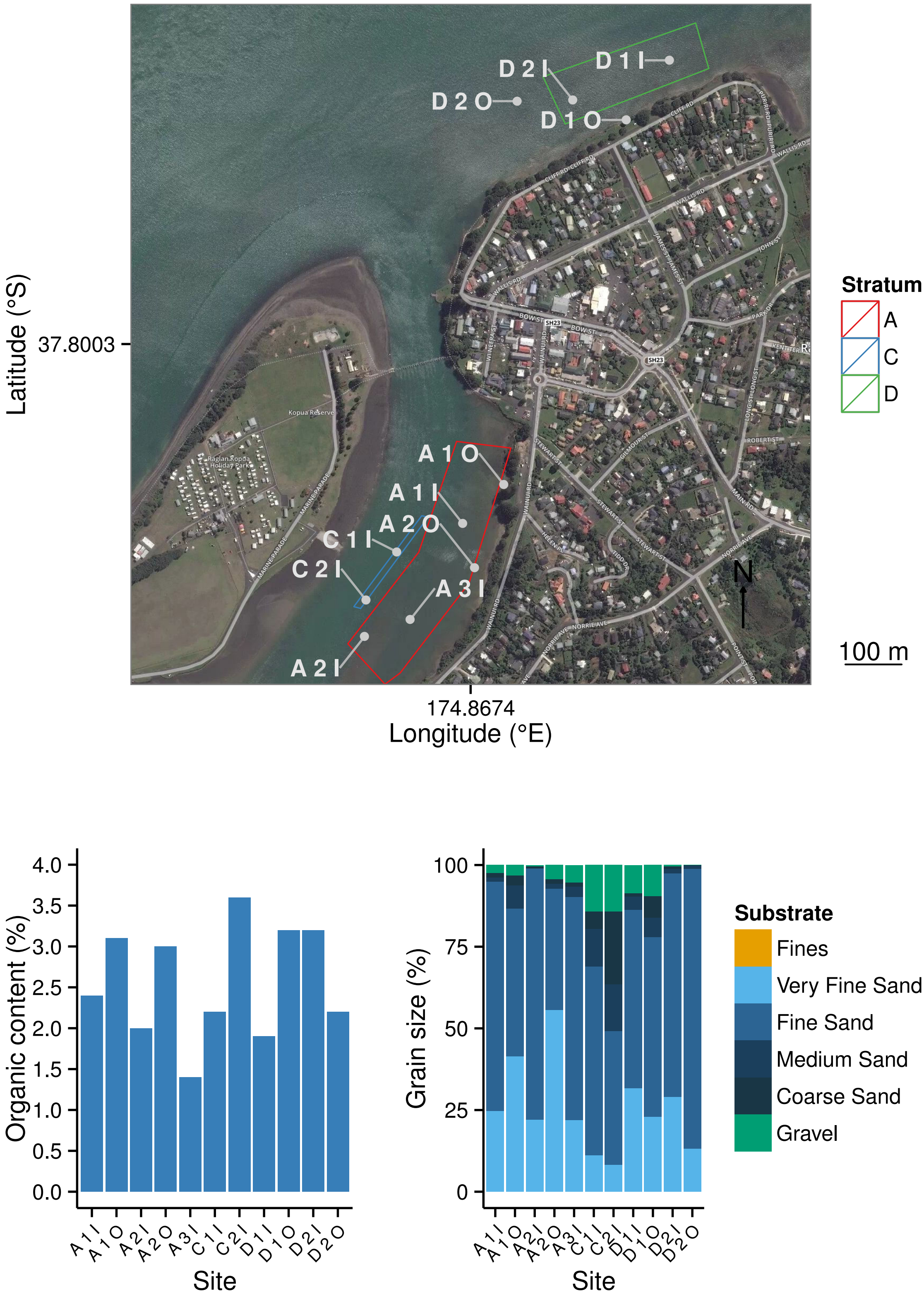


Figure 35: Sediment sample locations and characteristics at Raglan Harbour. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.22 Cockles at Raglan Harbour

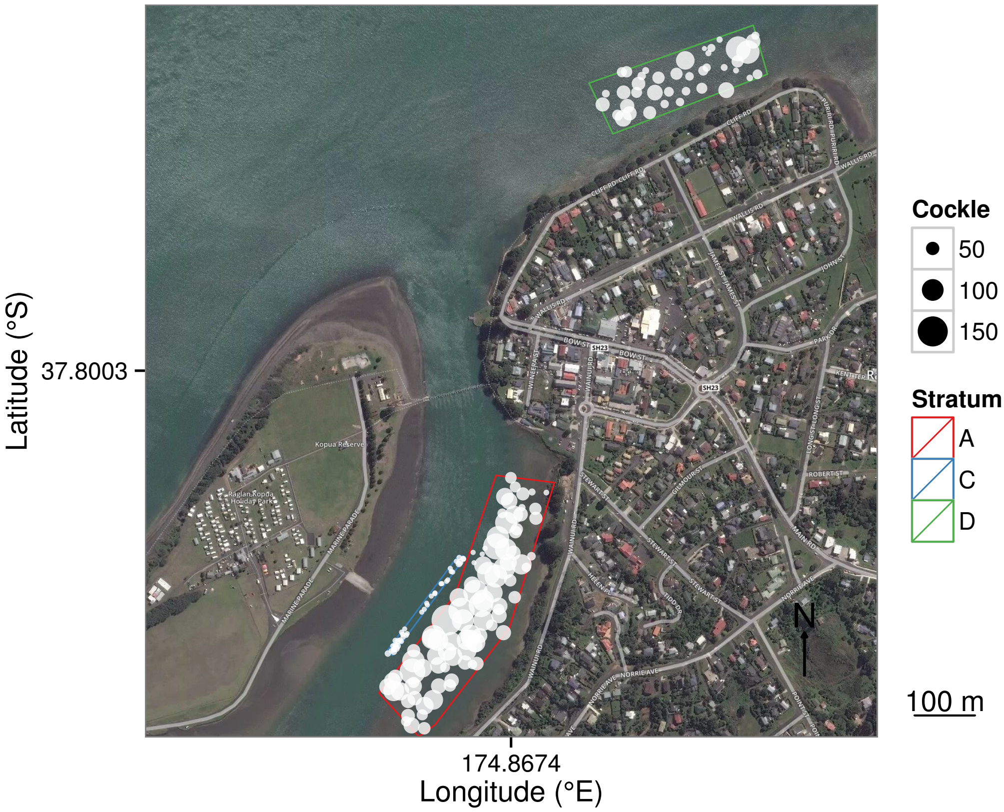


Figure 36: Map of sample strata and individual sample locations for cockles at Raglan Harbour, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 40: Estimates of cockle abundance at Raglan Harbour, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	4.6	95	6 086	83.33	1 830	5.45
C	0.2	90	148	0.10	47	20.41
D	2.5	41	1 521	26.13	1 060	11.33

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.1	184.49	1 827	3.64	6.56	65	12.56
2000–01	10.0	220.43	2 195	3.34	17.28	172	6.50
2002–03	8.2	92.26	1 120	3.78	4.17	51	9.47
2003–04	8.2	89.79	1 090	3.50	3.76	46	7.49
2009–10	9.2	125.59	1 365	5.23	5.90	72	20.79
2012–13	8.2	129.04	1 566	6.84	6.08	74	19.74
2014–15	7.2	109.56	1 513	4.95	2.44	34	15.20

Table 42: Summary statistics of the length-frequency (LF) distribution of cockles at Raglan Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	19.99	20	5–45	20.28	4.85
2012–13	21.37	20	4–45	12.24	4.71
2014–15	21.61	22	6–39	9.87	2.22

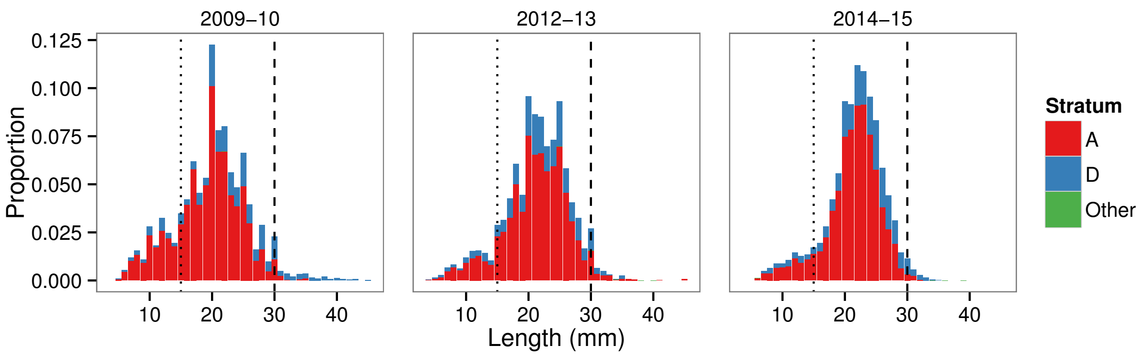


Figure 37: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Raglan Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.23 Pipi at Raglan Harbour

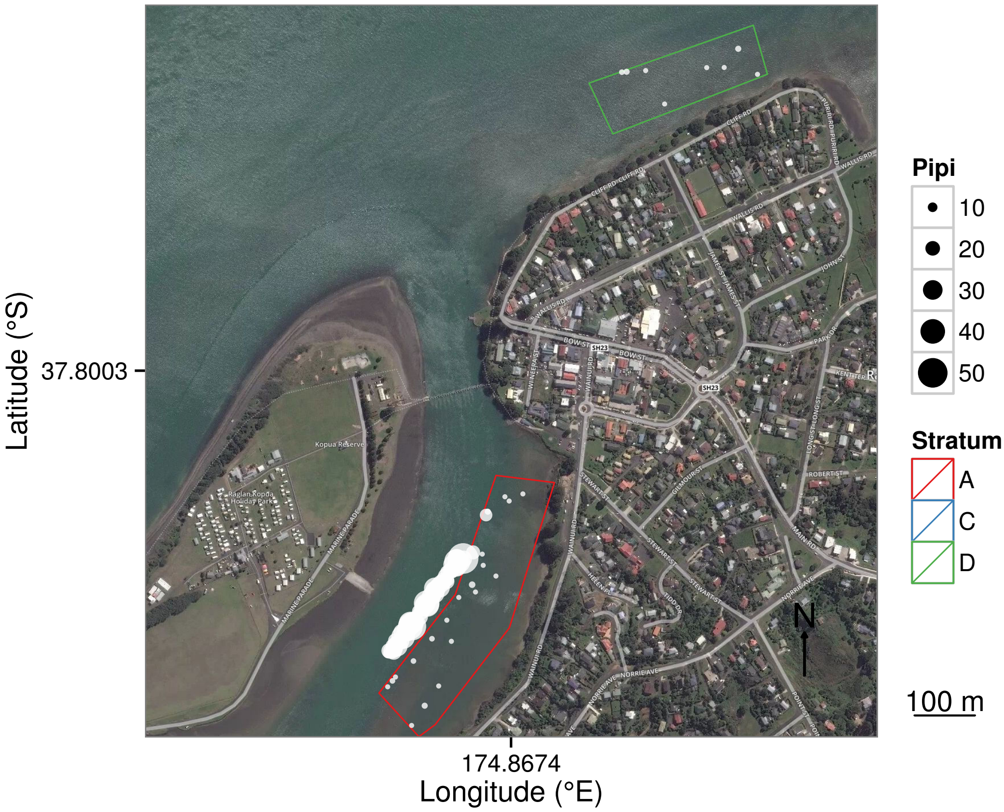


Figure 38: Map of sample strata and individual sample locations for pipi at Raglan Harbour, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 43: Estimates of pipi abundance at Raglan Harbour, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	4.6	95	65	0.89	20	38.90
C	0.2	90	1 755	1.23	557	6.28
D	2.5	41	13	0.22	9	37.25

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.1	0.31	3	15.14	0.00	0	
2000–01	10.0	1.46	15	11.75	0.23	2	8.33
2002–03	8.2	0.47	6	13.18	0.08	<1	17.69
2003–04	8.2	0.43	5	13.70	0.02	<1	20.92
2009–10	9.2	0.60	7	19.17	0.15	2	12.61
2012–13	8.2	1.78	22	14.51	0.13	2	43.37
2014–15	7.2	2.35	32	15.53	0.14	2	40.45

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	35.52	40	10–60	24.75	24.33
2012–13	33.45	35	3–61	12.06	7.46
2014–15	37.49	43	8–59	5.83	6.09

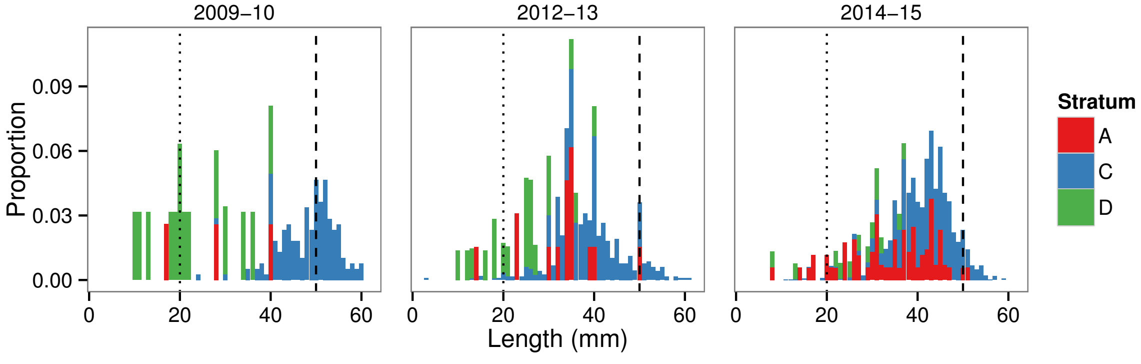


Figure 39: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Raglan Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.24 Ruakaka Estuary

Ruakaka Estuary is a small Northland estuary, just south of Whangarei. It was first included in the bivalve surveys in 2006–07, and the current assessment was the third survey in the series (see Appendix A, Tables A-1, A-2). The most recent previous survey was in 2010–11.

This estuary is dominated by a tidal channel that divides its different habitats, including an elevated sandbank area in the middle of the estuary and a sandspit at the estuary entrance. The course of this channel has changed over time, causing changes to the size and shape of the sandbank and sandspit. In 2014–15, the channel entered the estuary to the northwest, before sharply changing direction to the south and then turning northwest again in the southern part of the main estuary.

Because of the movement of the channel, the sampling extent at Ruakaka Estuary has changed across surveys. Establishing the sampling extent required extensive on-site reconnaissance to determine the current distribution of bivalves in the estuary. The 2014–15 sampling extent was largely focused on the main channel, and included a small area to the north that contained a side channel at high tide. There were four strata across this sampling extent, including three strata (AC, AN, AS) centred on the southern part of the main channel, and stratum B in the small side channel (Figure 40). There were no or only few bivalves in other parts of the estuary. This sampling extent was smaller than the preceding survey area, but of similar size to the 2006–07 sampling extent. Within this sampling extent, a total of 169 sampling points were sampled for cockles and pipi (Table 46).

Sediment at Ruakaka Estuary was characterised by a low organic content, with a maximum of 2.1% of organic matter (Figure 40, and see details in Appendix B, Table B-3). Sediment grain size was variable in the proportion of fines (<63 µm grain size), which ranged from no or a low percentage of fines to 15.1% of sediment in this grain size fraction. The bulk of the sediment was fine (>125 µm grain size) and medium (>250 µm grain size) sands.

Cockles were present across all strata, but their numbers were low in the main channel, in stratum AC (Figure 41, Table 46). They were abundant in the other strata, particularly in stratum AN, adjoining the main channel on the northern side. Across all strata, the total population estimate for 2014–15 was 43.97 million (CV: 8.77%) cockles, and the population density was 675 individuals per m^2 (Table 47). Large cockles (≥30 mm shell length) were only a small part of the total population, and their population density was low; there were 0.15 million (CV: 35.4%) large cockles in the Ruakaka Estuary population, with a population density of 2 large individuals per m^2. These current estimates marked considerable increases from the previous population assessment at Ruakaka Estuary in 2010–11, especially in view of the small sampling extent in 2014–15, compared with the preceding survey.

The length-frequency distributions partly explained these increases, revealing a strong bias towards small-sized individuals in the cockle population (Table 48, Figure 42). Although data from the previous survey show that the cockle population at Ruakaka Estuary largely consisted of small-sized individuals, the mode showed a marked decrease in the current study from a mode of 20-mm shell length in 2010-11 to 14-mm shell length in the present assessment. At the same time, the proportion of recruits (≤15 mm shell length) increased to 53.82% of the total population with a concomitant decrease in the proportion of large cockles, which declined to 0.35% in 2014–15. Although the cockle population was unimodal throughout the recent surveys, the single cohort showed a consistent shift towards smaller sizes over time.

Pipi in Ruakaka Estuary were also distributed across all strata, but showed the opposite distribution pattern to cockles, and were most abundant in the channel, in stratum AC (Figure 43, Table 49). Within this stratum, their densities were high in the deep part of the channel, on the northern side. Although pipi were present throughout the other strata, their numbers were low. The total pipi population at Ruakaka Estuary in 2014–15 was estimated at 81.23 million (CV: 16.51%) individuals, and their corresponding population density was 1247 pipi per m^2 (Table 50). Although these estimates were substantial increases from the previous assessment in 2010–11 (25.93 million (CV: 19.84%) cockles, and 235 pipi per m^2), there was no corresponding increase in the population of large pipi (≥50 mm shell length). Instead, the pipi population continued to include only a small number of large individuals, with an estimated 0.08 million (CV: 83.35%) large pipi in 2014–15. The population density of large pipi was also low, with 1 large pipi per m^2.

