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Intertidal shellfish monitoring in the northern North Island region, 2013–14

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EXECUTIVE SUMMARY

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Coastal environments throughout New Zealand contain a number of bivalve species that are valued in recreational and customary fisheries. In sheltered, sedimentary habitats, these bivalves include cockles (*Austrovenus stutchburyi*) and pipi (*Paphies australis*), which are both common in a range of embayments, estuaries, and harbours. Throughout northern North Island, cockle and pipi populations are often the main target for recreational and customary fisheries. To monitor the sustainability of these non-commercial fisheries, regular population surveys have been commissioned by Ministry for Primary Industries to assess the cockle and pipi populations in areas targeted by non-commercial fisheries in the wider Auckland region, Northland, Waikato, and Bay of Plenty.

This study presents the findings from the most recent cockle and pipi survey in the northern North Island region, conducted in the 2013–14 fishing year. The sites included in the current survey were Cockle Bay, Grahams Beach, Little Waihi Estuary, Marsden Bank, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, Waikawau Beach, Waiotahi Estuary, and Whangateau Harbour. In addition to assessing the cockle and pipi populations, the current survey collected sediment data to provide baseline information on possible causative factors for population change (sediment organic content and grain size) across the survey sites.

Cockle populations were present at nine sites, and population estimates ranged from 4.41 million individuals at Grahams Beach to 545.24 million cockles at Whangateau Harbour. Cockle population densities varied between the lowest value of 16 cockles per m^2 at Grahams Beach and the highest estimate of 1317 cockle per m^2 at Pataua Estuary. A number of populations were characterised by small-sized individuals ($<$30 mm shell length), and most sites had declining trends in the number of large-size cockles over time. Only two sites, Cockle Bay and Umupuia Beach contained high numbers of large individuals in the cockle population, although the total number of cockles at Cockle Bay was markedly lower in the present survey than in the previous assessment in 2012–13.

Pipi populations were present at seven sites, and estimated population sizes varied from 3.23 million pipi at Marsden Bank to 113.46 million pipi at Little Waihi Estuary. The corresponding population densities ranged from 21 pipi per m^2 at Marsden Bank to 941 pipi per m^2 at Waiotahi Estuary. Numbers and densities of large pipi (defined as $\geq$50 mm shell length) were low at five of the seven sites that contained pipi, at $\leq$1 individual per m^2. At the remaining two sites, densities of large pipi were slightly higher, with 5 and 27 pipi per m^2 at Tairua Harbour and Little Waihi Estuary, respectively.

Population estimates for pipi at Marsden Bank reflected a continued decline in 2013–14, following a marked reduction documented in the previous survey in 2012–13. At Waikawau Beach, the pipi population has disappeared since the preceding survey in 2005–06, coinciding with a change from a sedimentary habitat to a beach characterised by large gravel and pebbles.

The present study also provided broad-scale information of sediment properties at the survey sites, including organic content and grain size. Most sites were characterised by low sediment organic content (i.e., $<$5%) and a small proportion of fines (silt and clay, $<$63 μm grain size), although the latter was high in some samples, most notably at Cockle Bay and Umupuia Beach (up to 42 and 77%, respectively).

1. INTRODUCTION

New Zealand's coastal, sedimentary habitats support a number of infaunal bivalve species that are valued resources for recreational and customary fisheries, and treasured as traditional Māori food (kai moana), including cockles (tuangi, or littleneck clam, *Austrovenus stutchburyi*) and pipi (*Paphies australis*) (Hauraki Māori Trust Board 2003, Hartill et al. 2005). Both species are found in a range of sheltered and semi-enclosed marine habitats such as embayments, estuaries, and harbours, where they frequently form high-density patches and/or extensive beds, with population densities exceeding 1000 individuals per square metre (Morton & Miller 1973).

In northern North Island, cockles and pipi are the principal target species in sheltered coastal environments open to recreational and customary fishing (Morrison et al. 1999a). At the same time, many of the northern North Island cockle and pipi populations are in close proximity to urban and metropolitan areas, making them easily accessible and, therefore, vulnerable to overexploitation (Grant & Hay 2003). In addition, their propensity to form dense aggregations enables relatively easy collection, further increasing their susceptibility to overfishing. Although cockle and pipi populations are still relatively widespread and abundant, localised depletion in northern North Island has been attributed to non-commercial fishing pressure (Morrison et al. 1999a, Hartill et al. 2005).

Concern about the sustainability of the regional cockle and pipi populations has prompted the Ministry for Primary Industries (MPI, formerly Ministry of Fisheries) to commission regular (generally annual) bivalve surveys, starting in 1992 (Morrison et al. 2009). Since their introduction, the spatial extent of the monitoring surveys has been expanded from the wider Auckland metropolitan area to include sites throughout the Auckland Fisheries Management Area (FMA 1)(see information about the surveys in Appendices A and B).

Information from this monitoring programme is pertinent for supporting MPI management strategies that ensure sustainable recreational and customary fisheries, as outlined in “Fisheries 2030” (Ministry of Fisheries 2009), and the “Draft National Fisheries Plan for Inshore Shellfish” (Ministry of Fisheries 2011). Management measures applied to the northern cockle and pipi populations have included temporal closures and reductions in bag limits, with data from the surveys underpinning the validity of these measures.

The data collection at each site has been focused on providing information about the abundance and population structure (size-frequency distribution) of cockle and pipi populations (most recently, Pawley & Smith 2014). 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 only target 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). Instead, the data collection is focused on the fisheries target areas only, allowing present-day and longer-term assessments of the bivalve populations that are subject to fishing pressure.

The present study continued the series of (generally) annual 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 2013–14 fishing year.

The survey sites included in this study were (in alphabetical order): Cockle Bay, Grahams Beach, Little Waihi Estuary, Marsden Bank, Okoromai Bay, Pataua Estuary, Tairua Harbour, Umupuia Beach, Waikawau Beach, Waiotahi Estuary, Whangateau Harbour (see Figure 1).

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.