The low number of large pipi was evident in the size-frequency distributions at Ruakaka Estuary (Table 51, Figure 44). Large individuals only contributed 0.09% to the total population (a decrease from 0.20% in the preceding survey), compared with 24.91% of recruits ($\leq$20 mm shell length). Although the mean shell length has remained similar across surveys at about 27 mm, there was a recent decrease in the modal size of the pipi population, from 30-mm shell length in 2010-11 to 25-mm in 2014–15. These findings document a unimodal pipi population dominated by small- and medium-size individuals.

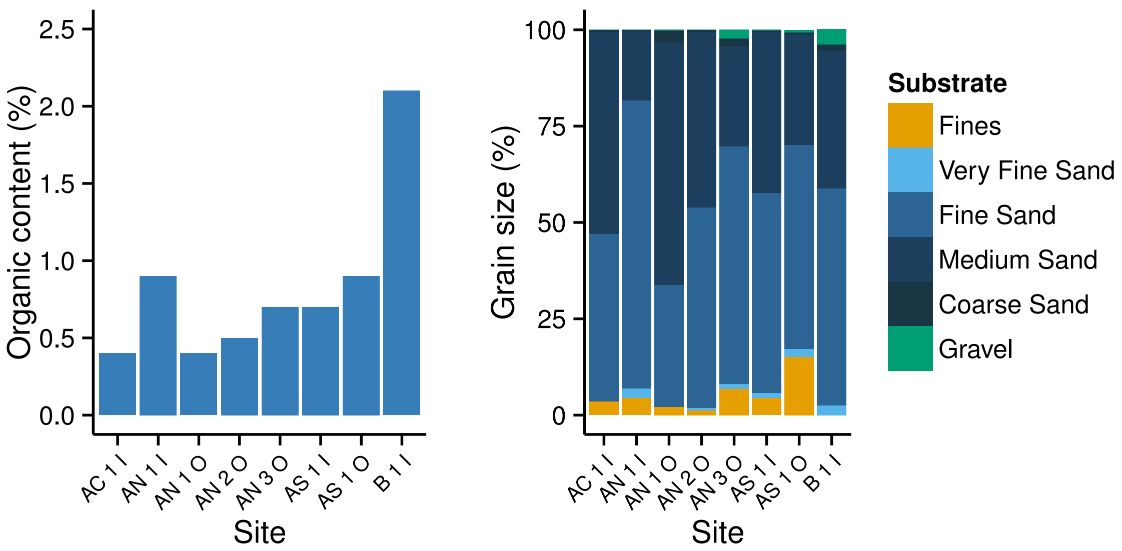


Figure 40: Sediment sample locations and characteristics at Ruakaka Estuary. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.25 Cockles at Ruakaka Estuary

Figure 41: Map of sample strata and individual sample locations for cockles at Ruakaka Estuary, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 46: Estimates of cockle abundance at Ruakaka Estuary, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
AC	3.6	58	394	7.08	194	27.68
AN	0.9	43	2 731	15.56	1 815	10.89
AS	1.6	41	1 528	16.78	1 065	16.54
B	0.4	27	994	4.54	1 052	15.02

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

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

Table 48: Summary statistics of the length-frequency (LF) distribution of cockles at Ruakaka Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	23.30	20	7–38	7.47	19.30
2010–11	16.18	20	2–35	45.95	1.22
2014–15	15.87	14	5–40	53.82	0.35

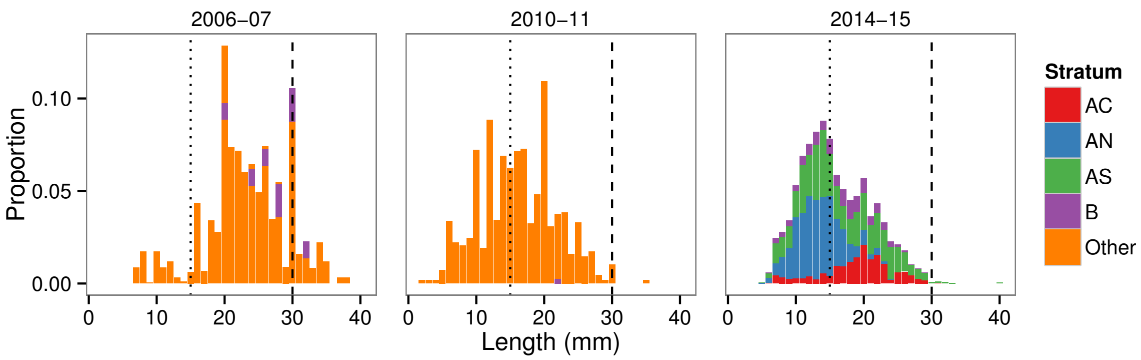


Figure 42: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Ruakaka Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.26 Pipi at Ruakaka Estuary

Figure 43: Map of sample strata and individual sample locations for pipi at Ruakaka Estuary, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 49: Estimates of pipi abundance at Ruakaka Estuary, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
AC	3.6	58	4 387	78.81	2 161	17.00
AN	0.9	43	24	0.14	16	24.80
AS	1.6	41	183	2.01	128	31.39
B	0.4	27	59	0.27	62	21.72

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

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

Table 51: Summary statistics of the length-frequency (LF) distribution of pipi at Ruakaka Estuary. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	27.13	15	5–65	41.91	4.35
2010–11	27.30	30	7–55	22.59	0.20
2014–15	26.52	25	8–51	24.91	0.09

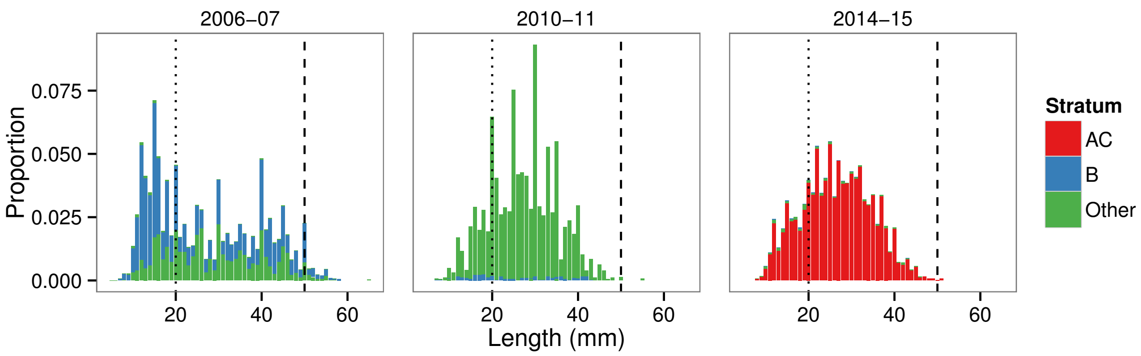


Figure 44: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Ruakaka Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.27 Te Haumi Beach

Te Haumi Beach is a relatively small Northland beach, located on the east coast, immediately south of Paihia. Prior to the present study, Te Haumi Beach has been surveyed eight times since 1999–2000, most recently in 2012–13 (see Appendix A, Tables A-1, A-2). Bivalve sampling at this beach has consistently focused on two separate areas, including a small estuarine area west of State Highway 11, and the intertidal sandflat on the main beach. The current study surveyed the same sampling area, and included the same strata used in previous surveys: there were two strata on the main beach, strata A and B, and a smaller stratum C in the western area (Figure 45). In addition, it included an an additional stratum E, as on-site reconnaissance indicated that pipi were abundant in this area directly adjacent to stratum A. Including stratum E resulted in a similar size sampling extent to the two preceding surveys when they included additional stratum D. The two preceding surveys also sampled bivalves in an area south of strata A and B, additional stratum D, but did not include this stratum in the population estimates. Across the strata used in the current survey, there was a total of 157 sampling points in 2014–15 (Table 52).

Sediment samples taken at Te Haumi Beach revealed a consistently low organic content of 1.8 to 2.8% (Figure 45, and see details in Appendix B, Table B-3). Sediment grain size distributions showed some variation, with generally a low proportion of fines (<63 µm), although this grain size fraction exceeded 20% in one sample (in stratum C). The prevalent grain size at Te Haumi Beach was generally fine sand (>125 µm grain size), with varying proportions of coarser particles, i.e., medium and coarse sands (>250 µm) and >500 µm grain size). The proportion of gravel (>2000 µm grain size) was also variable, with relatively high proportions of gravel in some of the samples, including one sample taken south of strata A and B that contained 48.8% gravel.

The cockle population at Te Haumi Beach was distributed across all strata, showing highest densities in the southern part of stratum B, including the high-intertidal zone (Figure 46, Table 52). There were relatively few cockles in stratum E. Excluding this stratum from the assessment resulted in an estimated 34.10 million (CV: 11.54%) cockles at Te Haumi Beach in 2014–15 (Table 53). The corresponding mean density was 351 cockles per m^2. The total population included 3.28 million (CV: 20.29%) large cockles (≥30 mm shell length) that had a mean density of 34 individuals per m^2.

Based on a similar sampling extent, the estimates for the total population and for large cockles were comparable to values in the recent surveys in 2009–10 and 2012–13. Estimates for the total population varied between 30 and 41 million cockles in 2009–10 and 2012–13, and the respective population sizes of large cockles were slightly lower than the current estimate with an estimated 0.9 and 2 million large individuals in these earlier surveys.

The length-frequency distributions of the cockle population were also similar across recent surveys (Table 54, Figure 47). The mean and modal sizes in 2014–15 were 20.45-mm and 18-mm shell length. Recruits (≤15 mm shell length) decreased in their proportion of the total population, from over 30% in the preceding two surveys to 21.40% of the total population in the current assessment. At the same time, the proportion of large individuals remained similar, with 9.67% of the total population in this size class.

Pipi at Te Haumi Beach were concentrated in stratum C and in the northwestern corner of stratum B, where densities were highest in the northwestern corner. Smaller concentrations of pipi were at the western and eastern ends of stratum E (Figure 48, Table 55). Without data from stratum E, there was an estimated total of 40.02 million (CV: 23.92%) pipi in 2014–15, at a mean density of 412 pipi per m^2 (Table 56). Large pipi (≥50 mm shell length) played a small part in the total population, and there were an estimated 0.25 million (CV: 21.02%) individuals in this size class. Their mean density was 3 large pipi per m^2.

In comparison with data from previous surveys across a similar sampling extent, the current estimates reflected a considerable decrease from previous values, especially in the number and density of large pipi. This size class was only about a third of its size of the preceding estimate two years earlier, although this estimated value was within the range of previous population sizes since 2009–10.

The size-frequency distributions showed that there was an increase in mean shell length in the Te Haumi Beach population from 22.19-mm shell length in 2012–13 to 28.22-mm shell length in 2014–15 (Table 57, Figure 49). The concomitant decrease in the proportion of recruits ($\leq$20 mm shell length) corresponded with the increase in size as the former was 36.92% in the current assessment compared with 54.30% in the previous survey. Nevertheless, large individuals constituted only a small proportion of the total population, even though their contribution increased from 0.93% in 2012–13 to 2.07% in 2014–15.

Over the time frame of the three surveys since 2009–10, pipi at Te Haumi Beach changed from a largely unimodal population with a strong cohort of small-sized individuals to a bimodal population of recruits and medium-size to large individuals. A number of individuals in this latter cohort were in additional stratum E; without this stratum, the second cohort was considerably smaller.

Stratum E was also one of two strata that contained evidence of recent pipi mass mortality events at this site. During the reconnaissance in December 2014, one area within stratum E contained a bank of recently dead and moribund pipi (see Appendix C). At the same time, stratum C contained large patches of dead pipi shells from another recent large-scale die-off. The reason, or reasons, for the mass mortalities of predominantly large pipi at this site remain/s unknown, as laboratory testing is still ongoing (A. Pande, MPI, pers. comm.). The mortality event in December 2014 was after two days of stormy weather with strong easterly winds (K. Berkenbusch pers. obs.). It is possible that adverse weather conditions caused or contributed to the observed pipi deaths at this site.

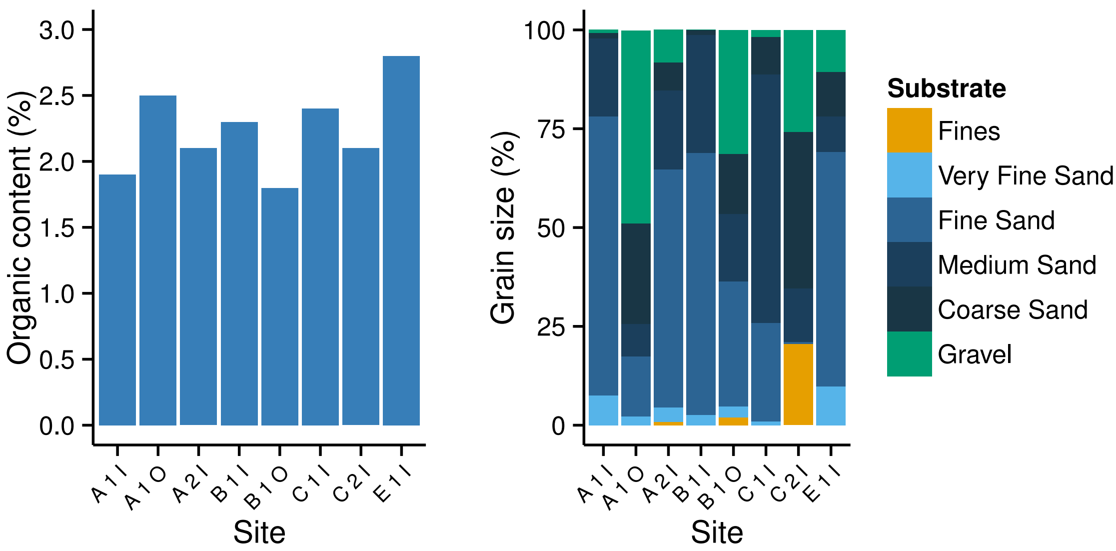


Figure 45: Sediment sample locations and characteristics at Te Haumi Beach. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.28 Cockles at Te Haumi Beach

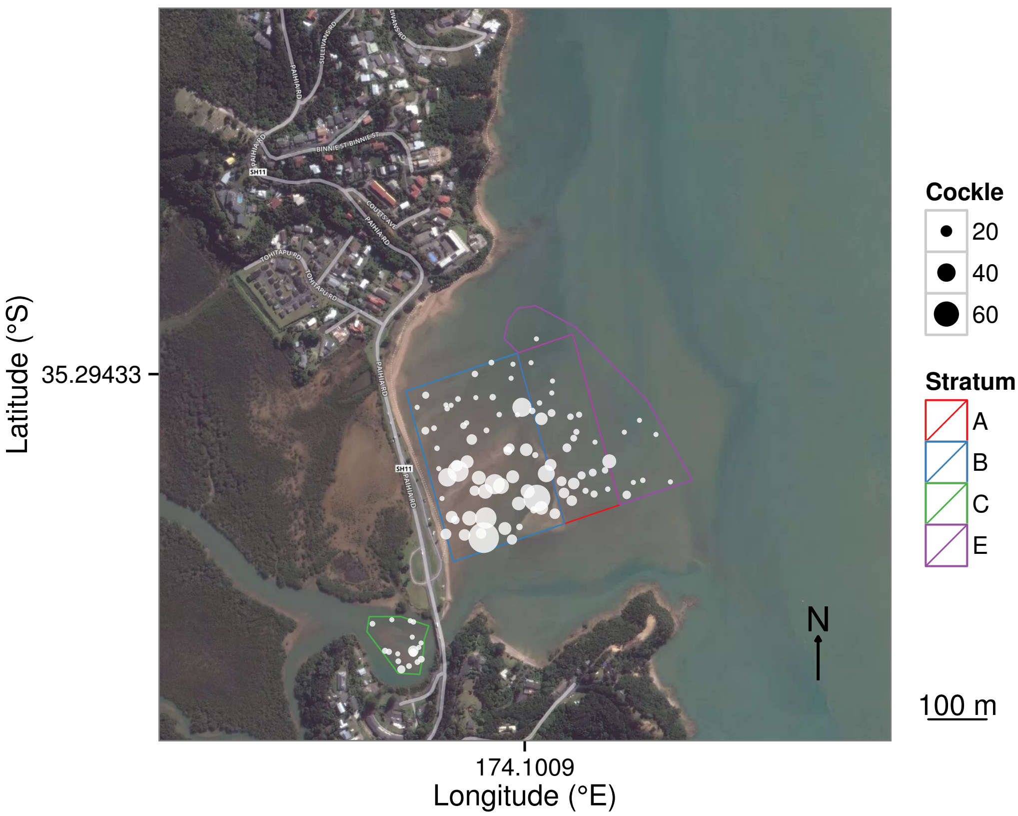


Figure 46: Map of sample strata and individual sample locations for cockles at Te Haumi Beach, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 52: Estimates of cockle abundance at Te Haumi Beach, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	3.0	29	196	5.78	193	19.77
B	6.0	60	978	27.90	466	13.48
C	0.7	36	72	0.41	57	30.86
E	3.1	32	46	1.26	41	62.23

Table 53: Estimates of cockle abundance at Te Haumi Beach for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.0	34.73	347	7.95	8.36	84	8.86
2000–01	9.9	17.06	172	11.00	4.11	41	10.27
2001–02	9.9	24.67	249	9.92	1.75	18	11.52
2002–03	9.9	41.77	422	7.97	2.16	31	13.99
2006–07	9.8	15.73	160	12.87	1.98	20	14.53
2009–10	12.1	34.99	290	9.66	2.13	18	26.58
2009–10*	9.8	30.55	312	9.08	0.91	9	37.37
2012–13	12.1	44.67	370	12.28	3.27	27	40.71
2012–13*	9.8	41.88	427	12.72	1.99	20	17.66
2014–15	12.8	35.36	277	11.35	3.42	27	19.75
2014–15*	9.7	34.10	351	11.54	3.28	34	20.29

Table 54: Summary statistics of the length-frequency (LF) distribution of cockles at Te Haumi Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	19.09	20	5–48	35.82	8.21
2012–13	18.74	15	5–42	37.95	7.33
2014–15	20.45	18	6–38	21.40	9.67

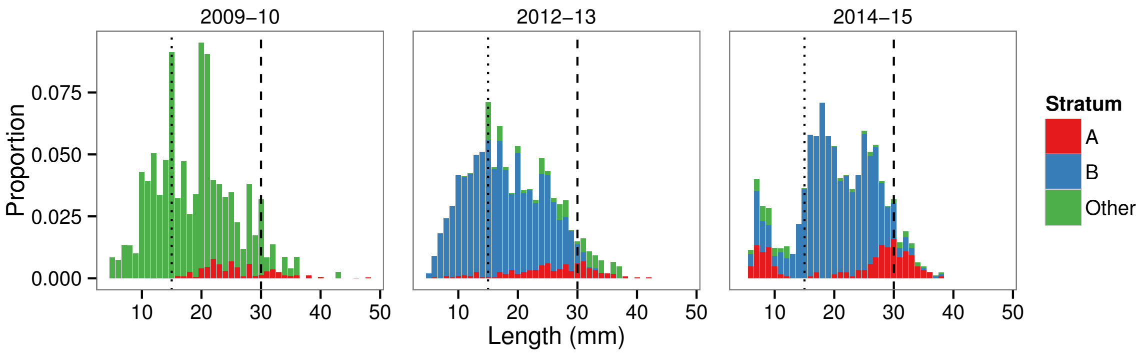


Figure 47: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Te Haumi Beach. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.29 Pipi at Te Haumi Beach

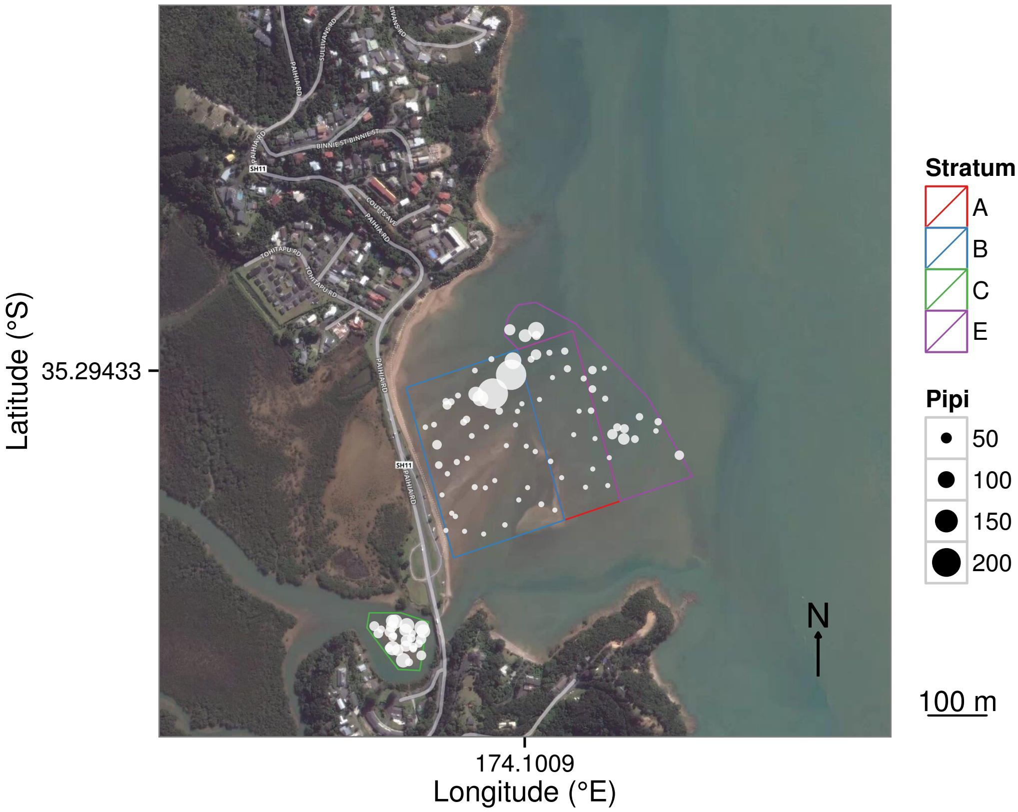


Figure 48: Map of sample strata and individual sample locations for pipi at Te Haumi Beach, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 55: Estimates of pipi abundance at Te Haumi Beach, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	3.0	29	146	4.31	144	37.00
B	6.0	60	995	28.39	474	33.08
C	0.7	36	1 290	7.32	1 024	13.10
E	3.1	32	579	15.90	517	23.50

Table 56: Estimates of pipi abundance at Te Haumi Beach for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	10.0	41.70	417	10.97	7.29	73	17.30
2000–01	9.9	62.33	630	9.35	12.17	123	11.94
2001–02	9.9	16.73	169	13.44	1.85	19	16.64
2002–03	9.9	34.04	344	11.17	2.39	24	24.56
2006–07	9.8	31.84	325	13.07	1.14	12	18.85
2009–10	12.1	43.93	364	12.64	0.20	2	33.60
2009–10*	9.8	43.93	448	12.64	0.20	2	33.60
2012–13	12.1	76.45	634	20.73	0.71	6	74.98
2012–13*	9.8	66.81	681	19.18	0.29	3	37.71
2014–15	12.8	55.91	438	18.38	1.16	9	47.92
2014–15*	9.7	40.02	412	23.92	0.25	3	21.02

Table 57: Summary statistics of the length-frequency (LF) distribution of pipi at Te Haumi Beach. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2009–10	21.39	20	1–60	59.94	0.50
2012–13	22.19	20	6–54	54.30	0.93
2014–15	28.22	19	8–58	36.92	2.07

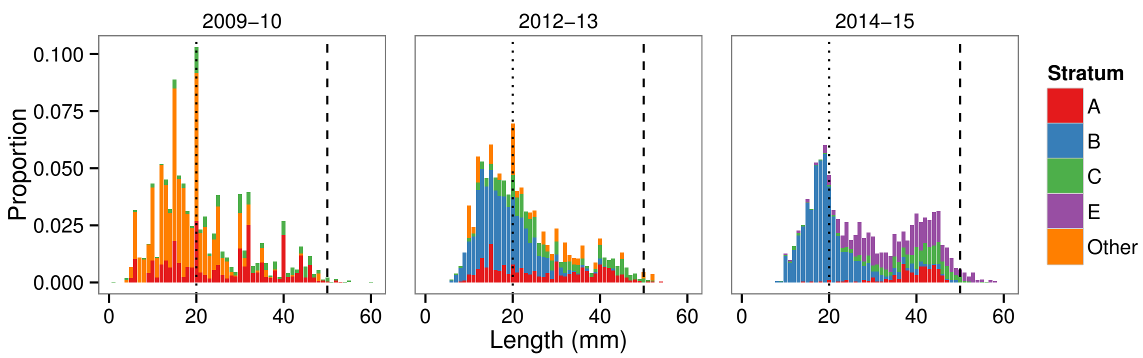


Figure 49: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Te Haumi Beach. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.30 Whangamata Harbour

Whangamata Harbour is in the Waikato region, on the east coast of Coromandel Peninsula. Bivalves in this harbour have been regularly surveyed since 1999–2000, with eight surveys preceding the current assessment (see Appendix A, Tables A-1, A-2). Throughout the survey series, the sampling extent has been relatively consistent, involving two areas on either side of the channel from Moanaanuanu Estuary that flows into the main harbour. In these two areas, there have generally been four strata delineated for the bivalve sampling, with minor changes to the strata throughout the survey series. In the current survey, the four strata sampled included strata AN and AS that were separated by an elevated sandbank but both in the main channel (Figure 50). Stratum C was higher up the shore in the same area, whereas stratum B was on the intertidal sandflat on the other side of the side channel, directly adjacent to the main channel. There were 203 sampling points across these strata in 2014–15, including 71 points allocated to phase-2 sampling (Table 58).

Sediment at Whangamata Harbour was characterised by a low organic content that ranged between 2.0 and 3.1% (Figure 50, and see details in Appendix B, Table B-3). The proportion of fines (<63 µm grain size) was also low, with a maximum of 3.1% of sediment in this grain size fraction, and several samples without any fines. The bulk of the sediment was fine (>125 µm grain size) and medium (>250 µm grain size) sands, with a small proportion of coarser sediment in most samples.

Cockles were predominantly in the intertidal area of stratum B, and in stratum C (Figure 51, Table 58). There was also a small concentration of cockles at the northwestern end of stratum AS, with only two cockles sampled in the neighbouring stratum AN. The estimated total abundance of cockles at this site was 104.53 million (CV: 6.59%) individuals, reflecting an increase from the previous survey estimate of 84.83 million (CV: 7.06%) cockles in 2010–11 (Table 59). The estimated population density of 1372 cockles per m^2 in 2014–15 was slightly lower than the preceding density estimate of 1441 cockles per m^2 in 2010–11.

For large cockles (≥30 mm shell length), the current population estimate was 2.73 million (CV: 19.83%) individuals, and their mean density was 36 cockles per m^2. The small number of large cockles was reflected in their small contribution to the total population, with only 2.61% of individuals in this size class. Although this proportion was a small increase from the previous survey, the proportion of large cockles has consistently been low in the Whangamata Harbour population (Table 60, Figure 52). In contrast, recruits (≤15 mm shell length) made up a a more substantial part of the population, particularly in the two preceding surveys when this size class represented over 35% of individuals. In 2014–15, the proportion of recruits dropped to 21.27%.

The prevalence of recruits and small-sized cockles was evident in the mean and modal sizes of the population. Both size parameters remained similar across recent surveys, and the population consisted of a single cohort with a modal size of 20 mm shell length. The mean size was slightly smaller, and was 19.92 mm shell length in 2014–15.

The pipi population in Whangamata Harbour was largely concentrated in stratum AN, where pipi occurred at high densities throughout the stratum (Figure 53, Table 61). In addition, the channel area of stratum B also contained a number of pipi, whereas only single individuals were distributed throughout strata AS and C. The population estimate for 2014–15 was 3.79 million (CV: 19.69%) pipi at this site, with at a mean density of 50 pipi per m^2 (Table 62). These estimates were a decrease from the total population size and density in 2010–11 of 5.56 million (CV: 15.02%) pipi and 94 individuals per m^2, respectively.

The estimated population size of large pipi (≥50 mm shell length) was 1.53 million (CV: 75.18%) individuals in the current study, and their corresponding mean density was 20 large pipi per m^2. In view of the total population, large-size pipi represented a substantial proportion of individuals, with 40.59% of the total population in this size class (Table 63, Figure 54). Although both large pipi and recruits (≤20 mm shell length) each constituted about a third of the total population in 2010–11, the increase in the proportion of large pipi in the current assessment was accompanied by a decrease in the proportion of recruits to 10.71% in 2014–15.

The large proportion of large-size pipi within the current population was consistent with findings from the preceding assessments in 2006–07 and 2010–11. As a consequence, both the mean and modal sizes of the pipi population at Whangamata Harbour were consistently large in recent years. In 2014–15, the mean shell length was 41.81 mm, with a slightly larger mode of 51 mm shell length.

The length-frequency distributions confirmed the influence of large pipi on the total population, with a strong cohort around this size class, and a smaller, second cohort of small-sized individuals in 2010–11 and 2014–15. The majority of large pipi in the latter survey were in stratum B, with a range of pipi sizes, including small individuals in stratum AN.

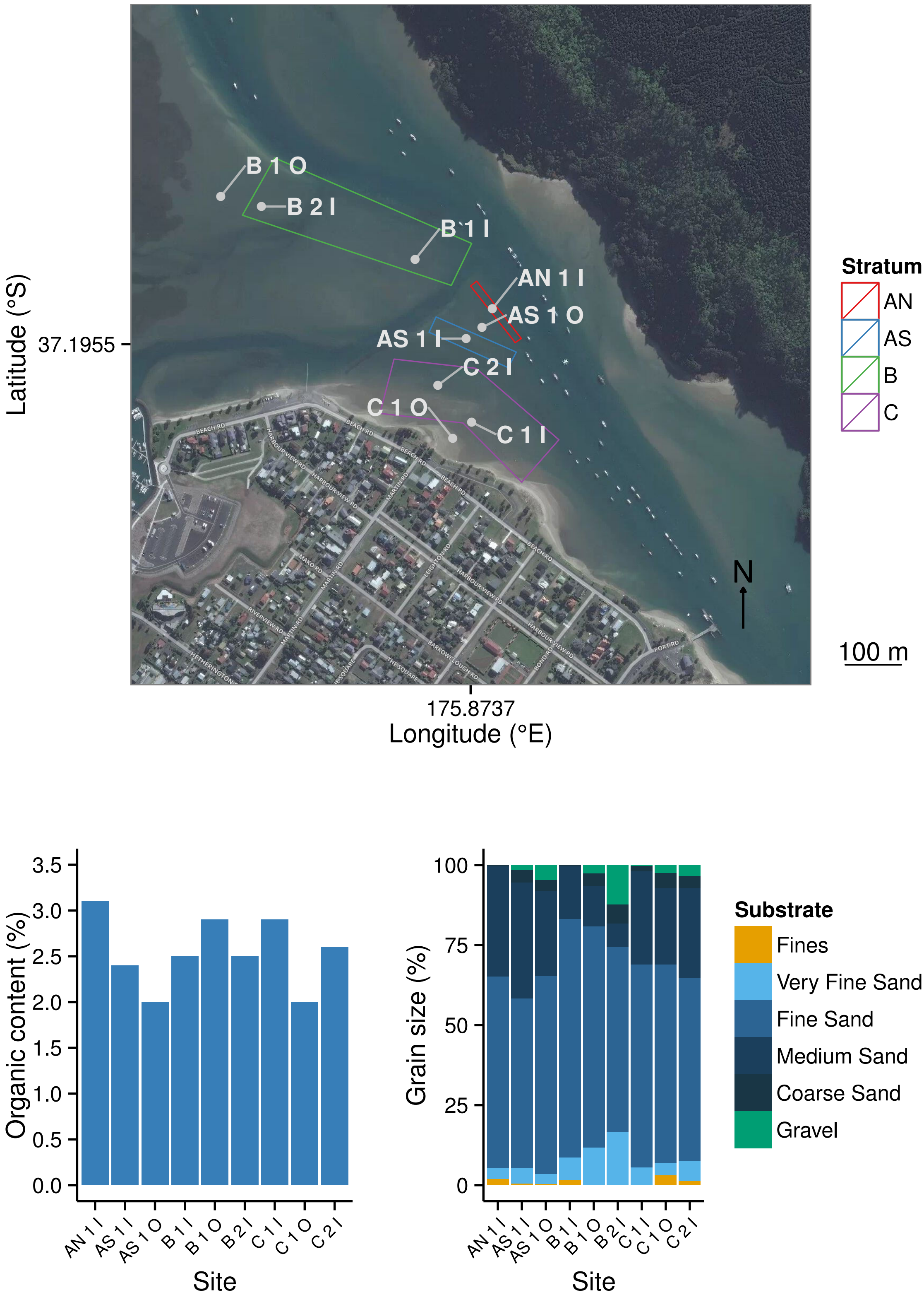


Figure 50: Sediment sample locations and characteristics at Whangamata Harbour. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.31 Cockles at Whangamata Harbour

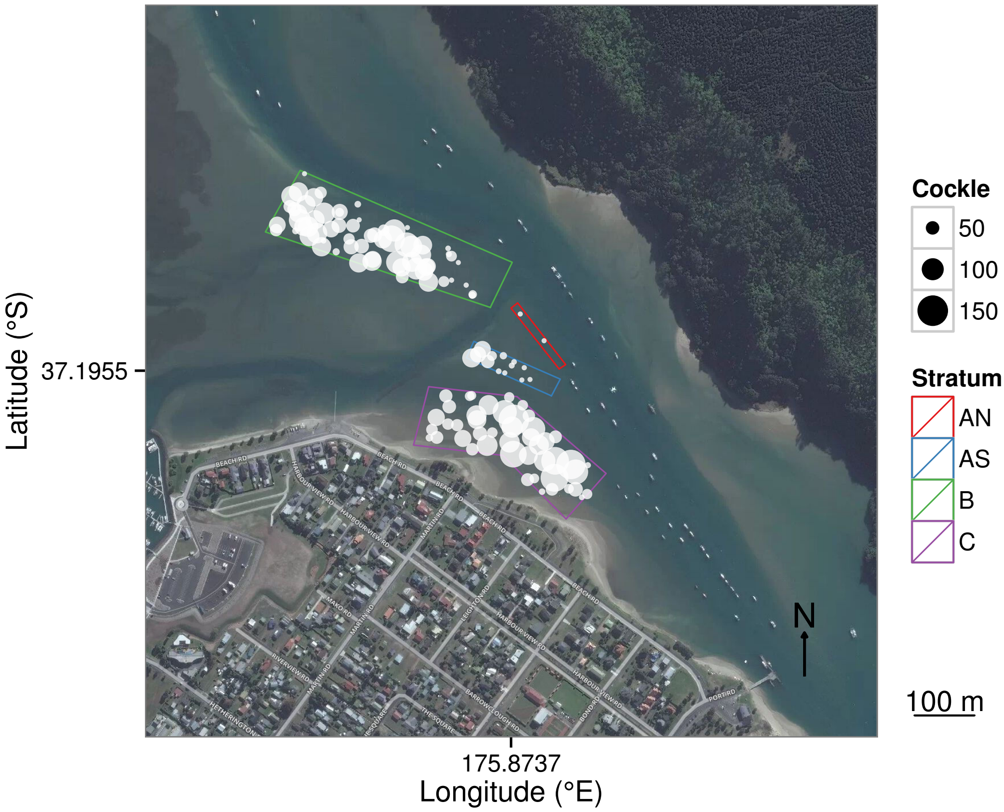


Figure 51: Map of sample strata and individual sample locations for cockles at Whangamata Harbour, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 58: Estimates of cockle abundance at Whangamata Harbour, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
AN	0.2	45	2	0.00	1	69.90
AS	0.5	20	331	2.26	473	36.67
B	3.9	91	3 763	45.75	1 181	10.01
C	3.1	47	3 003	56.51	1 826	8.99