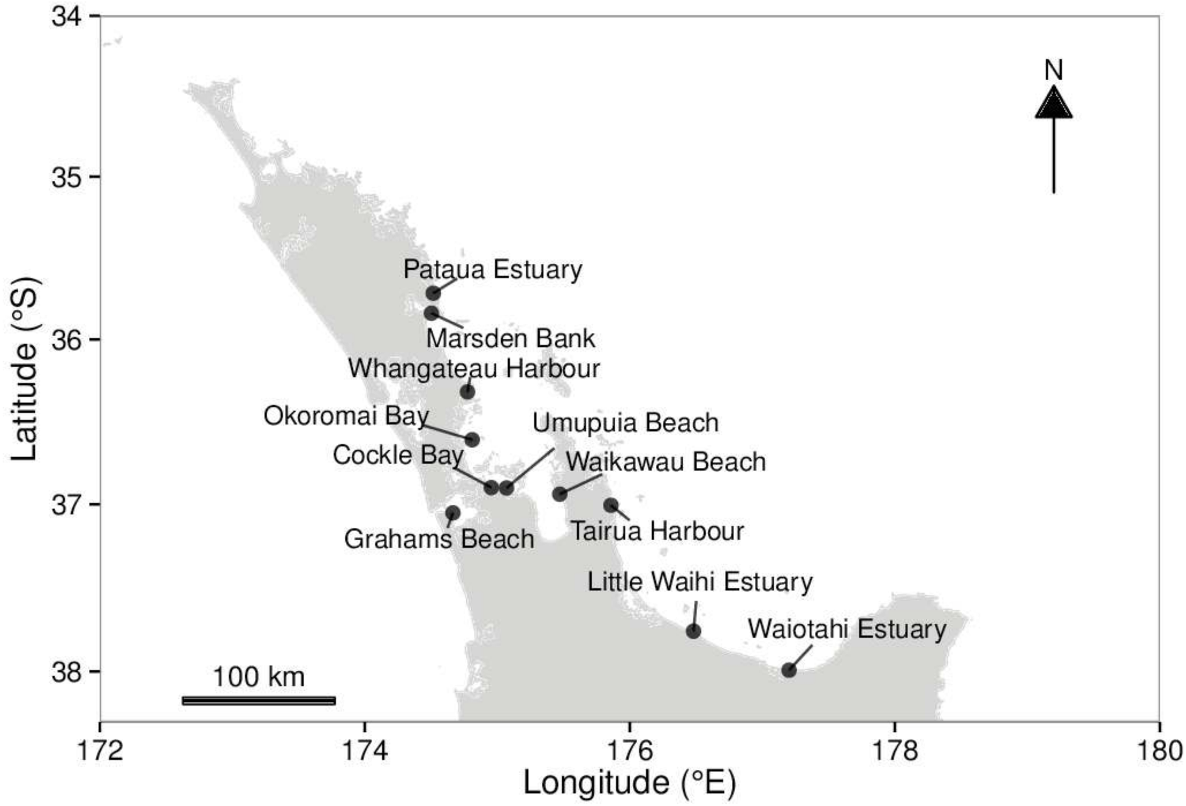

Figure 1: Sites included in the northern North Island intertidal bivalve surveys in 2013–14.

2.1 Survey methods

At each site, the intertidal area/s 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 <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. The allocation of random sampling points used computer-generated GPS coordinates within a sampling grid across each stratum. Random points were allocated to a first and a second sampling phase within each systematic stratum. The second sampling phase was implemented when the coefficient of variation (CV) of the total abundance estimate after sampling in the first phase exceeded the target CV of 20%.

2.2 Field sampling - bivalves

The field component of this study was carried out between January and April 2014, with the intertidal sampling at each site conducted during periods of low tide (see sampling dates for the present and previous surveys in Appendix B, Tables B-1, B-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. This subsample involved measuring the first 50 individuals that had been counted.

2.3 Field sampling - sediment

In view of the importance of sediment properties for infaunal bivalves, the present monitoring programme also included sediment sampling to provide baseline information about sediment properties at the survey sites (see detailed information in Appendix C). 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. Subsequent grain size analysis of the sediment samples used a combination of wet and dry sieving to ascertain the proportion of different size classes, ranging from sediment fines (silt and clay, <63 µm) to different sand fractions of very fine to very coarse sands (i.e., 125 to 2000 µm grain size) (Eleftheriou & McIntyre 2005). Each sample was homogenised before wet sieving on the 63-µm mesh to determine the proportion of fines, i.e., sediment<63 µm grain size. Sediment retained on the sieve (i.e, >63 µm grain size) was subsequently dried to constant weight at 60°C before processing it on a stack of sieves, determining the different fractions >63 µm grain size. The sediment organic content of each sample was determined by loss on ignition (4 hours at 550°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 (discrepancies between values from previous surveys derived for the present study and those reported in previous survey reports are listed in Appendix D). Comparisons with previous surveys from 1999–2000 onwards were made for estimates of abundance and population density. Length frequencies 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

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

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

$$CV = 100 \times \frac{\sigma_{\hat{N}}}{\hat{N}}. \tag{3}$$

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

$$\hat{n}_{l,s} = \frac{n^m_{l,s}}{p^m_s}. \tag{4}$$

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 as reference lengths) at each site, summing numbers at length of individuals greater than the reference length r for each species:

$$\hat{n}_{l \geq r,s} = \sum_{l=r}^{max(l)} \hat{N}_l. \tag{5}$$

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 Cockle Bay

Cockle Bay is within the metropolitan Auckland area, and has been part of the northern shellfish surveys since 2009–10 (see Appendix B, Tables B-1, B-2). This beach has been closed to shellfish gathering for the summer period (1 October to 30 April) since 1 October 2008. A maximum daily bag limit of 50 cockles per gatherer per day applies at other times.

There have been three previous surveys at Cockle Bay; the previous surveys encompassed the same sampling strata as those included in 2013–14. The 2013–14 shellfish survey at Cockle Bay involved two strata that were of equal size, strata A and B (Figure 2, Table 1). There were 40 sampling points in each stratum, resulting in 80 cockle and pipi sampling points. Across all sampling points, there were only five pipi sampled, all of which were <15 mm shell length. Owing to their low sample size at Cockle Bay, pipi are not further reported on here.

Sediment samples at Cockle Bay were characterised by a low organic content, about 1–2% (see details in Appendix C, Table C-3). Sediment grain size was also similar across samples, which was mostly very fine (>63 µm) and fine sand (>125 µm). The proportion of fines (<63 µm grain size) was generally low (<5%), except for one sample in stratum A, where this grain size fraction was 41.5%.

The cockle population at Cockle Bay was distributed across both strata, and cockle were particularly prevalent in the mid-intertidal area (Figure 2, Table 1). Population estimates were similar in both strata, and the estimate for the total cockle population in 2013–14 was 33.40 million (CV: 8.14%) individuals, with a mean density of 212 cockles per m^2 (Table 2).

For large cockles (≥30 mm shell length), the population estimate was 20.84 million (CV: 9.50%) individuals, with a mean density of 132 cockles per m^2. Although the large size class dominated the cockle population (as in the previous survey in 2012–13), it showed a decrease in overall abundance and population density in 2013–14 compared with the preceding survey. At the same time, the population size of all cockles decreased, and this decline was a continuation from the two preceding surveys.

The relatively large size of cockles at this beach was also reflected in the length-frequency distributions (Table 3, Figure 3). The mean shell length of cockles was 29.99 mm in 2013–14. Although cockles of all sizes were present, recruits (≤15 mm shell length) only made up 6.09% of the cockle population. Nevertheless, this value was an increase from 1.53% of recruits in the previous survey.