Table 59: Estimates of cockle abundance at Whangamata Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	70.55	1 287	4.31	17.14	313	6.65
2000–01	5.5	60.33	1 101	4.29	13.95	255	7.60
2001–02	5.5	38.80	708	4.08	6.87	125	7.24
2002–03	5.5	29.78	543	6.61	8.03	146	9.27
2003–04	5.5	43.47	793	4.18	13.10	239	5.18
2004–05	5.5	38.85	709	4.64	9.94	181	4.62
2006–07	24.6	348.01	1 414	0.71	2.86	52	12.99
2006–07*	5.7	32.57	570	7.55	2.86	52	12.99
2010–11	5.9	84.83	1 441	7.06	1.38	23	18.66
2014–15	7.6	104.53	1 372	6.59	2.73	36	19.83

Table 60: Summary statistics of the length-frequency (LF) distribution of cockles at Whangamata Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤15 mm and large individuals by a shell length of ≥30 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	19.06	20	3–45	36.12	8.79
2010–11	17.50	20	4–40	35.92	1.62
2014–15	19.92	20	5–35	21.27	2.61

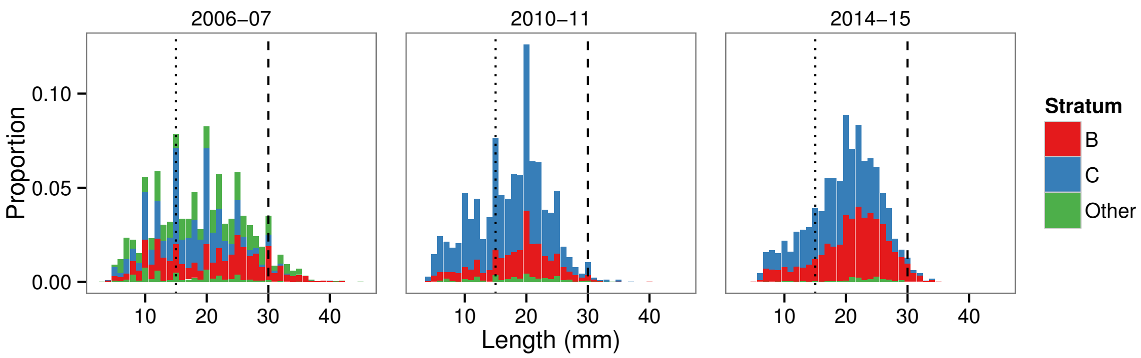


Figure 52: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangamata Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.32 Pipi at Whangamata Harbour

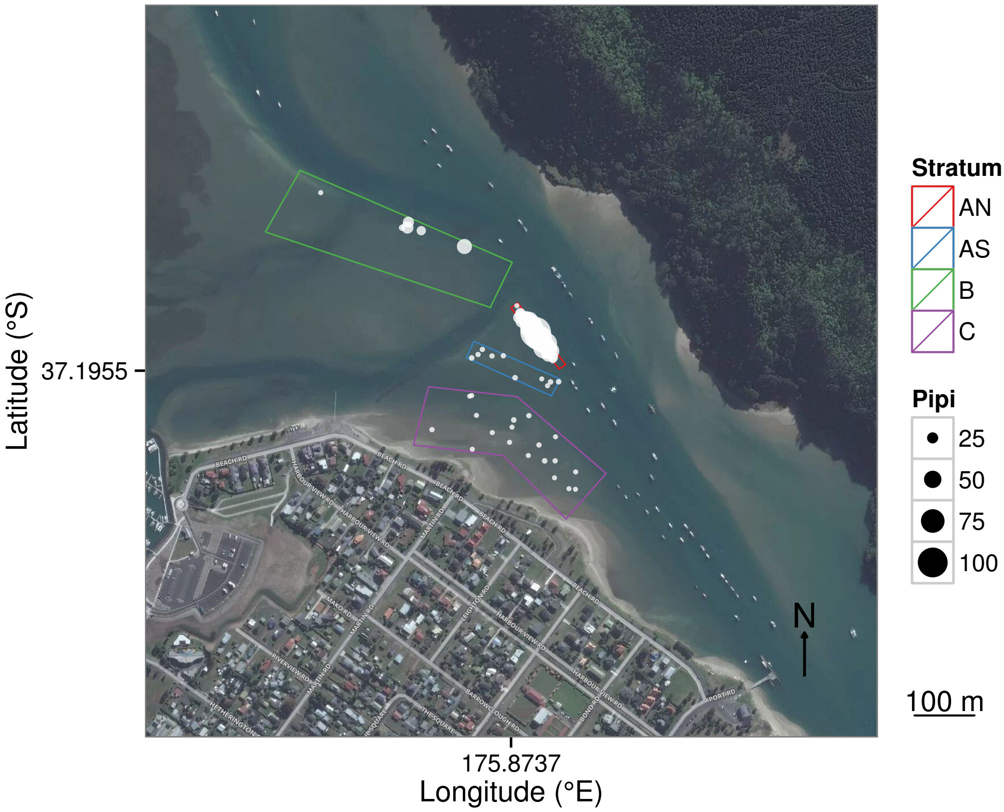


Figure 53: Map of sample strata and individual sample locations for pipi at Whangamata Harbour, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 61: Estimates of pipi abundance at Whangamata Harbour, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
AN	0.2	45	1 511	1.67	959	12.52
AS	0.5	20	22	0.15	31	25.46
B	3.9	91	120	1.46	38	48.50
C	3.1	47	27	0.51	16	21.01

Table 62: Estimates of pipi abundance at Whangamata Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	5.5	15.07	275	9.25	7.25	132	10.78
2000–01	5.5	11.86	216	11.17	5.05	92	21.86
2001–02	5.5	6.38	116	10.45	2.71	50	19.77
2002–03	5.5	5.95	109	10.95	1.60	29	10.55
2003–04	5.5	4.84	88	7.82	2.03	37	9.50
2004–05	5.5	2.30	42	11.13	1.26	23	12.05
2006–07	24.6	3.26	13	7.50	1.49	26	15.43
2006–07*	5.7	3.26	57	7.50	1.49	26	15.43
2010–11	5.9	5.56	94	15.02	1.62	27	39.20
2014–15	7.6	3.79	50	19.69	1.53	20	75.18

Table 63: Summary statistics of the length-frequency (LF) distribution of pipi at Whangamata Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2006–07	43.84	60	4–76	12.26	45.57
2010–11	35.00	52	5–73	31.67	29.97
2014–15	41.81	51	9–62	10.71	40.59

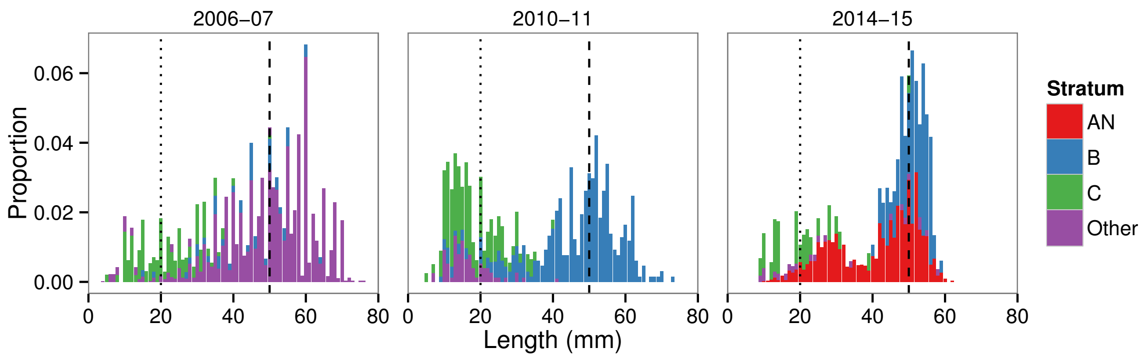


Figure 54: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangamata Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.33 Whangapoua Harbour

Whangapoua Harbour is a large inlet on the east coast of Coromandel Peninsula. This site was first included in the bivalve surveys in 2002–03, with five assessments preceding the current survey, most recently in 2010–11 (see Appendix A, Tables A-1, A-2). The current survey used the same sampling design as previous assessments, with the addition of another stratum that targeted pipi. The sampling extent was spread across two areas, east and west of the main channel and harbour entrance (Figure 55).

Strata A and B were on the intertidal sandflat at Matarangi, on the eastern side of the main channel. On the western side of the channel, Strata C to E were associated with the side channel that . Strata C and D were sampled in previous assessments, predominantly targeting cockles and pipi, respectively. The current study added an additional area, stratum E, to the sampling extent, to account for the movement of the tidal channel and the pipi bed at the eastern point of stratum D. Both strata D and E were in a high-flow area that was dominated by tidal movement. Across the entire sampling extent, bivalves were surveyed in a total of 241 sampling points, including 195 sampling points in phase 1, and 46 sampling points in phase 2 (Table 64).

Sediment samples were collected in all strata and in adjacent areas (Figure 55, and see details in Appendix B, Table B-3). The sediment had a low percentage of organic matter that was between 0.5 and 2.3%. The dominant sediment grain size fraction was fine sand (>125 µm grain size), followed by medium sand (>250 µm grain size). About half of the samples did not contain any fines (<63 µm grain size), and the proportion of fines in the remaining samples was small, with a maximum of 2.9%.

Cockles were distributed throughout all strata, and were abundant in strata A to C (Figure 56, Table 64). The highest cockle abundance and density were in stratum C, followed by stratum A on the other side of the main channel. There were few cockles in stratum E. The total population estimate for cockles was 33.67 million (CV: 9.54%) individuals in this survey, and the corresponding mean density was 533 cockles per m^2 (Table 65).

While the sampling extent was slightly larger in 2014–15, the current population size was similar to estimates in other recent surveys, but the mean cockle density was lower. For example, in 2010–11, cockle abundance was estimated at 32.06 million (CV: 9.71%) cockles, and their population density was 617 cockles per m^2. Most notably, the population of large cockles ($\geq$30 mm shell length) underwent a marked decrease, in particularly in their density, which declined from 54 large cockles per m^2 in the preceding survey to 23 large individuals per m^2 in 2014–15.

The decrease in the population of large cockles resulted in a smaller proportion of this size class in the total population in 2014–15 (Table 66, Figure 57). Large cockles made up 4.25% of the total population in the current assessment compared with 8.82% in 2010–11 and character(0)% in 2003–04. As the proportion of recruits ($\leq$15 mm shell length) also decreased to 10.55%, the mean size of cockles remained similar to that in the preceding survey at 21.83 mm shell length. At the same time, the modal size increased to 25 mm shell length from the 20-mm mode in 2010–11. The unimodal cockle population in 2014–15 consisted of a cohort of small- to medium-sized individuals around this shell length, with a smaller range of sizes in the population than in previous surveys.

The distribution of pipi in 2014–15 was considerably more restricted than that of cockles in Whangapoua Harbour (Figure 58, Table 67). The former species was only present in the western strata, and only showed a high abundance in stratum E. This stratum contained a highly abundant pipi bed, with a population density of 558 individuals per per m^2 (CV: 20.65). Stratum E was added during the reconnaissance of this site as few pipi were observed in the previous pipi stratum D in the same area; at the same time, the channel appeared to have shifted since the preceding survey in 2010–11, making it likely that the pipi bed had also moved to remain in a high-flow area.

Owing to the absence or very low abundance of pipi in other strata, stratum E supported almost the entire pipi population across the sampling extent. The current abundance estimate of 2.27 million (CV: 20.24%) individuals was only slightly higher than the estimate for this stratum, and the total population density was relatively low at 36 pipi per m^2 (Table 68). Included in the population were an estimated 0.34 million (CV: 22.32%) large pipi ($\geq$50 mm shell length) that occurred at a mean density of 18 individuals per m^2.

Compared with previous surveys, the recent assessment revealed the lowest estimates for both the total and the large pipi populations, especially in view of the slightly larger sampling extent. Although population estimates were also low in the preceding survey, the current study confirmed a continued decrease in the abundance and density of pipi. This decline was particularly evident for large pipi, and also documented in the smaller proportion of large individuals in the current study: in 2014–15, 14.90% of the total population consisted of large individuals, compared with 43.14% in 2010–11 and 50.23% in 2004–05 (Table 69, Figure 59).

Although recruits ($\leq$20 mm shell length) only made up a small proportion of the pipi population at Whangapoua Harbour, this size class showed an increase from 0.30% in 2004–05 to 10.78% in the present survey. The changes in the abundance of recruits and large pipi resulted in a smaller mean size of 38.42 mm shell length compared with 48.56 mm shell length in 2004–05; however, the modal size of 47 mm shell length in 2014–15 was similar to that in 2004–05. Nevertheless, the size-frequency distributions differed across surveys, including a unimodal population with a strong, single cohort in 2004–05, compared with a wider range of sizes in subsequent surveys with less discernible cohorts.

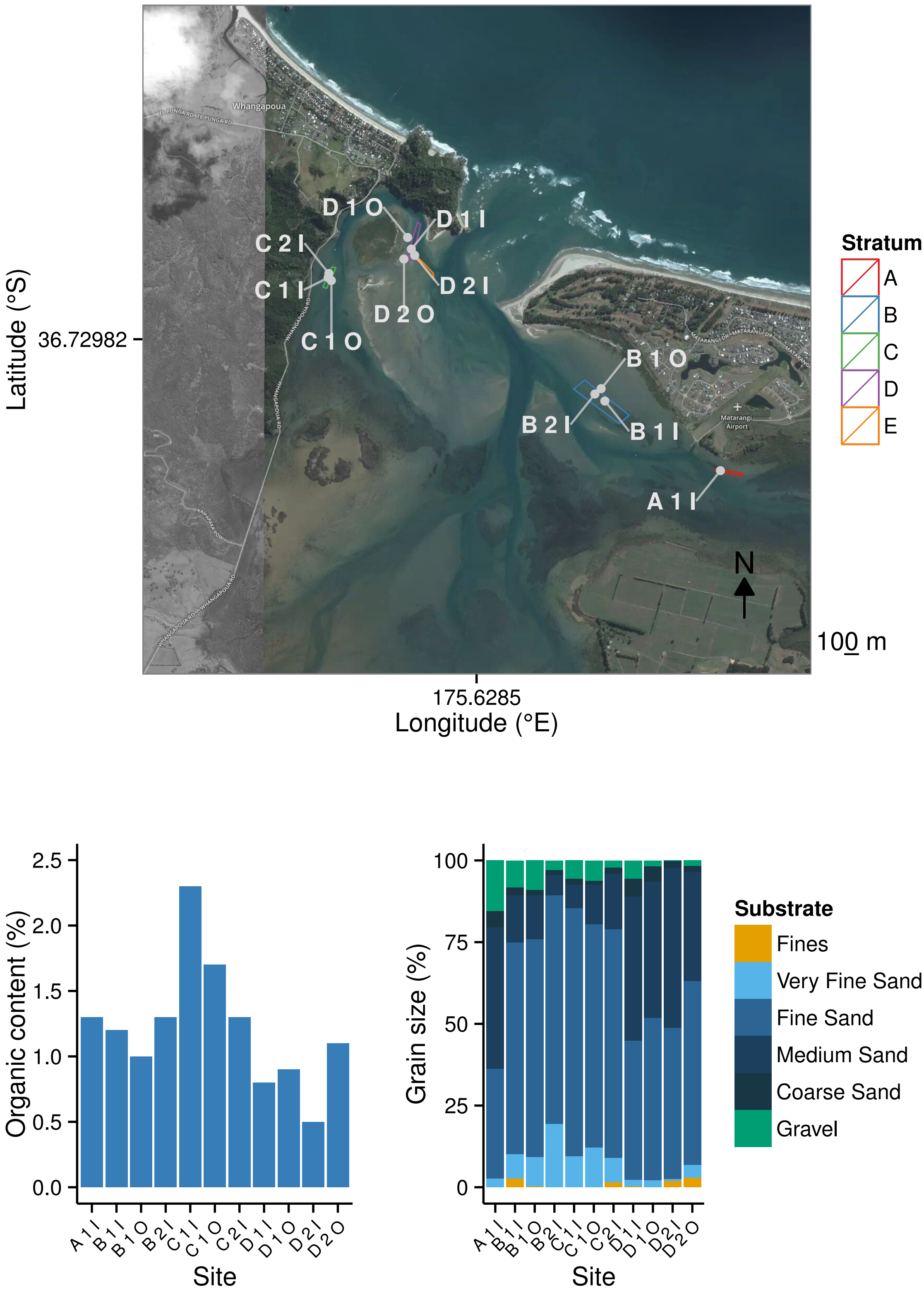


Figure 55: Sediment sample locations and characteristics at Whangapoua Harbour. Sample labels include a letter corresponding with the stratum, the sample number, and its location in- (I) and outside (O) of strata. Graphs show sediment organic content (% dry weight) and grain size fractions (% of total). Sediment grain size fractions include fines (silt and clay; <63 µm), sands (very fine, >63 µm; fine, >125 µm; medium, >250 µm; coarse, >500 µm), and gravel (>2000 µm) (see details in Table B-3).

3.34 Cockles at Whangapoua Harbour

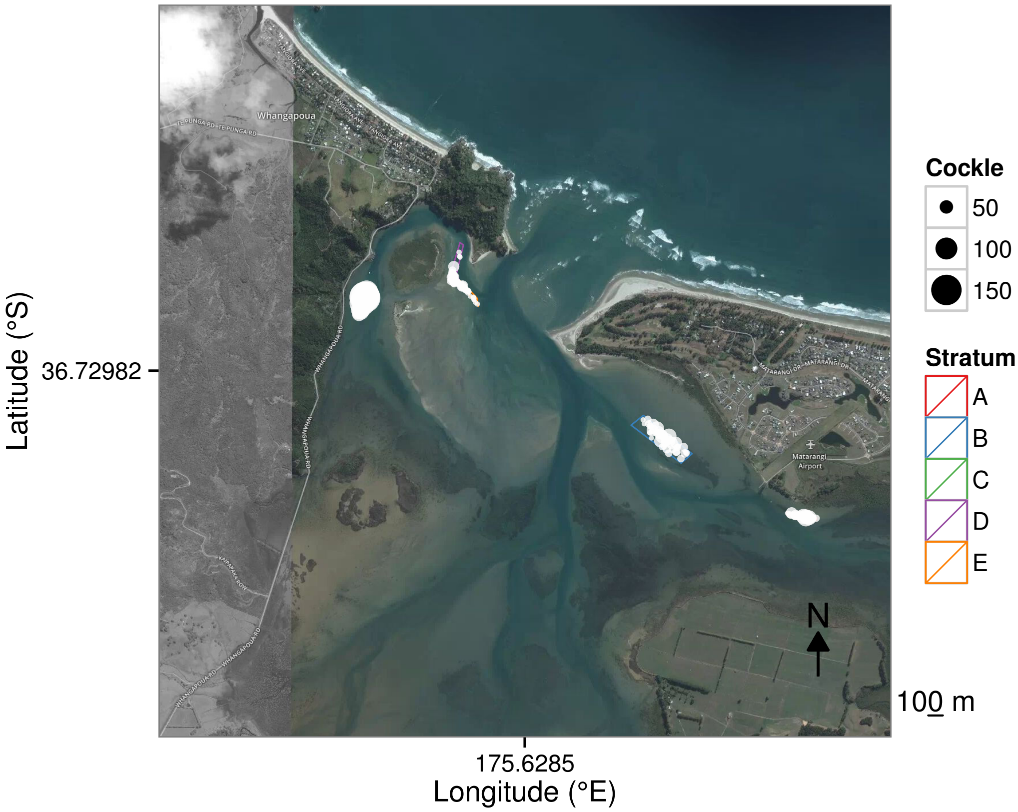


Figure 56: Map of sample strata and individual sample locations for cockles at Whangapoua Harbour, with the size of the circles proportional to the number of cockles found at each location. Only samples with positive counts are shown.

Table 64: Estimates of cockle abundance at Whangapoua Harbour, by stratum, for 2014–15. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	19	545	2.78	820	15.89
B	4.1	44	797	21.13	518	14.38
C	0.5	40	2 288	7.83	1 634	11.14
D	1.0	53	311	1.71	168	21.60
E	0.4	85	170	0.23	57	32.19

Table 65: 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). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

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	133	8.45
2004–05	5.2	33.19	638	4.07	5.18	100	9.22
2010–11	5.2	32.06	617	9.71	2.83	54	18.88
2014–15	6.3	33.67	533	9.54	1.43	23	15.18
2014–15*	5.9	33.44	565	9.61	1.36	23	15.72

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

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	25.17	25	4–45	4.34	16.47
2010–11	20.76	20	2–45	20.74	8.82
2014–15	21.83	25	6–40	10.55	4.25

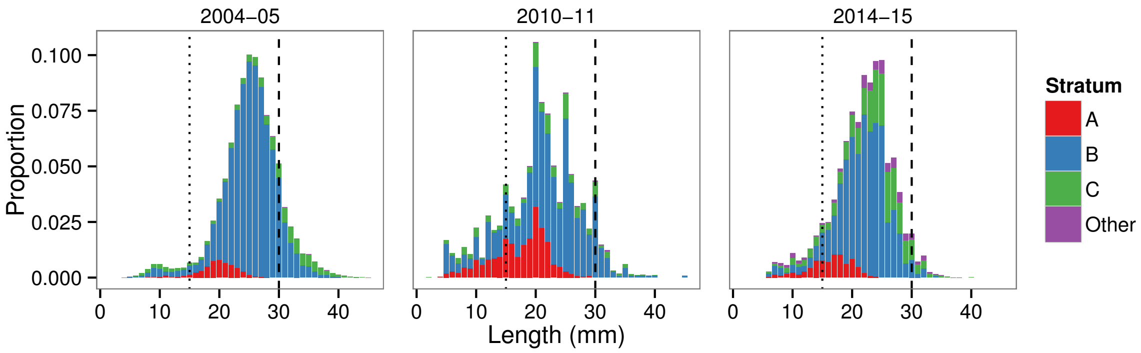


Figure 57: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangapoua Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

3.35 Pipi at Whangapoua Harbour

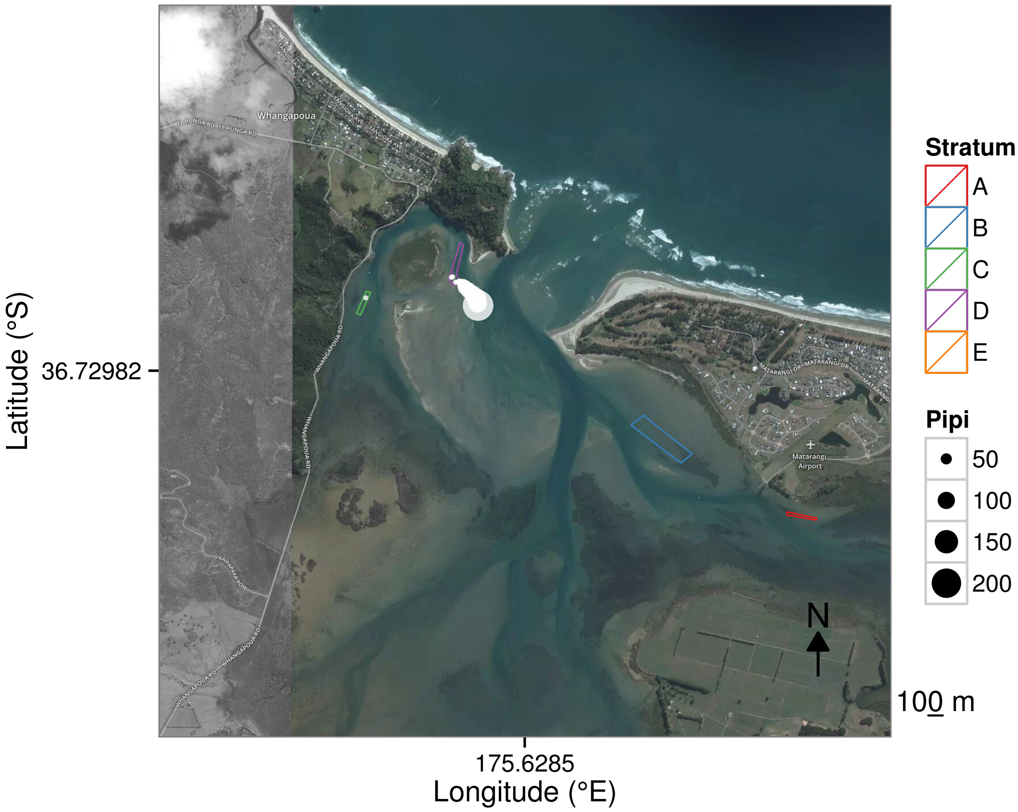


Figure 58: Map of sample strata and individual sample locations for pipi at Whangapoua Harbour, with the size of the circles proportional to the number of pipi found at each location. Only samples with positive counts are shown.

Table 67: Estimates of pipi abundance at Whangapoua Harbour, by stratum, for 2014–15. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.3	19	0	0.00	0	
B	4.1	44	0	0.00	0	
C	0.5	40	1	0.00	<1	>100
D	1.0	53	8	0.04	4	48.54
E	0.4	85	1 659	2.23	558	20.65

Table 68: 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). Asterisk indicates estimates based on the approximate sampling extent used in previous surveys.

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	1.7	5.62	338	10.16	1.73	432	8.28
2003–04	5.2	5.05	97	9.98	1.75	218	7.9
2004–05	5.2	7.47	144	5.25	3.75	469	5.08
2010–11	5.2	2.74	53	18.82	1.18	98	22.54
2014–15	6.3	2.27	36	20.24	0.34	18	22.32
2014–15*	5.9	0.05	<1	45.60	0.01	<1	>100

Table 69: Summary statistics of the length-frequency (LF) distribution of pipi at Whangapoua Harbour. LF distributions (in mm) were estimated for all strata in each survey and subsequently summed to give the distribution of total LFs. Recruits were defined by a shell length of ≤20 mm and large individuals by a shell length of ≥50 mm.

Year	Mean	Mode	Range	Recruits (%)	Large size (%)
2004–05	48.56	50	15–73	0.30	50.23
2010–11	45.60	40	11–72	4.13	43.14
2014–15	38.42	47	9–60	10.78	14.90

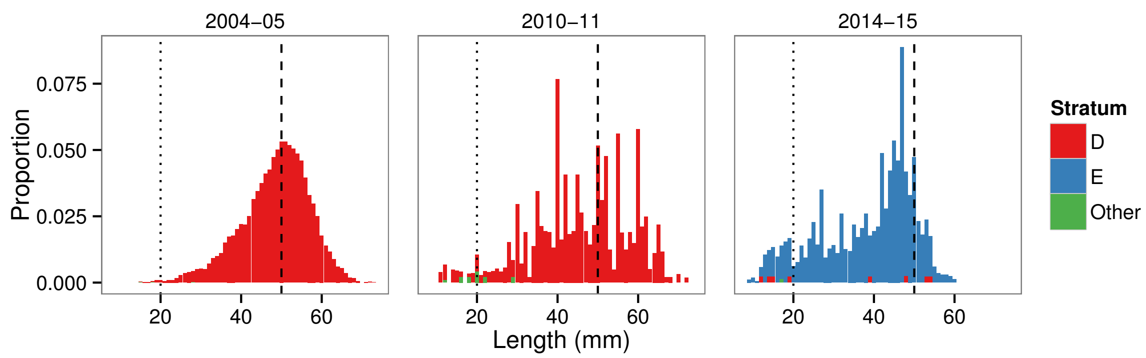


Figure 59: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangapoua Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively.

4. SUMMARIES

4.1 Cockle populations

There were cockle populations at all sites included in the 2014–15 survey, and their population sizes ranged from 16.66 million (CV: 9.56%) cockles at Mill Bay to the largest population of 109.56 million (CV: 4.95%) individuals at Raglan Harbour (Table 70). Cockle populations were also relatively large at Whangamata Harbour and Ngunguru Estuary, with an estimated 104.53 million (CV: 6.59%) and 92.67 million (CV: 7.53%) cockles, respectively. All of the population estimates had a CV of less than 20%; at the majority of sites, it was less than 10%.

Although differences in survey area and habitat characteristics prevent direct comparisons across sites, density estimates provide some comparative measure of cockle populations that are potentially targeted in non-commercial fishing activities. There were three sites with high cockle densities (i.e., more than 1000 individuals per m^2), including Ngunguru Estuary, Raglan Harbour, and Whangamata Harbour. Density estimates at these sites were similar, ranging from 1372 cockles per m^2 (Whangamata Harbour) to 1696 cockles per m^2 (Ngunguru Estuary). Cockle densities at the remaining sites were considerably lower, with the next highest estimate of 675 cockles per m^2 (CV: 8.77%) at Ruakaka Estuary. The lowest population density was 68 cockles per m^2 (CV: 16.59%) at Eastern Beach. Although Mill Bay had the lowest cockle abundance of all sites, the corresponding population density was relatively high with an estimated 342 cockles per m^2 at this site.

Most cockle populations only included a comparatively small number of large individuals ($\geq$30 mm shell length), although there was some variation in their population sizes. The highest abundance of cockles in this size class was at Kawakawa Bay (West), followed by Eastern Beach, with 19.80 million (CV: 15.8%) and 12.84 million (CV: 26.54%) large cockles within the total population, respectively. At both sites, the relatively high abundance of large cockles in relation to the total population meant that this size class made up a significant part of the population. In contrast, all other sites were characterised by small populations of large cockles (i.e., less than 3.5 million individuals), and the lowest abundance of this size class was at Mill Bay, where there were 0.07 million (CV: 42.43%) large individuals.

Corresponding with their small population sizes, population densities of large cockles were also consistently low across sites. Maximum population densities of this size class were 31 to 36 individuals per m^2 at four sites, including (in ascending order) Eastern Beach, Kawakawa Bay (West), Raglan Harbour, and Whangamata Harbour. At five sites, large individuals were particularly scarce and only occurred at low densities (i.e., less than eight individuals per m^2), including the lowest density estimates at Otumoetai (Tauranga Harbour) (<1 large cockle per m^2; CV: >100%) and Mill Bay (1 large cockle per m^2; CV: 42.43%). These data highlighted that small- and medium-size individuals dominated the cockle populations across the 2014–15 survey sites.

Time-series comparisons of density estimates within individual strata showed that the distribution of cockle densities within strata in the 2014–15 assessment was similar to that in the two preceding surveys (Figure 60) Throughout the survey series, most surveys revealed a unimodal frequency distribution of strata with cockle densities of less than 1000 individuals per m^2. In early surveys, the frequency distributions were skewed towards strata with lower population densities (e.g., less than 500 individuals per m^2). In contrast, the three most recent surveys also included a notable proportion of strata that contained higher cockle densities, with similar maximum density estimates in these recent surveys.

This finding was in part explained by the prevalence of small- and medium-size cockles that occurred at relatively high densities compared with large individuals. Across the different surveys, the study sites were generally characterised by unimodal length-frequency distributions (Figure 61). Throughout the series, cockle populations were dominated by small- and medium-size individuals, with a shift towards smaller sizes in recent surveys. While earlier surveys showed that the populations also included a number large cockles that exceeded 30 mm shell length, recent assessments documented notably fewer individuals in this size class, with the number of large cockles diminishing since 2005–06. Even though there was a strong cohort of medium-sized cockles in each survey, these individuals did not contribute to the large cockle size class in subsequent assessments, leading to their general scarcity in recent surveys.

The decrease in the density of large cockles was evident at several sites in the time-series comparison (Figure 62). Although the density estimates were already comparatively low for most populations (i.e., less than 20 large individuals per m^2), there was a recent decline in this community measure at six sites sampled in 2014–15, including Aotea Harbour, Mangawhai Harbour, Mill Bay, Otumoetai (Tauranga Harbour), Raglan Harbour, and Whangapoua Harbour. For Mangawhai Harbour, Mill Bay, and Whangapoua Harbour, the decline in the density of large cockles in 2014–15 continued a decreasing trend. At three sites, Eastern Beach, Ruakaka Estuary, and Ngunguru Estuary, there was an increase in the density of large cockles, although this increase was only noteworthy at Eastern Beach (which is permanently closed to the collection of all shellfish). At the other two sites, cockle densities remained low in spite of the recent increase, with 2 and 8 cockles per m^2 at Ruakaka Estuary and Ngunguru Estuary, respectively. At Kawakawa Bay (West), Te Haumi Beach, and Whangamata Harbour, the densities of large cockles were similar to the preceding assessment, and showed little change.

Table 70: Estimates of cockle abundance for all sites where more than ten cockles were found in the 2014–15 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	74.20	381	13.37	0.55	3	45.13
Eastern Beach	28.16	68	16.59	12.84	31	26.54
Kawakawa Bay	74.44	122	9.69	19.80	33	15.8
Mangawhai Harbour	52.73	617	7.58	2.05	24	15.95
Mill Bay	16.66	342	9.56	0.07	1	42.43
Ngunguru Estuary	92.67	1 696	7.53	0.38	8	32.11
Otumoetai	37.28	486	7.20	0.02	<1	>100
Raglan Harbour	109.56	1 513	4.95	2.44	34	15.2
Ruakaka Estuary	43.97	675	8.77	0.15	2	35.4
Te Haumi Beach	35.36	277	11.35	3.42	27	19.75
Whangamata Harbour	104.53	1 372	6.59	2.73	36	19.83
Whangapoua Harbour	33.67	533	9.54	1.43	23	15.18