Considering length-frequency distributions in the two strata, most of the large cockles in the current survey were in stratum B. In contrast, in the two preceding surveys, this size class was mostly found in stratum A. Cockles in stratum A included large individuals, but most individuals were <30 mm shell length.

3.1.1 Cockles at Cockle Bay

Figure 2: Map of sample strata and individual sample locations for cockles at Cockle Bay, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 1: Estimates of cockle abundance at Cockle Bay, by stratum, for 2013–14. 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	7.9	40	280	15.64	198	13.58
B	7.9	40	318	17.76	225	9.56

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	16.0	59.54	372	5.60	6.27	39	12.38
2010–11	16.0	72.20	451	5.61	21.29	133	8.08
2012–13	16.0	54.67	342	7.51	36.46	228	8.70
2013–14	15.8	33.40	212	8.14	20.84	132	9.50

Table 3: Summary statistics of the length-frequency (LF) distribution of cockles at Cockle Bay. LF distributions 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 (%)
2010–11	25.74	30	3–45	8.31	29.49
2012–13	30.40	32	6–44	1.53	66.69
2013–14	29.99	34	6–45	6.09	62.41

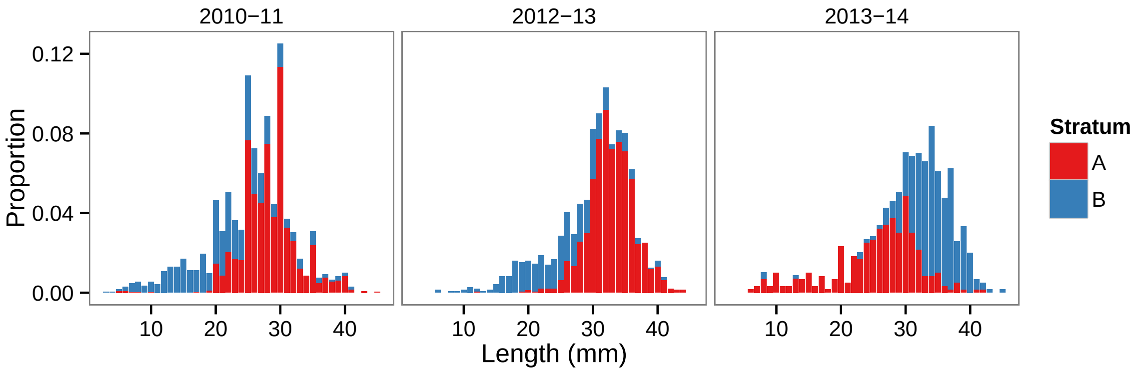

Figure 3: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Cockle Bay. LF distributions were estimated for all strata in each survey to give the distribution of total LFs.

3.2 Grahams Beach

Grahams Beach is in the western part of Manukau Harbour, on Awhitu Peninsula. This beach was first included in the northern shellfish surveys in 2006–07, with three surveys preceding the current population study (see Appendix B, Tables B-1, B-2). Prior to 2013–14, the bivalve populations were most recently assessed in 2012–13. Consistent with the previous surveys, the sampling in 2013–14 included the length of the beach within a single stratum. The sampling extent, i.e., the size of the stratum was slightly larger in the current survey than in the 2012–13 assessment, but similar to earlier surveys. Across this stratum, cockles and pipi were targeted in 134 sampling points (Figure 4, Table 4).

Sediment samples at Grahams Beach were taken within and outside the survey stratum (see details in Appendix C, Table C-3). The sediment was low in organic content (<1.5%) and in the proportion of fines (grain size <63 µm); most samples contained no or less than 0.4% fines. Instead, the sediment consisted mostly of fine to medium or coarse sand (grain size >125 µm to >500 µm).

The cockle survey in 2013–14 sampled 78 cockles across the 134 sampling points at Grahams Beach (Figure 4, Table 4). Based on these data, the total population estimate was 4.41 million (CV: 19.20%) cockles at this site (Table 5). The corresponding population density was 16 cockles per m^2. There were only few large cockles (≥30 mm shell length) within the population, with 0.12 million (CV: >100%) individuals within this size range, and a mean density of <1 cockle per m^2.

The population estimates were similar to values in the preceding survey in 2012–13 (Table 5). The number of large cockles showed an increase from previous surveys as individuals in this size class were previously absent or only present at very low numbers. Overall, the total cockle population at Grahams Beach has been small (<5 million cockles) across the surveys since 2006–07, except for a one-off, high estimate of 25.22 million cockles in 2010–11.

Although there was an increase in the proportion of large cockles within the population, the length-frequency distributions were similar between the two recent surveys (Table 6, Figure 5). The mean shell length of cockles in 2013–14 was 16.27 mm. Recruits (≤15 mm shell length) constituted about half (52.56%) of the cockle population. Following their prevalence in 2010–11, the proportion of recruits decreased in subsequent surveys. This decrease was evident in the change from a single mode of small-sized cockles (≤20 mm shell length) to two and three population modes in the two recent assessments, encompassing larger cockle sizes.

Sampling of the pipi population at Grahams Beach involved the same sampling points as the cockle sampling (Figure 6, Table 7). Pipi were present close to the shore and were patchily distributed across the stratum, with highest densities at the southern end. There were a total of 205 pipi sampled, resulting in a total population estimate of 11.60 million (CV: 21.72%) pipi and a mean density of 43 pipi per m^2 (Table 8). Similar to the cockle population, there were few large pipi (≥50 mm shell length) in the Grahams Beach population, with 0.06 million individuals within this size range, and a mean density of <1 pipi per m^2.

The total population estimate and the population density of pipi in 2013–14 reflected increases from previous surveys, although the size of the sampling extent varied slightly across the surveys (Table 8, see also Table B-2). For large pipi, there was a small increase in their total number at Grahams Beach, where this species was distributed close to the shore along most of the sample extent, with localised patches in the southern area. The slight increase in large pipi was evident in the length-frequency distributions (Table 9, Figure 7). Nevertheless, the mean shell length of pipi in the current assessment was 25 mm, half the length of the definition of the large size class. Considering recruits (≤20 mm shell length), there was a continuous decrease in their proportion in the population from 89.47% in 2010–11 to 40.27% in 2013–14. This change in pipi size modes was reflected in the shift from a generally unimodal population of small pipi in 2010–11 to several modes in subsequent surveys.

Overall, both the cockle and pipi populations at Graham Beach were small and contained few large individuals in the 2013–14 survey. This finding was consistent with previous surveys in recent years.

3.2.1 Cockles at Grahams Beach

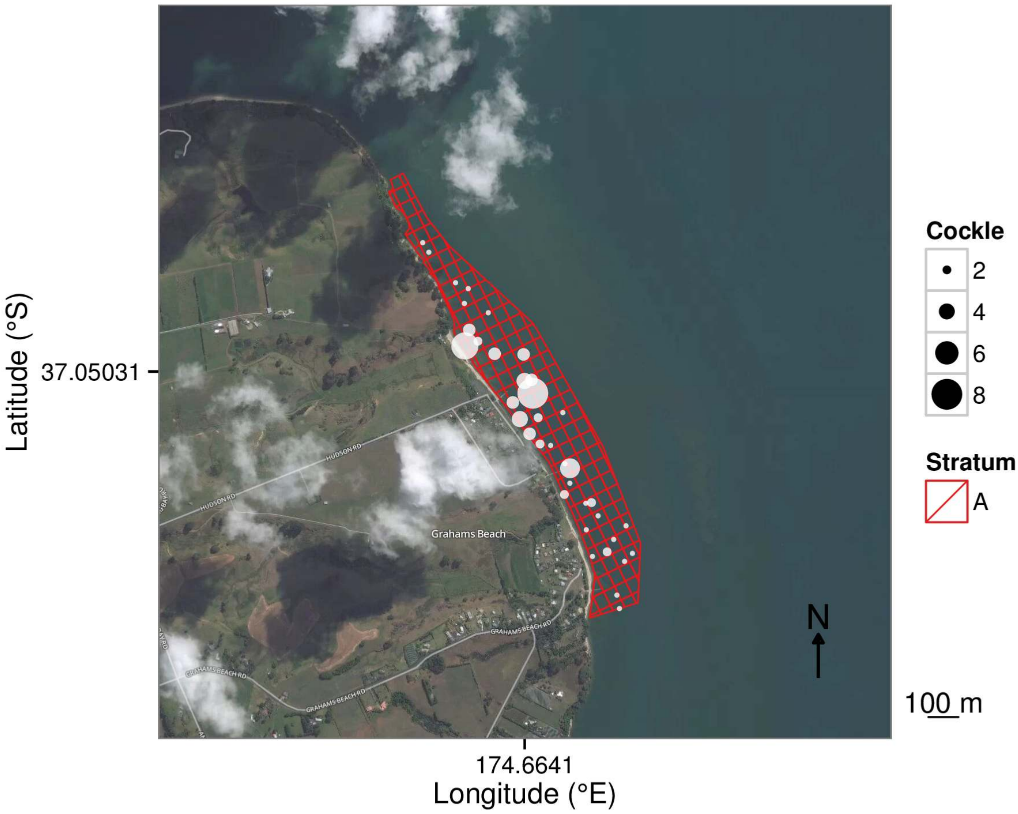

Figure 4: Map of sample strata and individual sample locations for cockles at Grahams Beach, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 4: Estimates of cockle abundance at Grahams Beach, by stratum, for 2013–14. 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	26.8	134	78	4.41	16	19.20

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2006–07	24.8	4.90	20	32.99	0.00	0	
2010–11	25.1	25.22	100	20.39	0.02	<1	>100
2012–13	20.1	4.23	21	21.00	0.00	0	
2013–14	26.8	4.41	16	19.20	0.12	<1	>100

Table 6: Summary statistics of the length-frequency (LF) distribution of cockles at Grahams Beach. LF distributions 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 (%)
2010–11	11.00	10	4–32	91.31	0.07
2012–13	18.69	22	6–28	31.68	0.00
2013–14	16.27	10	5–31	52.56	2.56

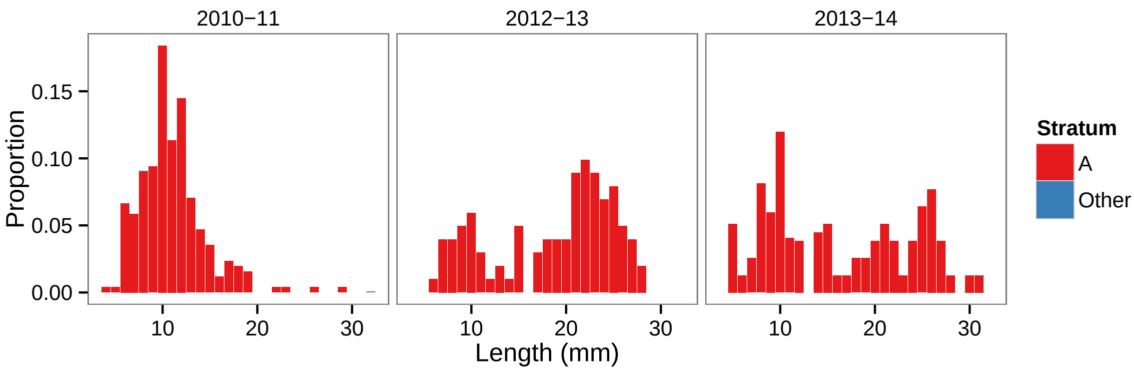

Figure 5: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Grahams Beach. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.2.2 Pipi at Grahams Beach

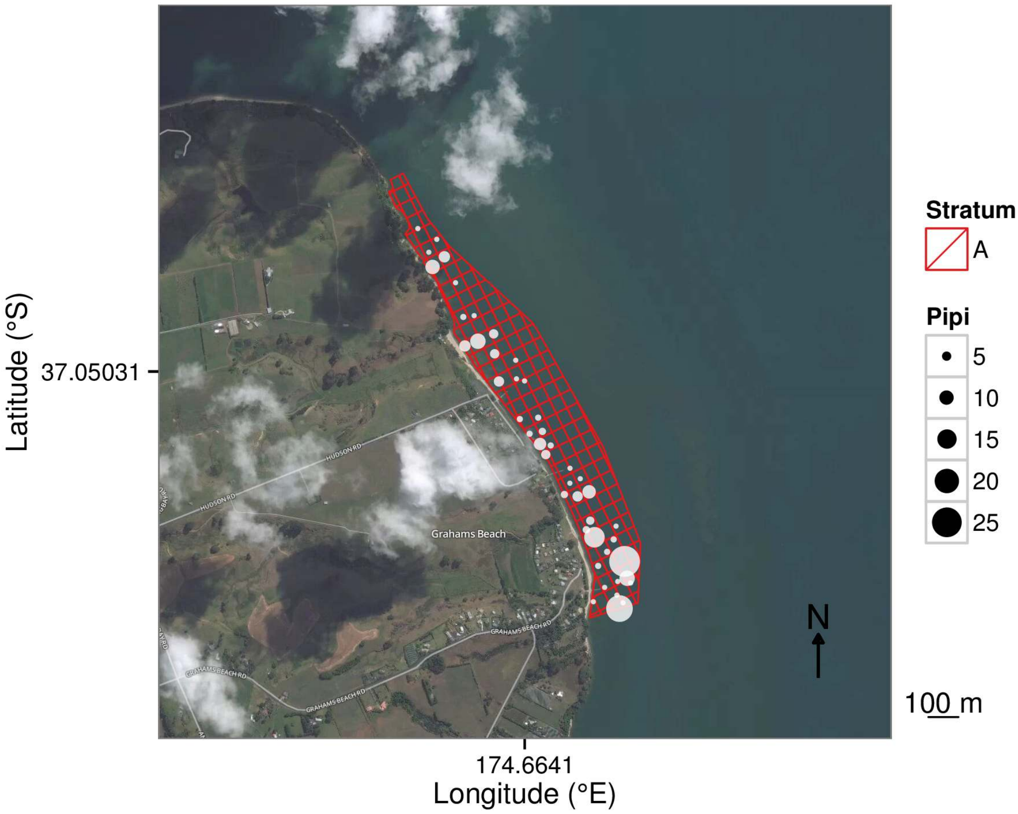

Figure 6: Map of sample strata and individual sample locations for pipi at Grahams Beach, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 7: Estimates of pipi abundance at Grahams Beach, by stratum, for 2013–14. 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	26.8	134	205	11.60	43	21.72