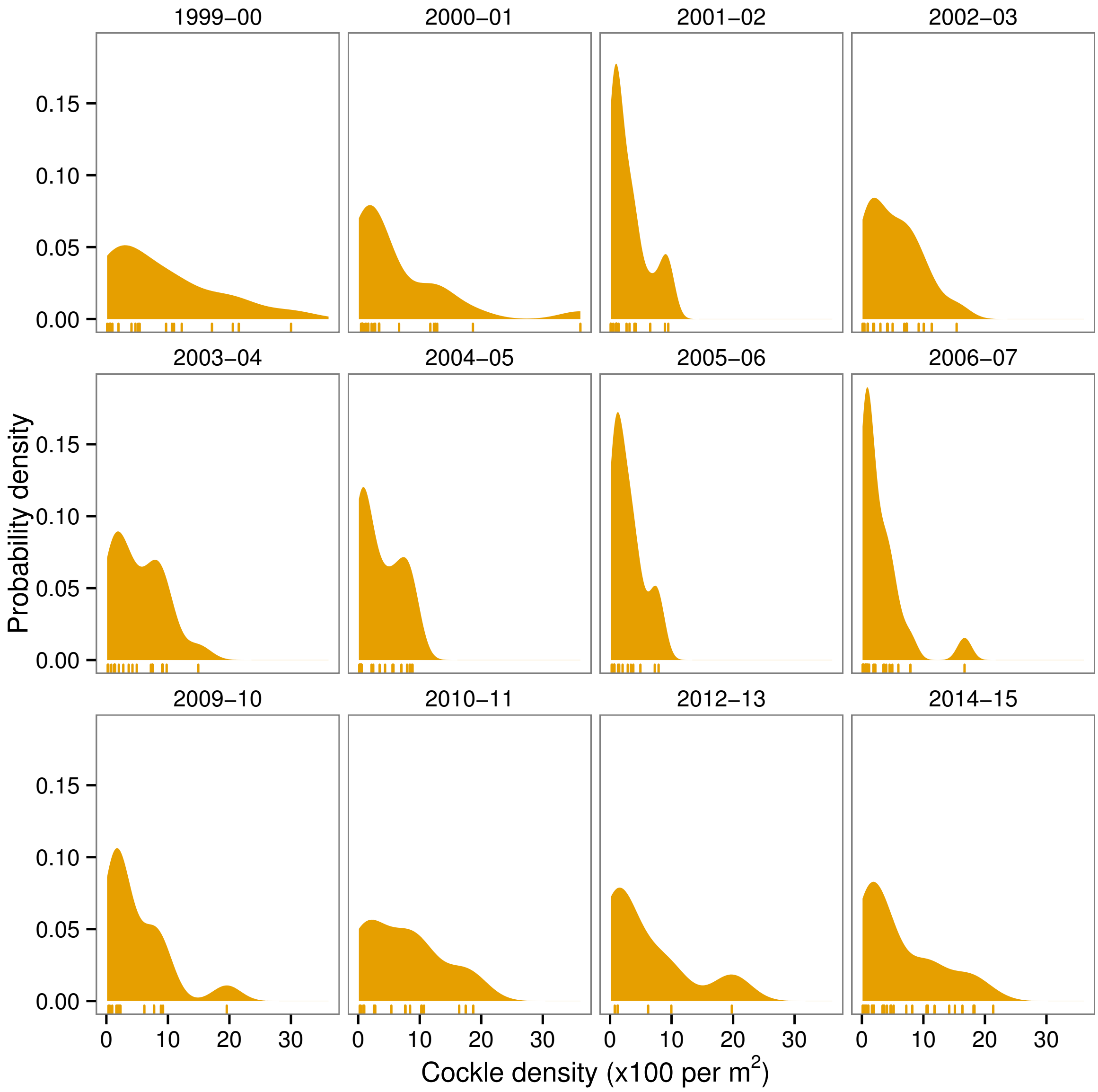


Figure 60: Cockle densities over time at sites included in the 2014–15 survey, estimated independently for all strata. Only strata with more than ten cockles per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

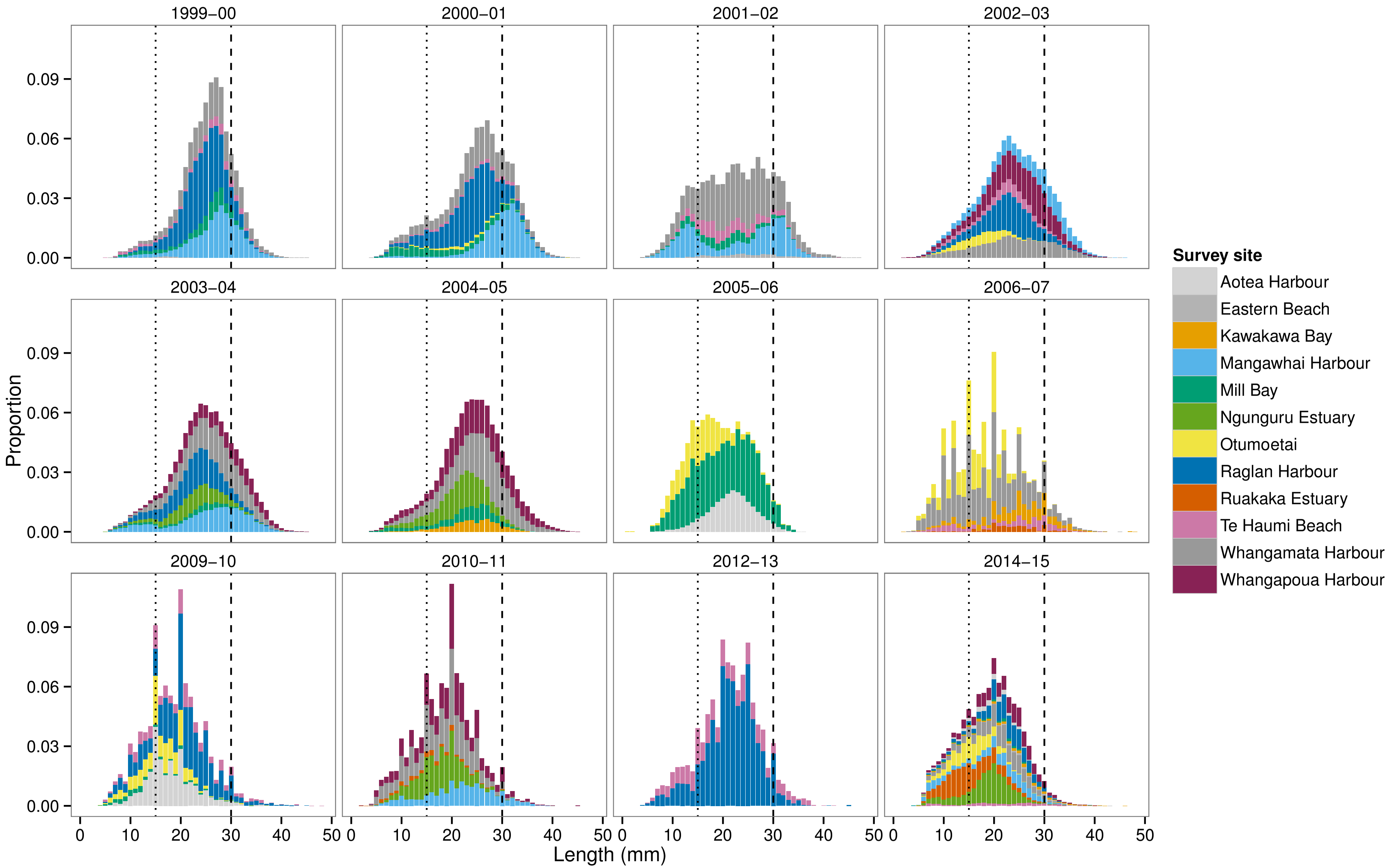


Figure 61: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2014–15 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

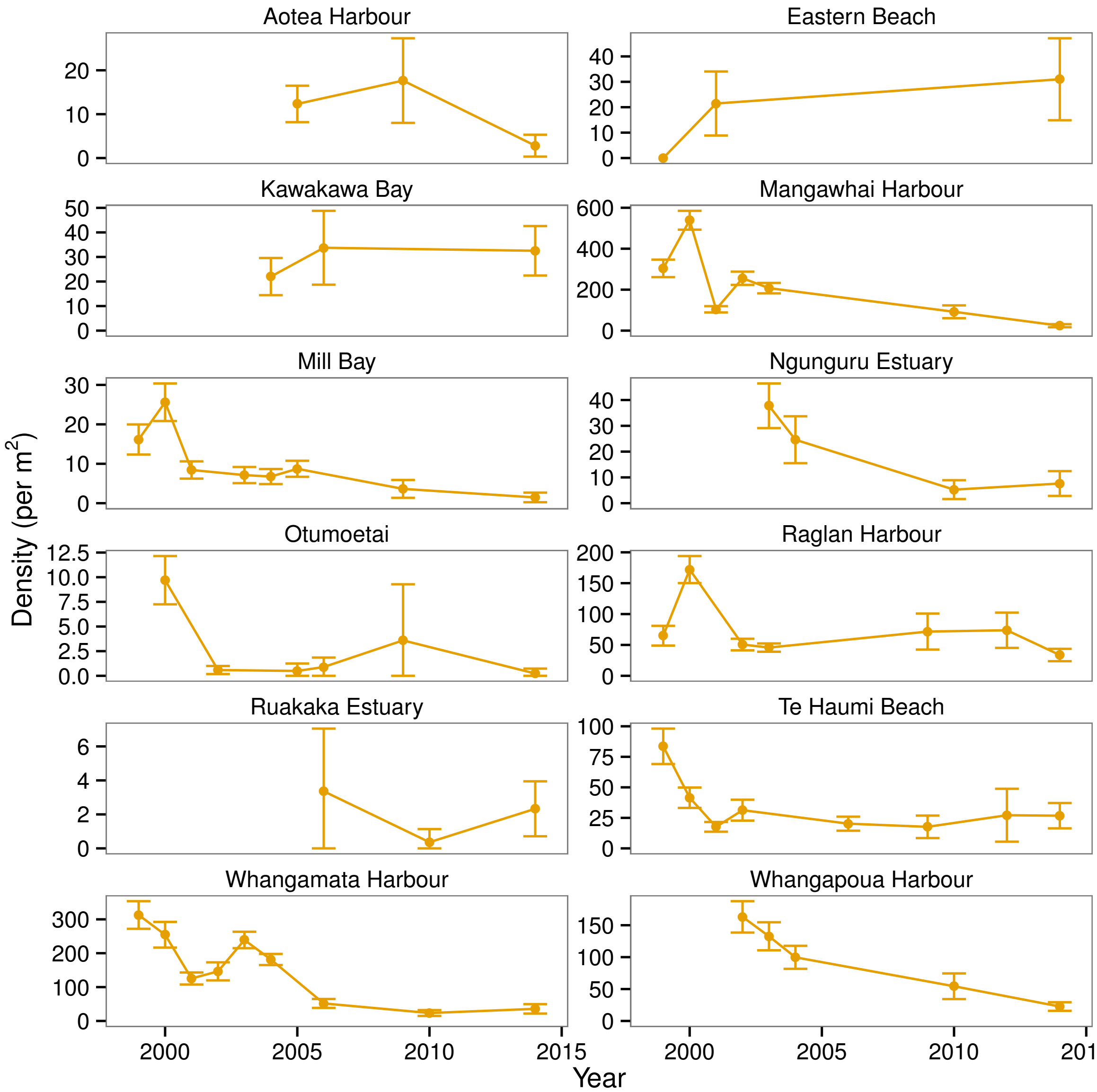


Figure 62: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large cockles across years within each year's survey strata, bars indicate 95% confidence intervals.(Note different scales on the y-axes.)

4.2 Pipi populations

All of the sites in the 2014–15 survey contained pipi populations, except for Aotea Harbour, where only one individual was sampled (resulting in a non-robust population estimate with a CV exceeding 100%) (Table 71). Most of the pipi populations were characterised by low abundance and density estimates, and only three sites supported relatively large pipi populations; they were Otumoetai (Tauranga Harbour), Ruakaka Estuary, and Te Haumi Beach. The highest pipi abundance was at Otumoetai (Tauranga Harbour) with an estimated total of 92.59 million (CV: 5.59%) pipi, followed by 81.23 million (CV: 16.51%) pipi at Ruakaka Estuary, and 55.91 million (CV: 18.38%) pipi at Te Haumi Beach. The relatively large population sizes at these sites corresponded with high density estimates, with 1207 pipi m^2 and 1247 pipi per m^2 at Otumoetai (Tauranga Harbour) and Ruakaka Estuary, and 438 pipi per m^2 at Te Haumi Beach.

At the remaining sites, the pipi populations were considerably smaller, and the lowest reliable population estimate was at Eastern Beach, which contained 0.34 million (CV: 49.71%) pipi. Pipi population densities were also low at these sites; the lowest reliable density estimate was at Eastern Beach with <1 pipi per m^2. The small number and patchy distribution of pipi led to some estimates with CV values exceeding 20%, such as at Aotea Harbour, Eastern Beach, Mangawhai Harbour, Ngunguru Estuary, and Whangapoua Harbour.

Large pipi ($\geq$50 mm shell length) were generally scarce in the 2014–15 survey, and this size class was absent at Eastern Beach, Kawakawa Bay (West), Mill Bay, and Ngunguru Estuary. Only two sites had abundance estimates that exceeded 0.5 million large individuals, with 1.53 million (CV: 75.18%) large pipi at Whangamata Harbour and 1.16 million (CV: 47.92%) large pipi at Te Haumi Beach. Whangamata Harbour was also the only site where the large size class made up a considerably component of the pipi population. The highest density estimate for large pipi was also at Whangamata Harbour, where they were present at 20 large individuals per m^2. Density estimates were markedly lower at the other sites that contained large pipi, varying between <1 large pipi per m^2 and 9 large individuals per m^2 (at Te Haumi Beach).

Within individual strata, population densities showed a similar distribution across surveys, most frequently with up to 500 individuals per m^2 and fewer strata having density estimates above this value (Figure 63). A few surveys also involved strata with high pipi densities (i.e., over 1500 pipi per m^2), such as the two most recent assessments in 2012–13 and 2014–15. Some of the variation across surveys could be due to changes in the proportion of the pipi population that is accessible to the intertidal sampling. As pipi populations extend into subtidal areas, the estimated population densities per stratum (and overall) are based on the fraction that is accessible during the survey, which may vary over time.

The length-frequency distributions of the pipi populations shifted towards smaller shell lengths in recent surveys, i.e., since 2005–06 (Figure 64). Earlier surveys included a substantial number of large pipi ($\geq$50 mm shell length), evident in a distinct cohort that reflected the main size mode in some surveys, such as in 2004–05. In subsequent surveys, the length-frequency distributions included a broader range of sizes, particularly in the smaller size class, with recruits ($\leq$20 mm shell length) dominating the populations in 2012–13 and 2014–15. Although not all of the 2014–15 sites were sampled in each of the preceding surveys, this pattern was consistent throughout the survey series.

At survey sites where large pipi were present at least once, there was a trend of declining densities of this large size class over time (Figure 65). While the most significant decline occurred early in the survey period, subsequent assessments showed that their densities remained low or continued to decrease. Large pipi densities in the current study were generally similar to those in the preceding assessment, although there was a notable decrease in large pipi densities at Ngunguru Estuary and Whangapoua Harbour. Although the density estimates for this size class were already low (less than 25 individuals per m^2 within strata) in the preceding assessment in 2010–11, there was a further decrease in 2014–15, resulting in the disappearance of large pipi at Ngunguru Estuary. The only site in the time series with a documented increase in the density of large pipi was Raglan Harbour; however, densities of large pipi have been consistently low at this site, with maximum values between one and two individuals per m^2.

Table 71: Estimates of pipi abundance for all sites on which more than ten pipi were found in the 2014–15 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 (%)
Eastern Beach	0.34	<1	49.71	0.00	0	
Kawakawa Bay	6.17	10	19.19	0.00	0	
Mangawhai Harbour	6.00	70	21.28	0.03	<1	72.74
Mill Bay	4.41	90	14.32	0.00	0	
Ngunguru Estuary	0.74	14	34.26	0.00	0	
Otumoetai	92.59	1207	5.59	0.47	7	29.21
Raglan Harbour	2.35	32	15.53	0.14	2	40.45
Ruakaka Estuary	81.23	1247	16.51	0.08	1	83.35
Te Haumi Beach	55.91	438	18.38	1.16	9	47.92
Whangamata Harbour	3.79	50	19.69	1.53	20	75.18
Whangapoua Harbour	2.27	36	20.24	0.34	18	22.32

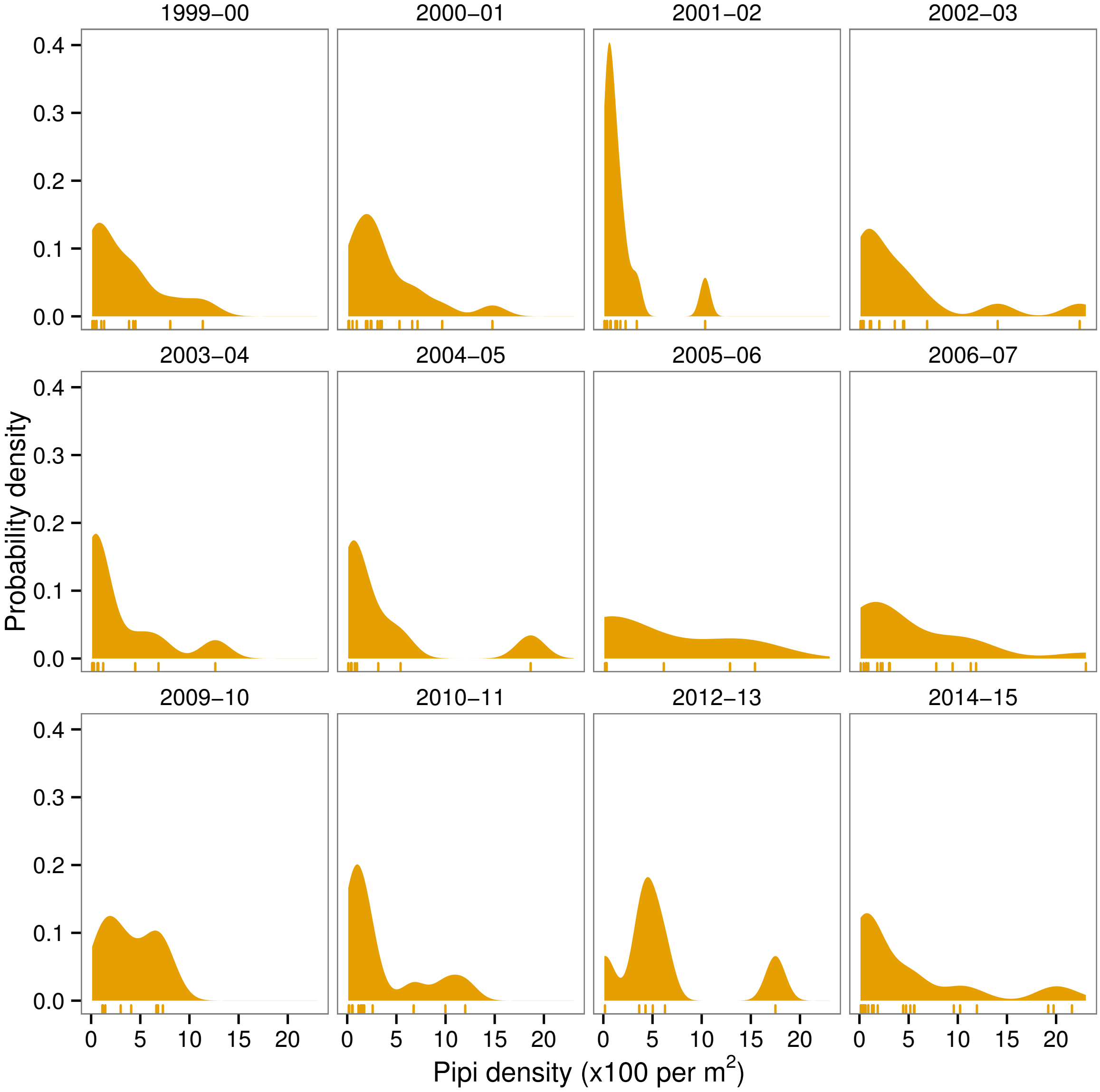


Figure 63: Pipi densities over time at sites included in the 2014–15 survey, estimated independently for all strata. Only strata with more than ten pipi per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