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2010–11	25.1	3.75	15	27.65	0.00	0	
2012–13	20.1	2.93	15	35.01	0.00	0	
2013–14	26.8	11.60	43	21.72	0.06	<1	>100

Table 9: Summary statistics of the length-frequency (LF) distribution of pipi at Grahams Beach. LF distributions 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 (%)
2010–11	12.95	10	6–32	89.47	0.00
2012–13	18.13	12	10–35	65.71	0.00
2013–14	25.00	11	4–53	40.27	0.49

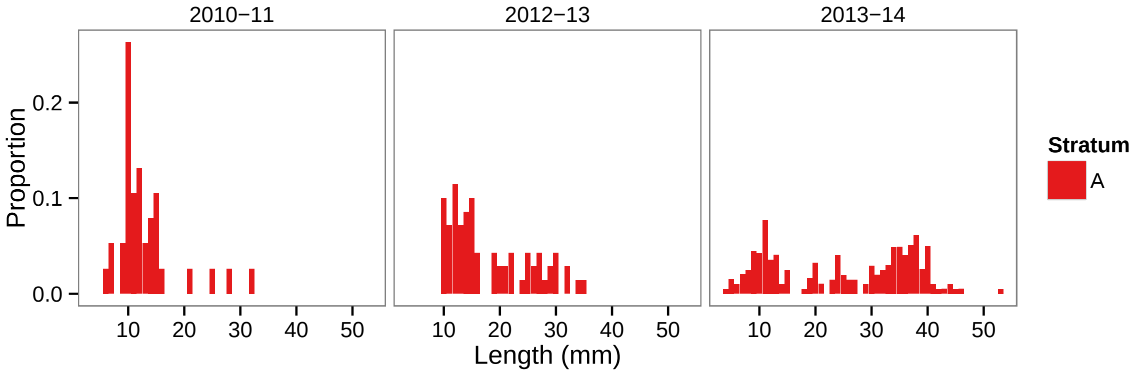

Figure 7: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Grahams Beach.

3.3 Little Waihi Estuary

Little Waihi Estuary is situated in Bay of Plenty, east of Tauranga. This estuary has been included in the bivalve surveys since 2000–01, encompassing eight surveys, including the current 2013–14 assessment (see Appendix B, Tables B-1, B-2). Across the surveys, the areas of the sampling extent for cockles and pipi has markedly increased in recent years (i.e., since 2009–10) compared with earlier surveys. There was also an increase in the sampling extent between the surveys in 2012–13 and 2013–14.

The bivalve sampling in 2013–14 involved five strata close to the entrance of the estuary (e.g., Figure 8, Table 10). Most of stratum A was in the main channel directly at the estuary entrance, with strata B and E extending from the entrance along the main channel. There was a smaller channel (branching off the main channel) through strata C and D. Cockles and pipi were surveyed across all strata, with a total of 196 sampling points.

Sediment samples at Little Waihi Estuary were characterised by low organic content (generally less than 2%) and grain sizes dominated by fine and medium sand (i.e., grain sizes >125 µm and >250 µm)(see details in Appendix C, Table C-3). There was a low proportion of fines (grain size <63 µm), which ranged from 0.8 to 2.3%. In general, there was little variation in sediment properties across samples.

Cockles in Little Waihi Estuary in 2013–14 were mostly in strata C–E, and in the southern area of stratum B (Figure 8, Table 10). The highest population density was in Stratum D, with 228 cockles per m^2 (CV: 15.29%), followed by 177 cockles per m^2 (CV: 33.99%) in stratum C (Table 10) and 142 cockles per m^2 (CV: 44.44%) in stratum E.

The total population estimate for 2013–14 was 21.45 million cockles (CV: 14.77%); the corresponding mean density was 126 cockles per m^2 (Table 11). Large cockles (≥30 mm shell length) were only a small component of the overall population, with an estimated 0.34 million cockles (CV: 59.9%) in this size class. This finding was consistent across surveys since 2002–03, as the large size class generally only contributed a small number of individuals to the overall cockle population, and densities of large individuals were low.

Length-frequency distributions confirmed the prevalence of small-sized cockles in Little Waihi Estuary (Table 12, Figure 9). The mean shell length was 17.77 mm in 2013–14, with recruits (≤15 mm shell length) constituting 35.50% of the cockle population. This pattern was similar in the two preceding surveys, with the cockle population largely consisting of small-sized individuals. In contrast, large cockle only made up a small proportion (0.43% to 1.27%) of the total population.

Comparing the population estimates across the three recent surveys that had a similar sampling extent, the cockle population was similar in size and in the proportion of large cockles. While there were few individuals in the latter size class, the population mostly consisted of small and medium-sized cockles and to a lesser extent, of recruits.

Sampling of pipi in Little Waihi Estuary in 2013–14 encompassed the same strata and sampling points as the cockle survey (Figure 10, Table 13). Across the sampling area, pipi were mostly associated with the submerged parts of strata B, C, and E, with few pipi present in other areas. Most of the pipi population was in strata B and E, where the estimated population densities were 1069 pipi m^2 (CV: 21.60%) and 1287 pipi m^2 (CV: 21.94%), respectively.

The total pipi population in 2013–14 was estimated as 113.46 million individuals (CV: 14.61%), with a mean density of 664 pipi m^2 (Table 14). This total population estimate included only a small proportion of large pipi (≥50 mm shell length), with 4.55 million (CV: 31.30%) individuals in this size class. The pipi population estimates in 2013–14 were a marked decrease from the previous estimates in 2012–13, especially in view of the slightly larger sampling extent in the present survey.

The small proportion of large pipi was also evident in the length-frequency distributions, which were similar in the recent surveys, including 2013–14 (Table 15, Figure 11). Mean pipi sizes were less than 34 mm shell length. Recruits (≤20 mm shell length) contributed 17.71% pipi to the total population.