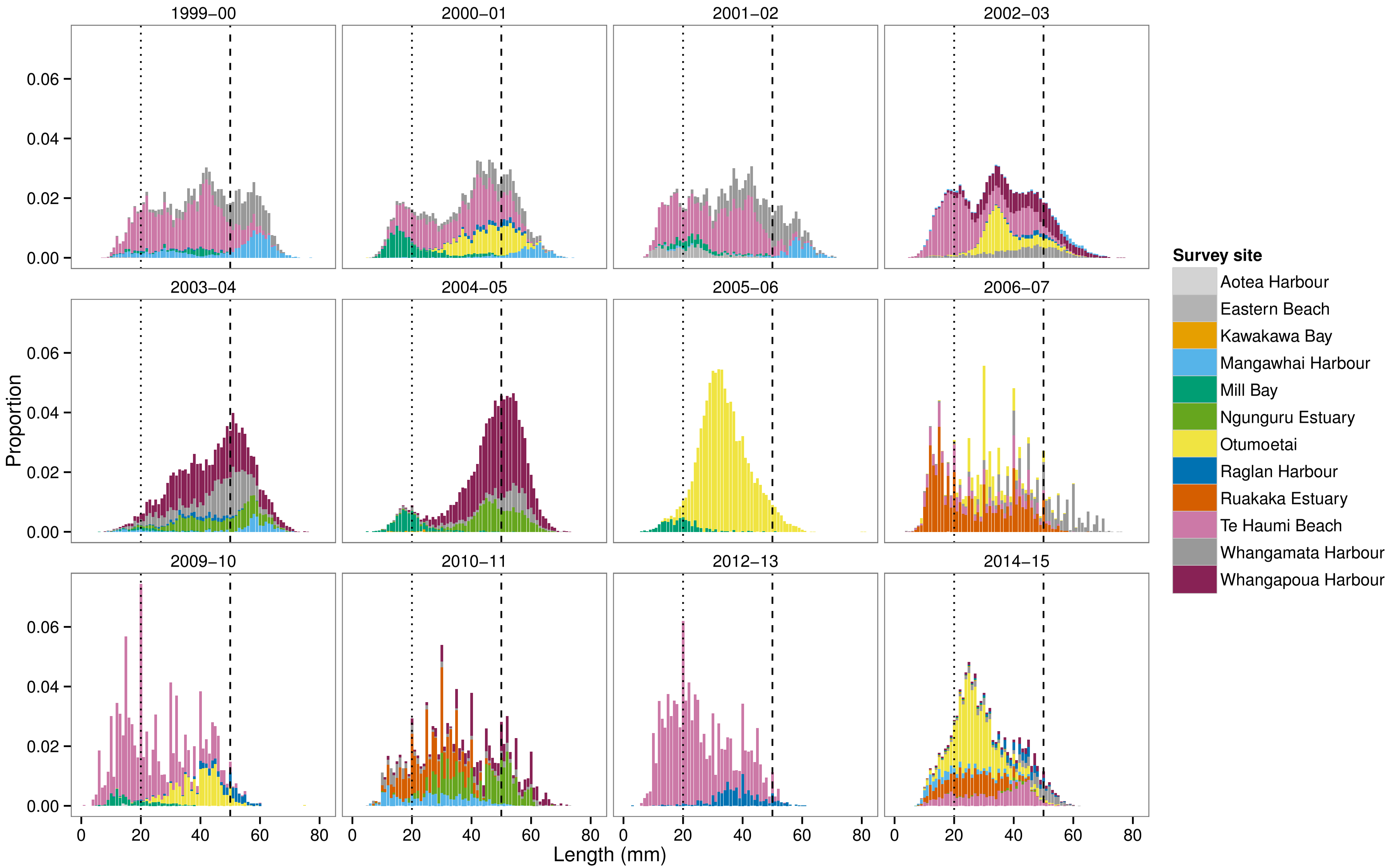


Figure 64: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2014–15 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. Vertical dotted and dashed lines indicate the cut-off sizes for recruits and large individuals, respectively. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

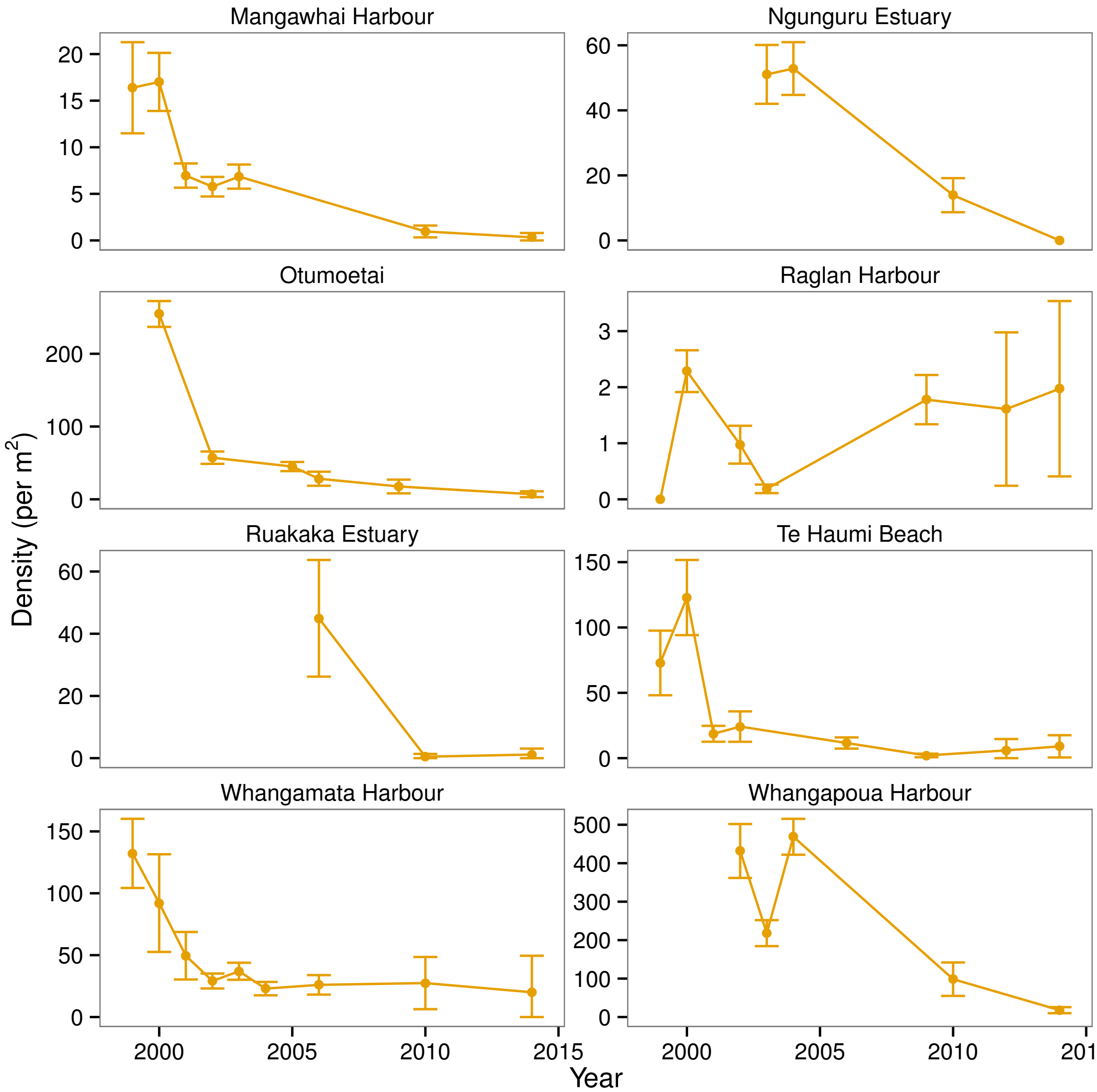


Figure 65: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large pipi across years within each year's survey strata, bars indicate 95% confidence intervals.

5. DISCUSSION

All of the sites sampled in the 2014–15 survey contained cockle populations, and all but one site (Aotea Harbour) contained pipi beds. The bivalve populations at the majority of the current sites have been regularly surveyed since 1999–2000, while four sites have only been sampled twice prior to the current study, including Aotea Harbour, Eastern Beach, Kawakawa Bay (West), and Ruakaka Estuary. For Eastern Beach and Kawakawa Bay (West), the immediately preceding surveys were in 2000–01 and 2005–06, respectively, but at the other sites, previous assessments were more recent.

The 2014–15 population estimates were based on the same or similar strata used in previous surveys, and changes in the sampling extent were generally due to changes in the pipi strata. As pipi populations extend into subtidal areas, frequently in physically-dynamic areas, they may shift following the movement of tidal channels (e.g., at Ruakaka Estuary). For this reason, parts of the population may become inaccessible to the intertidal sampling, requiring pipi strata to be redefined and adjusted across surveys. Even with these adjustments, part of the population may still remain in subtidal areas, affecting the population estimates. Furthermore, recruitment events may result in the identification of new pipi beds during reconnaissance prior to the field survey (e.g., at Mangawhai Harbour), leading to the sampling of additional strata. Another factor determining changes to the sampling extent is a change in the areas targeted by non-commerical fishing, ascertained through the knowledge of local residents and iwi. This factor was relevant in 2014–15 for Aotea Harbour, where one cockle stratum (stratum B) was no longer considered to be one of the main target areas; in addition, movement of the channel meant that this stratum was not accessible to the intertidal sampling (and presumably neither to the shellfish collection).

Based on the current data collection, total population estimates in 2014–15 were similar to those in the previous surveys at these sites, especially in recent years. In general, cockle populations were dominated by small- and medium-sized individuals, with only a small number of large cockles ($\geq$30 mm shell length) included in the populations. Data from the survey series highlight the decline in large individuals over time; only one site, Eastern Beach, showed an increase in the density of large cockles in the 2014–15 assessment. Eastern Beach was the only survey site included in the 2014–15 survey that had a permanent closure in place (since 1993).

Similar to cockles, the pipi populations in 2014–15 consisted largely of small individuals, with recruits ($\leq$20 mm shell length) dominating at a number of sites, whereas large pipi ($\geq$50 mm shell length) were scarce or absent at most sites. Large pipi estimates have been consistently low in recent surveys, with the current assessment showing a continuing decrease in the densities of large individuals at two sites (Ngunguru Estuary and Whangapoua Harbour). Although some sites recorded increases in total population estimates, the lack of large pipi highlights that current population sizes were primarily based on recruitment events and the inclusion of highly abundant small-sized individuals.

It is unknown if the large numbers of recruits and small individuals observed in the current study will persist and subsequently contribute to the adult population. This aspect is pertinent for the sustainability of cockle and pipi populations, and also relevant in a fisheries context as large individuals are considered to be the primary target group. Although monitoring the proportion of large individuals potentially provides some information about fishing pressure affecting the resident bivalve populations at the survey sites, the lack of catch data prevents an accurate assessment of the relationship between fishing activities and population trends. For example, the lack of large individuals at a site may lead to a shift toward the targeting of smaller-sized individuals, as non-commercial fishers may continue to collect shellfish even when there are no bivalves at the preferred large sizes available.

The lack of fishing information also makes it difficult to assess the effectiveness of management measures, such as permanent and seasonal closures. In 2014–15, the only site with a marked increase in the density of large individuals (i.e., cockles) was Eastern Beach, which has been permanently closed to the collection of shellfish since 1993 (Morrison et al. 1999a). Previous surveys at sites that also had closures in place (e.g., Cockle Bay, Umupuia Beach) indicate similar findings, with bivalve abundance and density estimates showing substantial increases following fishing restrictions (Pawley & Smith 2014, Berkenbusch et al. 2015). Although it is not possible to establish a conclusive link between observed population increases and fishery closures without catch information, these survey data suggest that the reduction in fishing pressure may aid the recovery of bivalve populations.

Furthermore, factors other than fishing influence bivalve populations, including population dynamics, environmental factors, and habitat characteristics. The latter include changes in sediment properties such as elevated levels of suspended sediment and increased sedimentation, which have been shown to adversely affect bivalve populations (Gibbs & Hewitt 2004). Both cockles and pipi are relatively vulnerable to changes in the sediment regime, and declines in their populations have been attributed to elevated levels of sediment fines (<63 µm grain size). Although broad-scale sediment sampling in the current study showed that most sites were characterised by fine and medium sands, individual samples at some sites contained high proportions of sediment fines that were between 10 and 21%. As cockles and pipi show a preference for sediment that contains less than 11 and 3% of fines, respectively (Thrush et al. 2005, Anderson 2008), areas that contain a higher proportion of sediment in this grain size fraction may be unsuitable habitat for either species.

At Eastern Beach, large-scale changes in the benthic habitat at either end of the sampling extent are likely to have affected bivalve populations over time, and may have contributed to the noted decline in the pipi population at this site. Both strata C and D contained abundant cockles and pipi in the previous survey in 2000–01, but not in 2014–15, when these strata showed a general lack in individuals of either species. Extensive areas of rocky outcrops and platforms with little sediment on top made both strata largely unsuitable for infaunal bivalves, reflecting significant changes in their habitat characteristics since the preceding survey. In addition, large-scale erosion and sand movement caused by storms have been documented at Eastern Beach in recent times (e.g., in 2014, and the year before; Smith (2014)). It is possible that these large-scale habitat changes also impact on cockles and pipi in other parts of the beach.

In addition to large-scale habitat changes influencing the distribution and abundance of bivalve populations, mass mortality events also have the potential to significantly affect cockle and pipi populations. On-going pipi mortalities were observed at Te Haumi Beach in December 2014 just before the commencement of the current data collection, with an earlier mortality event also noted, which had been reported by Northland Regional Council the previous month. While test results to date do not provide an explanation for the pipi mortalities, it is possible that adverse weather conditions may have adversely affected the bivalves. Adverse weather conditions have also been suggested as the cause of observed mass mortalities of pipi congeners and other bivalves elsewhere in New Zealand (Eggleston & Hickman 1972). Large-scale mortalities of pipi, cockles, and tuatua (*Paphies subtriangulata*) have been subsequently reported at Ngunguru Estuary (May 2015; Newlove (2015)), with no test results to date providing a potential cause of death. At another site included in the survey programme, Whangateau Harbour, infestations by parasites and mycobacteria caused a large-scale cockle die-off in 2009 (Townsend et al. 2010), with a similar mortality event occurring in April 2014. These examples highlight that factors other than fishing can cause substantial declines in bivalve populations, but may go undetected, especially at remote sites.

Overall, the findings from the 2014–15 survey were consistent with those of other recent surveys in the series e.g., Pawley & Smith (2014), Berkenbusch et al. (2015). Densities of large-size cockles and pipi showed a general decrease across the northern North Island sites included in the survey. The only populations that showed an increase in the number or densities of large individuals were at sites that had management measures in place. These increases indicate that populations are recovering where closures limit or prevent fishing pressure, although the exact causes for the increases (or the declines) remain unknown. Although a number of environmental and biological factors determine bivalve population dynamics, non-commerical fishing appears to also influence northern cockle and pipi populations.

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

Table A-1: Sampling years (coloured blue) for sites included in the northern North Island bivalve surveys since 1999–00.