3.3.1 Cockles at Little Waihi Estuary

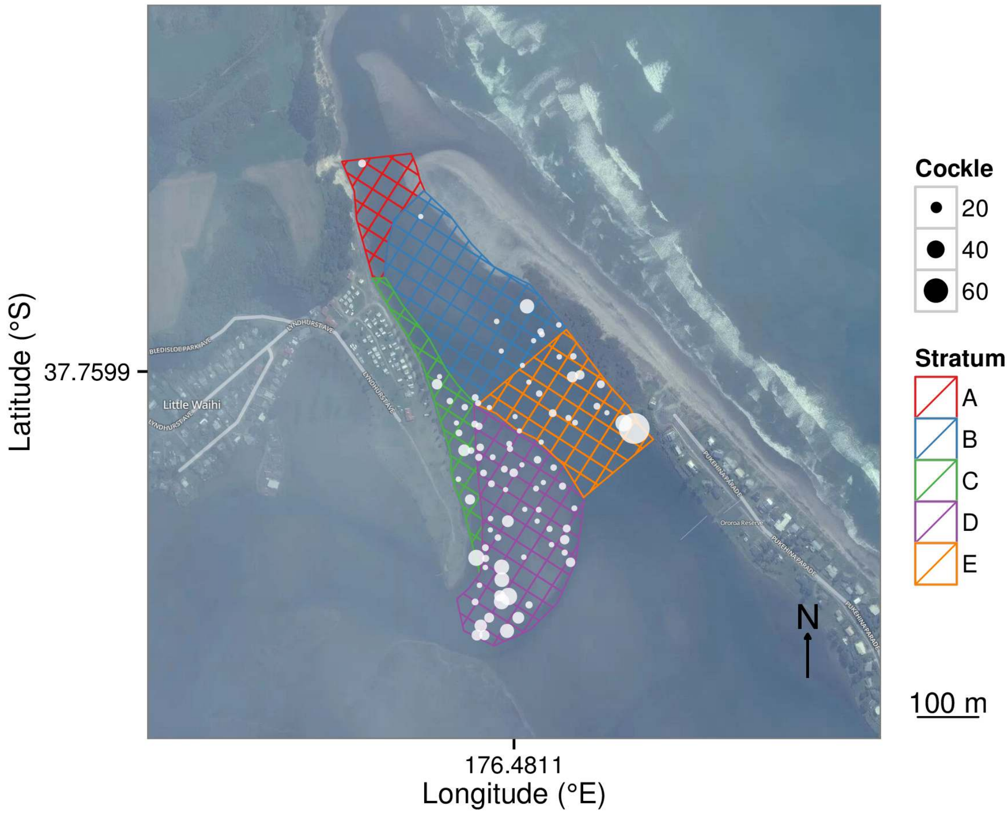

Figure 8: Map of sample strata and individual sample locations for cockles at Little Waihi Estuary, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 10: Estimates of cockle abundance at Little Waihi Estuary, by stratum, for 2013–14. 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	18	9	0.20	14	>100
B	5.2	61	55	1.33	26	54.67
C	1.7	19	119	2.98	177	33.99
D	5.2	59	475	11.82	228	15.29
E	3.6	39	196	5.12	142	44.44

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	4.44	148	11.06	0.95	32	13.04
2002–03	3.0	0.96	32	5.97	0.07	2	>100
2003–04	3.1	3.92	125	8.01	0.40	13	22.55
2004–05	3.8	3.73	99	9.65	0.17	4	25.95
2006–07	3.2	2.09	66	18.32	0.01	<1	>100
2009–10	13.9	20.55	148	16.57	0.08	<1	75.78
2012–13	15.4	17.77	115	18.58	0.20	1	56.47
2013–14	17.1	21.45	126	14.77	0.34	2	59.9

Table 12: Summary statistics of the length-frequency (LF) distribution of cockles at Little Waihi Estuary. LF distributions 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	18.04	16	5–32	29.05	0.43
2012–13	15.72	20	2–45	45.25	1.15
2013–14	17.77	22	6–33	35.50	1.27

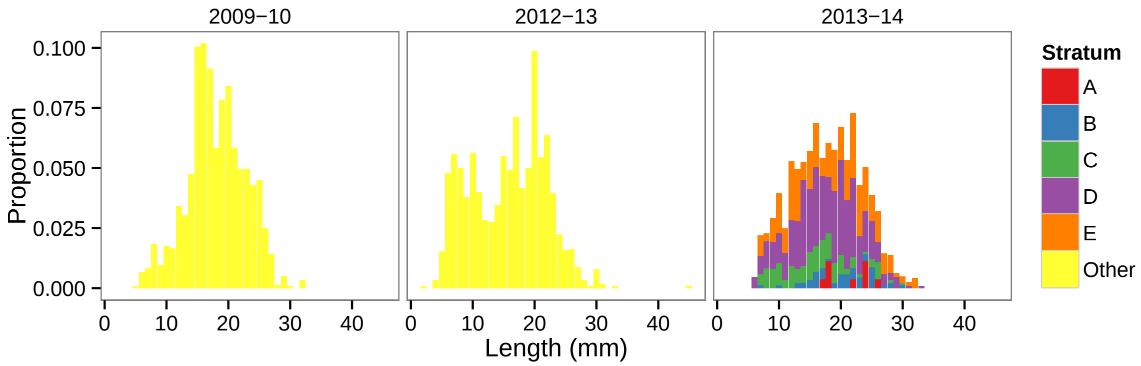

Figure 9: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Little Waihi Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in 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.