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

Table A-2: Sampling dates and size of the sampling extent for sites included in the northern North Island bivalve surveys since 1999–00, including the present survey in 2014–15. 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
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
Clarks Beach	2004–05	3 Feb–24 Feb	144.71	AKI2004-01
Cockle Bay	2009–10	16 Feb	32.00	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
Cornwallis Wharf	2001–02	26 Mar–20 Apr	2.65	AKI2001-01
Eastern Beach	1999–00	15 May–30 Jun	48.00	AKI1999-01
	2001–02	14 Mar–16 Apr	43.38	AKI2001-01
	2014–15	27 Jan–18 Feb	41.42	AKI2014-01
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
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
Little Waihi Estuary	2000–01	21 Mar–31 Mar	3.00	AKI2000-01
	2002–03	30 Jan–1 Feb	3.00	AKI2002-01
	2003–04	7 Jan–19 Jan	3.12	AKI2003-01
	2004–05	14 Jan–15 Jan	3.75	AKI2004-01
	2006–07	15 Jun–28 Jun	3.16	AKI2006-01
	2009–10	2 Mar	13.92	AKI2009-01
	2012–13	10 Feb	15.42	AKI2012-01
	2013–14	19 Mar–20 Mar	17.09	AKI2013-01
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
Marokopa Estuary	2005–06	18 Feb–20 Feb	2.35	AKI2005-01
	2010–11	16 May	2.35	AKI2010-01
Marsden Bank	2009–10	13 Nov	11.51	IPA2009-12
	2012–13	12 Dec	6.31	AKI2012-01
	2013–14	2 Feb	15.43	AKI2013-01
Mill Bay	1999–00	4 May–30 Jun	4.60	AKI1999-01
	2000–01	20 Feb–23 Feb	4.80	AKI2000-01

Continued on next page

Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2001–02	20 Mar–22 Apr	4.50	AKI2001-01
	2003–04	26 Jan–28 Jan	4.50	AKI2003-01
	2004–05	24 Dec–24 Jan	4.50	AKI2004-01
	2005–06	20 Dec–24 Dec	4.50	AKI2005-01
	2009–10	13 May	4.95	AKI2009-01
	2014–15	26 Feb	4.88	AKI2014-01
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
	2014–15	23 Jan–24 Jan	5.46	AKI2014-01
Ohiwa Harbour	2001–02	9 Apr–11 Apr	2.25	AKI2001-01
	2005–06	25 Feb–26 Feb	2.70	AKI2005-01
	2006–07	13 Jun–29 Jun	5.70	AKI2006-01
	2009–10	3 Mar	2.10	AKI2009-01
	2012–13	9 Feb–15 Mar	2.63	AKI2012-01
Okoromai Bay	1999–00	19 Apr–24 Apr	20.00	AKI1999-01
	2001–02	8 Apr–12 Apr	24.00	AKI2001-01
	2002–03	26 Dec–29 Dec	20.00	AKI2002-01
	2003–04	17 Mar–20 Mar	20.00	AKI2003-01
	2004–05	15 Jan–16 Jan	20.00	AKI2004-01
	2006–07	20 Mar	20.00	AKI2006-01
	2009–10	17 Feb	20.00	AKI2009-01
	2012–13	30 Jan	20.00	AKI2012-01
	2013–14	31 Mar	19.84	AKI2013-01
Otumoetai	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
	2014–15	31 Jan–1 Feb	7.67	AKI2014-01
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
Raglan Harbour	1999–00	26 May–30 Jun	10.10	AKI1999-01
	2000–01	13 Feb–10 Mar	10.04	AKI2000-01
	2002–03	13 Jan–16 Jan	8.24	AKI2002-01
	2003–04	14 Jan–16 Jan	8.24	AKI2003-01
	2009–10	26 Apr	9.20	AKI2009-01
	2012–13	11 Jan	8.24	AKI2012-01
	2014–15	20 Feb–23 Feb	7.24	AKI2014-01
Ruakaka Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
	2014–15	25 Jan–26 Jan	6.51	AKI2014-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
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
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
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
Waiotahi 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
Whangamata Harbour	1999–00	20 May–29 May	5.48	AKI1999-01
	2000–01	15 Feb–16 Feb	5.48	AKI2000-01
	2001–02	9 May–26 May	5.48	AKI2001-01
	2002–03	9 Mar–28 Mar	5.48	AKI2002-01
	2003–04	1 Jan–31 Jan	5.48	AKI2003-01
	2004–05	6 Feb–8 Feb	5.48	AKI2004-01
	2006–07	2 May–2 Aug	24.61	AKI2006-01
	2010–11	19 Apr	5.89	AKI2010-01
	2014–15	28 Jan–30 Jan	7.62	AKI2014-01

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Table A-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
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
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
Whitianga Harbour	2012–13	7 Feb	7.08	AKI2012-01

APPENDIX B: Substrate samples

Table B-3: Sediment organic content and sediment grain size distributions at sites surveyed in 2013–14 as part of the northern North Island bivalve surveys. The location letter indicates whether the sample was taken inside (I) or outside (O) of the stratum. The position of the sampling points is indicated in decimal degrees (World Geodetic System 1984). Sediments grain size fractions are defined as fines (silt and clay) <63 µm, very fine sand (VFS) >63 µm, fine sand (FS) >125 µm, medium sand (MS) >250 µm, coarse sand (CS) >500 µm, and gravel >2000 µm. Missing cells indicate missing data.

							Sediment grain size fraction (%)					
Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Aotea Harbour	A	I	1	-38.01501	174.82867	1.5	0.0	17.3	74.8	7.1	0.5	0.2
	A	I	2	-38.01299	174.83037	0.9	0.0	24.7	63.5	9.3	0.6	1.9
	A	I	3	-38.01325	174.83156	1.1	0.0	24.8	70.8	4.0	0.3	0.1
	A	O	1	-38.01282	174.83212	1.3	0.0	29.5	65.6	3.3	0.5	1.1
	A	O	2	-38.01412	174.82637	1.3	0.0	23.4	43.1	10.7	2.3	20.5
	D	I	1	-38.01680	174.82658	1.0	0.0	19.2	70.9	7.4	0.8	1.7
	D	I	2	-38.01615	174.82579	1.5	0.0	39.7	41.2	7.6	2.6	8.9
	D	O	1	-38.01802	174.82335	0.9	0.0	7.5	56.6	34.9	0.4	0.6
Eastern Beach	A	I	1	-36.87582	174.91747	1.9	0.0	21.8	54.2	13.6	3.2	7.3
	A	I	2	-36.87354	174.91495	1.6	0.0	11.4	53.3	34.7	0.5	0.1
	A	O	1	-36.87708	174.91853	1.6	0.0	5.1	22.9	24.4	22.4	25.3
	B	I	1	-36.87505	174.91750	1.6	0.0	38.2	56.2	5.2	0.3	0.2
	C	I	1	-36.87819	174.92020	2.1	0.0	2.2	14.3	16.3	20.8	46.4
	C	O	1	-36.87860	174.92075	1.4	0.7	1.9	30.2	17.1	30.0	20.1
	D	I	1	-36.86879	174.91277	1.3	0.1	21.3	77.7	0.4	0.3	0.1
	D	O	1	-36.86879	174.91570	1.4	2.9	47.1	49.6	0.4	0.0	0.0
Kawakawa Bay (West)	A	I	1	-36.94213	175.15044	3.9	3.7	8.5	5.4	4.7	11.8	65.8
	B	I	1	-36.94716	175.15268	2.4	0.0	77.8	15.7	1.1	0.7	4.7
	B	I	2	-36.94433	175.15140	1.5	0.0	70.8	26.0	2.1	0.1	0.9
	B	O	1	-36.94656	175.15053	1.8	0.0	1.1	14.7	12.5	15.7	56.1
	C	I	1	-36.94820	175.15759	1.5	0.0	38.9	50.2	8.8	0.6	1.4
	C	I	2	-36.94824	175.15581	1.2	0.0	44.6	50.3	2.0	0.5	2.7
	C	O	1	-36.95078	175.15776	3.0	5.8	37.2	26.2	13.0	9.9	7.9

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
							Fines	VFS	FS	MS	CS	Gravel
	D	I	1	-36.94922	175.16321	1.2	0.0	3.0	3.8	2.4	5.9	84.9
	D	I	2	-36.95008	175.15848	3.0	0.0	5.9	14.2	11.8	12.6	55.5
	D	I	3	-36.95014	175.15961	2.4	0.0	1.0	4.0	6.3	14.4	74.3
	D	O	1	-36.95020	175.16293	1.5	0.0	6.4	2.8	1.1	60.3	29.3
	E	I	1	-36.94737	175.15977	1.0	0.0	12.4	53.1	31.5	1.0	2.0
Mangawhai Harbour	A	I	1	-36.08552	174.59087	0.8	12.2	0.7	64.6	20.6	0.5	1.4
	A	I	2	-36.08441	174.59041	0.6	4.4	0.9	26.7	62.0	4.6	1.4
	A	O	1	-36.08464	174.58998	0.4	3.0	0.2	26.9	56.3	6.7	6.8
	A	O	2	-36.08465	174.58998	0.6	2.5	1.5	66.2	29.5	0.2	0.1
	B	I	1	-36.08662	174.59046	0.9	2.5	3.1	11.9	75.8	2.2	4.5
	C	I	1	-36.08820	174.59025	0.4	4.2	0.4	38.9	54.9	1.1	0.4
	C	O	1	-36.08776	174.58988	0.3	2.6	0.7	41.5	54.4	0.8	0.0
	D	I	1	-36.09734	174.59222	0.6	2.2	1.5	75.2	17.6	0.1	3.3
	D	I	2	-36.09842	174.59226	0.7	3.8	3.7	68.4	21.1	1.1	1.9
	D	O	1	-36.09842	174.59323	0.7	13.4	1.1	42.0	42.4	1.0	0.2
	E	I	2	-36.11636	174.59498	0.6	1.6	2.6	52.4	38.7	2.8	1.9
	E	I	1	-36.11528	174.59619	0.6	0.2	1.8	51.9	42.3	2.7	1.0
	E	O	1	-36.11634	174.59545	0.8	4.2	1.4	63.1	29.7	1.2	0.5
	F	I	1	-36.11043	174.60133	0.7	2.2	0.8	54.8	37.8	2.2	2.2
Mill Bay	A	I	1	-36.99341	174.60511	2.2	0.0	8.1	28.5	14.8	19.6	28.9
	A	I	2	-36.99433	174.60668	2.3	0.0	12.3	50.9	24.3	11.3	1.1
	A	I	3	-36.99401	174.60743	2.1	0.0	8.1	41.3	36.3	14.1	0.3
	A	I	4	-36.99474	174.60849	1.3	0.0	1.3	16.3	51.1	31.1	0.2
	A	I	5	-36.99505	174.60713	1.8	0.0	8.1	45.1	32.1	14.0	0.8
	A	I	6	-36.99405	174.60754	1.9	0.0	5.6	31.4	40.9	20.5	1.5
	A	I	7	-36.99303	174.60550	2.7	0.0	2.2	10.0	18.6	35.7	33.5
	A	O	1	-36.99412	174.60488	3.0	0.0	23.5	22.7	15.8	25.8	12.2

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
							Fines	VFS	FS	MS	CS	Gravel
	A	O	2	-36.99504	174.60811	1.3	0.0	5.4	38.4	28.2	19.0	8.9
Ngunguru Estuary	A	I	1	-35.63421	174.50145	2.1	0.0	15.8	74.8	5.8	2.6	1.0
	A	I	2	-35.63264	174.50250	1.9	2.8	25.0	64.2	2.7	1.6	3.7
	A	O	1	-35.63303	174.50188	1.8	3.7	10.3	61.9	18.4	5.7	0.0
	B	I	1	-35.63237	174.50520	1.2	14.6	1.3	71.6	12.4	0.0	0.0
	B	O	1	-35.63284	174.50502	1.4	2.1	0.4	82.9	14.4	0.1	0.1
	C	I	1	-35.63566	174.50481	1.2	2.8	8.2	60.2	8.7	6.3	13.7
	E	I	1	-35.63504	174.50278	2.1	2.9	13.3	68.8	1.3	0.9	12.8
	E	I	2	-35.63676	174.50233	2.5	0.0	18.9	78.1	1.2	0.8	1.0
	E	I	3	-35.63623	174.50163	1.7	0.0	23.7	66.1	2.2	2.7	5.3
	E	O	1	-35.63572	174.50308	2.3	0.0	15.2	65.6	17.6	0.8	0.9
Otumoetai (Tauranga Harbour)	A	I	1	-37.65492	176.12996	1.6	4.2	2.1	37.6	35.9	17.1	3.1
	A	O	1	-37.65671	176.12816	1.1	3.2	7.3	45.1	30.6	12.2	1.6
	B	I	1	-37.65344	176.13214	1.6	6.5	0.6	22.6	47.4	21.7	1.2
	B	O	1	-37.65387	176.13116	1.9	2.3	1.4	39.9	46.3	8.5	1.6
	B	O	2	-37.65484	176.13109	1.1	6.1	0.8	18.3	41.5	26.4	6.9
	C	I	1	-37.66454	176.15073	1.2	7.0	8.8	55.0	18.0	10.2	1.1
	C	O	1	-37.66502	176.15062	1.5	5.5	7.4	60.1	23.0	3.4	0.5
	C	O	2	-37.66435	176.15240	1.4	4.4	5.0	65.0	21.7	3.3	0.7
	D	I	1	-37.66404	176.15109	1.5	6.2	6.5	57.8	27.3	1.8	0.4
	D	I	2	-37.66390	176.15178	1.2	4.8	6.8	73.2	13.7	1.4	0.2
	E	I	1	-37.65666	176.12714	2.6	0.2	4.1	23.3	33.6	30.9	8.0
Raglan Harbour	A	I	1	-37.80316	174.86724	2.4	0.0	24.7	70.2	1.3	1.4	2.5
	A	I	2	-37.80496	174.86526	2.0	0.0	22.0	76.9	0.1	0.6	0.3
	A	I	3	-37.80469	174.86618	1.4	0.0	21.9	68.3	3.2	1.3	5.3
	A	O	1	-37.80254	174.86807	3.1	0.0	41.4	45.3	7.1	3.0	3.2
	A	O	2	-37.80386	174.86748	3.0	0.0	55.6	37.2	1.5	1.4	4.4

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Table B-3 – *Continued from previous page*

							Sediment grain size fraction (%)					
Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	C	I	1	-37.80361	174.86591	2.2	0.0	11.2	57.7	11.6	5.3	14.2
	C	I	2	-37.80438	174.86529	3.6	0.0	8.2	41.0	14.3	22.3	14.2
	D	I	1	-37.79578	174.87141	1.9	0.0	31.7	54.6	4.0	1.1	8.6
	D	I	2	-37.79641	174.86946	3.2	0.0	29.0	68.4	1.5	0.7	0.4
	D	O	1	-37.79673	174.87054	3.2	0.0	22.9	55.1	5.9	6.6	9.6
	D	O	2	-37.79643	174.86834	2.2	0.0	13.2	85.6	1.0	0.2	0.0
Ruakaka Estuary	AC	I	1	-35.90336	174.45897	0.4	3.6	0.0	43.5	52.3	0.6	0.0
	AN	I	1	-35.90139	174.45795	0.9	4.5	2.4	74.7	17.9	0.5	0.0
	AN	O	1	-35.90138	174.45940	0.4	2.1	0.1	31.6	62.9	3.1	0.2
	AN	O	2	-35.90099	174.45766	0.5	1.2	0.7	52.0	45.5	0.6	0.0
	AN	O	3	-35.90159	174.45851	0.7	6.8	1.3	61.6	26.0	2.0	2.3
	AS	I	1	-35.90264	174.45647	0.7	4.4	1.4	51.9	41.7	0.4	0.2
	AS	O	1	-35.90253	174.45569	0.9	15.1	2.1	53.0	28.6	0.5	0.6
	B	I	1	-35.89791	174.46065	2.1	0.0	2.5	56.4	35.7	1.6	4.0
Te Haumi Beach	A	I	1	-35.29439	174.10117	1.9	0.0	7.6	70.5	19.8	1.3	0.8
	A	I	2	-35.29545	174.10184	2.1	0.8	3.7	60.2	20.0	7.1	8.3
	A	O	1	-35.29696	174.10175	2.5	0.0	2.3	15.2	8.1	25.5	48.8
	B	I	1	-35.29507	174.09981	2.3	0.0	2.6	66.3	29.9	1.2	0.1
	B	O	1	-35.29643	174.09920	1.8	2.0	2.7	31.7	17.1	15.1	31.3
	C	I	1	-35.29822	174.09889	2.4	0.0	0.9	25.0	62.9	9.5	1.7
	C	I	2	-35.29839	174.09833	2.1	20.6	0.0	0.5	13.5	39.6	25.7
	E	I	1	-35.29607	174.10283	2.8	0.0	9.8	59.4	8.9	11.3	10.6
Whangamata Harbour	AN	I	1	-37.19493	175.87414	3.1	2.0	3.4	59.8	34.4	0.4	0.0
	AS	I	1	-37.19541	175.87361	2.4	0.6	4.8	52.9	36.3	3.8	1.5
	AS	O	1	-37.19523	175.87393	2.0	0.4	3.1	61.9	26.4	3.6	4.6
	B	I	1	-37.19414	175.87258	2.5	1.6	7.1	74.5	16.5	0.3	0.1
	B	I	2	-37.19329	175.86948	2.5	0.0	16.6	57.8	7.4	5.9	12.3

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Table B-3 – *Continued from previous page*

Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%)					
							Fines	VFS	FS	MS	CS	Gravel
	B	O	1	-37.19313	175.86866	2.9	0.0	11.7	69.2	12.7	3.8	2.7
	C	I	1	-37.19675	175.87372	2.9	0.0	5.6	63.4	29.0	1.8	0.2
	C	I	2	-37.19616	175.87304	2.6	1.3	6.2	57.2	28.1	3.8	3.3
	C	O	1	-37.19701	175.87334	2.0	3.1	3.9	61.9	23.9	4.8	2.5
Whangapoua Harbour	A	I	1	-36.73846	175.64853	1.3	0.0	2.7	33.5	43.4	5.0	15.5
	B	I	1	-36.73388	175.63904	1.2	2.7	7.5	64.7	14.4	2.5	8.2
	B	I	2	-36.73343	175.63822	1.3	0.0	19.4	69.9	6.3	1.5	2.8
	B	O	1	-36.73307	175.63874	1.0	0.2	9.1	66.6	13.4	1.7	9.0
	C	I	1	-36.72577	175.61632	2.3	0.0	9.5	76.0	7.1	1.9	5.6
	C	I	2	-36.72550	175.61637	1.3	1.6	7.4	69.9	17.1	1.8	2.1
	C	O	1	-36.72595	175.61658	1.7	0.0	12.1	68.4	12.1	1.2	6.2
	D	I	1	-36.72390	175.62315	0.8	0.3	2.0	42.6	44.1	5.4	5.5
	D	I	2	-36.72429	175.62342	0.5	1.9	0.7	46.2	48.9	2.1	0.2
	D	O	1	-36.72312	175.62284	0.9	0.0	2.1	49.8	41.6	4.7	1.7
	D	O	2	-36.72455	175.62254	1.1	2.9	4.0	56.2	33.3	2.0	1.7

APPENDIX C: Pipi mass mortality at Te Haumi Beach

Figure C-1: Images of pipi mass mortality events at Te Haumi Beach in 2014. Top left: Bank of recently dead and moribund pipi at Te Haumi Beach, December 2014. Top right: Remnant pipi shells from an earlier mortality event in the western part of Te Haumi Beach.