3.3.2 Pipi at Little Waihi Estuary

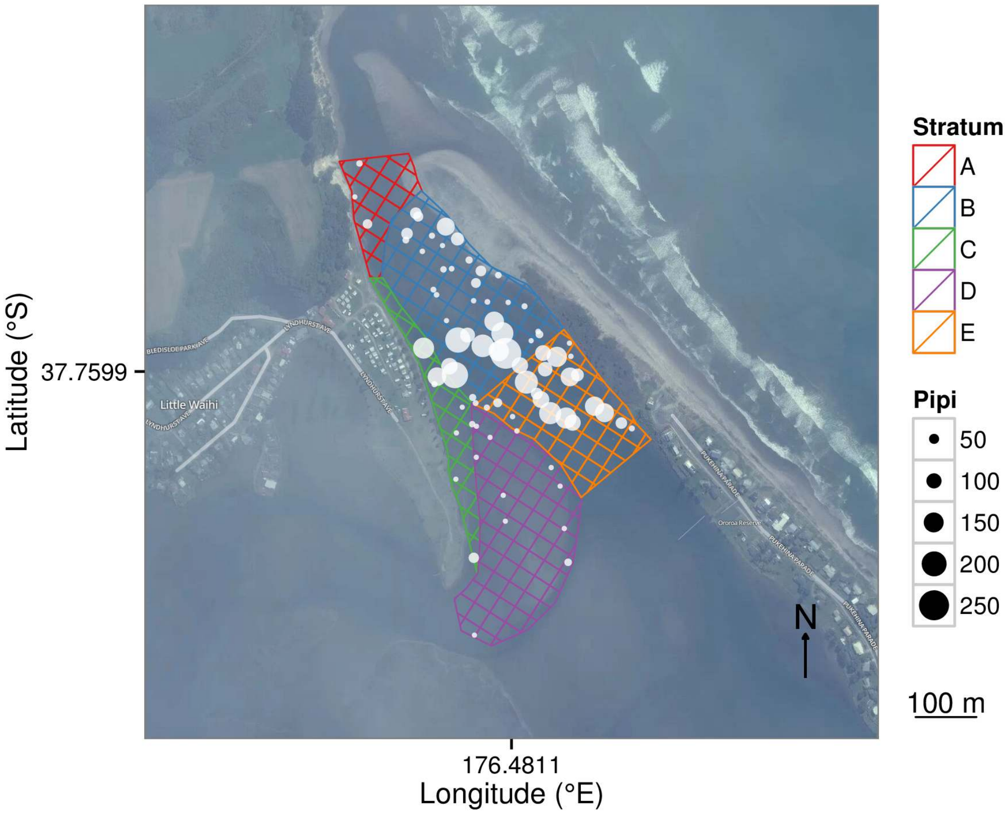

Figure 10: Map of sample strata and individual sample locations for pipi at Little Waihi Estuary, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 13: Estimates of pipi abundance at Little Waihi Estuary, by stratum, for 2013–14. 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	18	59	1.32	93	76.81
B	5.2	61	2 302	55.63	1 069	21.60
C	1.7	19	370	9.26	552	54.60
D	5.2	59	38	0.95	18	63.67
E	3.6	39	1 772	46.30	1 287	21.94

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2000–01	3.0	28.69	956	8.78	3.74	125	11.98
2002–03	3.0	5.81	194	7.39	0.48	16	54.14
2003–04	3.1	7.05	226	9.15	0.84	27	19.15
2004–05	3.8	48.00	1 280	6.16	1.90	51	14.53
2006–07	3.2	44.52	1 409	7.47	2.00	63	10.21
2009–10	13.9	271.99	1 954	11.54	10.12	73	20.08
2012–13	15.4	219.43	1 423	7.88	10.26	67	26.80
2013–14	17.1	113.46	664	14.61	4.55	27	31.30

Table 15: Summary statistics of the length-frequency (LF) distribution of pipi at Little Waihi Estuary. LF distributions 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	33.35	35	7–56	18.25	4.32
2012–13	33.16	40	5–59	15.32	4.68
2013–14	31.49	42	8–57	17.71	2.68

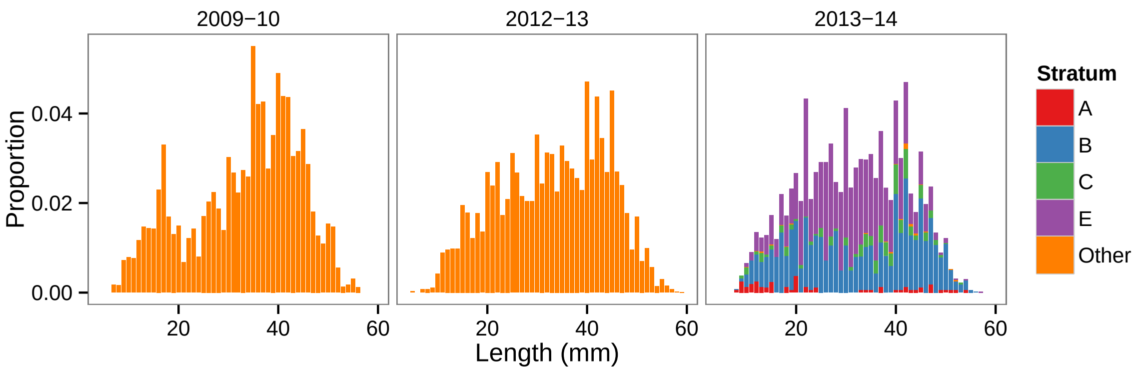

Figure 11: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Little Waihi Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.4 Marsden Bank

Marsden Bank is situated at Marsden Point, at the southern side of the entrance to Whangarei Harbour, directly adjacent to Mair Bank. There was a two-year closure to the take of pipi from 17 February 2011 to 16 February 2013, although this closure only included Marsden Bank. More recently, both Marsden and Mair banks were closed, with the closure coming into effect on 1 October 2014.

This site has been part of the northern shellfish surveys since 2010–11, with two surveys prior to the current study, including the recent survey in 2012–13 (see Appendix B, Tables B-1, B-2). Other recent surveys of the local pipi populations were conducted at Marsden Bank in May 2012 (Williams et al. unpubl. data) and at Mair Bank in February 2014 (Pawley 2014).

The 2013–14 survey at Marsden Bank encompassed the beach area directly adjacent to the Marsden Point Oil Refinery, immediately east of the wharf. The sampling extent consisted of two strata, A and B. There were 129 sampling points across both strata (e.g., Figure 12, Table 16). There were no cockles in either strata in 2013–14, so that the present study only provides a population assessment for pipi.

The sediment at Marsden Bank had a low organic content, with few samples exceeding 1% of organic content. Sediment grain size also showed little variation across samples, with the fine sand (grain size >125 µm) and the medium sand (>250 µm) fractions dominating the grain size distributions (see details in Appendix C, Table C-3).

In the 2013–14 survey, pipi were only present in stratum A, where they were highly localised within this stratum, at the centre of the bank. There were 92 pipi sampled in this survey, resulting in a total population estimate of 3.23 million (CV: 51.83%) pipi (Table 17). The average population density was 21 pipi m^{-2}. Owing to the low abundance and patchy distribution of pipi at Marsden Bank, the CV in the current survey was high.

There were no large individuals (≥ 50 mm shell length) within the Marsden Bank pipi population. While this finding was consistent with the previous survey in 2012–13, the total pipi population experienced a considerable decline from the total of 60.53 million (CV: 19.79%) pipi in the preceding survey. Similarly, the population density declined from 959 pipi m^{-2} in the previous year. (Note that the reported sampling extent for the 2012–13 survey may be incorrect, affecting the corresponding pipi population density in the same year, see details in Appendix D.)

While large pipi were absent at Marsden Bank, there were also few medium-size individuals, with small pipi dominating the population (Table 18, Figure 13). The mean shell length was 16.18 mm, and recruits (≤ 20 mm shell length) made up two thirds (69.10%) of the pipi population.

In summary, both the distribution and the abundance of pipi at Marsden Bank have substantially declined in recent years. The population consisted largely of small-sized pipi that were patchily distributed at a few points at the centre of the bank. At the same time, the presence of considerable numbers of large pipi shells at the time of sampling indicated recent pipi mortalities (K. Berkenbusch, pers. obs.). The reason for the mortalities is currently unknown, but a similar decline was observed in the pipi population at adjacent Mair Bank in February 2014 (Pawley 2014). At Mair Bank, the total pipi population declined from about 460 million individuals in 2010–11 to just under five million individuals in 2013–14. A recent review of available data attempted to identify potential factors that caused the observed pipi decline at Mair Bank, and did not find any evidence of disease in the population (Williams & Hume 2014). In view of this finding, the authors suggested that high natural mortality and low recruitment of the pipi population may be related to observed physical changes of Mair Bank (i.e., its morphology).

3.4.1 Pipi at Marsden Bank

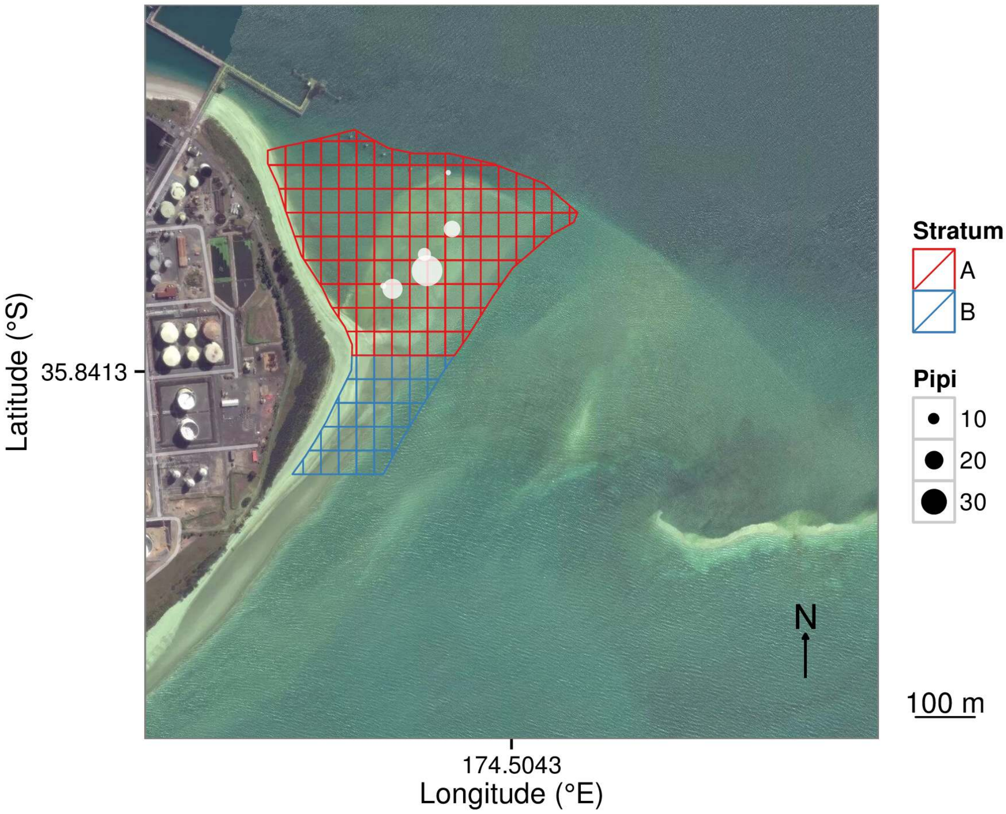

Figure 12: Map of sample strata and individual sample locations for pipi at Marsden Bank, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 16: Estimates of pipi abundance at Marsden Bank, by stratum, for 2013–14. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	12.4	100	92	3.23	26	51.83
B	3.0	29	0	0.00	0	

Table 17: Estimates of pipi abundance at Marsden Bank for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV).

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2009–10	11.5	210.88	1 833	20.28	8.00	69	41.14
2012–13	6.3	60.53	959	19.79	0.00	0	
2013–14	15.4	3.23	21	51.83	0.00	0	

Table 18: Summary statistics of the length-frequency (LF) distribution of pipi at Marsden Bank. LF distributions 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	17.99	13	3–78	80.23	3.98
2012–13	20.60	20	1–48	57.86	0.00
2013–14	16.18	9	6–40	69.10	0.00

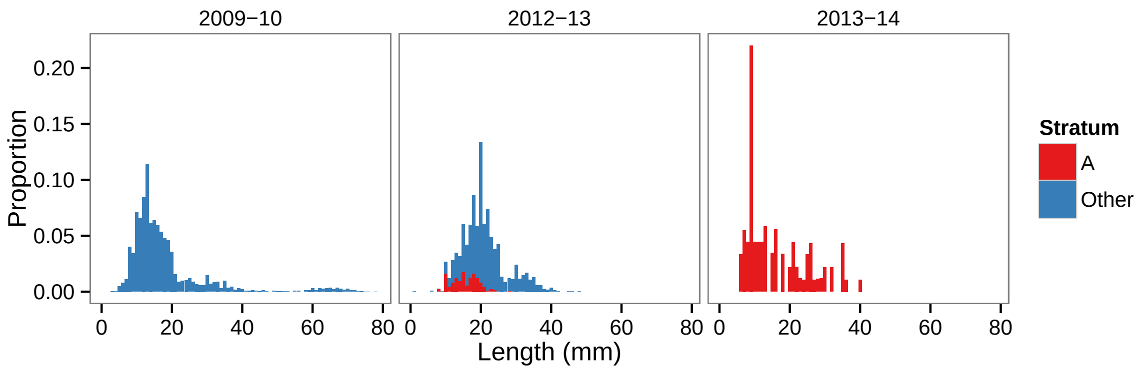

Figure 13: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Marsden Bank. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.5 Okoromai Bay

Okoromai Bay is north of Auckland, on the southern side of Whangaparoa Peninsula. This bay has been one of the most frequently surveyed sites within the survey series, with nine surveys since 1996–97, including a survey in the previous year, in 2012–13 (see Appendix B, Tables B-1, B-2). The size of the sampling extent at Okoromai Bay was similar throughout most of the surveys. In 2013–14, there were two strata across the intertidal sandflat, with 104 sampling points across the sampling extent (Figure 14, Table 19).

The sediment within the sampling extent at Okoromai Bay had a low organic content of 1.5 to 2.4% across the samples (see details in Appendix C, Table C-3). There was some variation in the proportion of fines (grain size <63 µm), which was generally low at less than 2%. The sediment grain size was largely very fine to fine sand (grain sizes >63 and >125 µm, respectively).

There were only seven pipi sampled across both strata at Okoromai Bay in 2013–14. All pipi were ≤20 mm shell length. Because of the low number of pipi, the current study only included a population assessment for cockles.

The cockle population at Okoromai Bay was distributed across both strata A and B, with relatively high densities at the western and eastern sides of stratum B. The total population estimate at this site was 27.78 million (CV: 12.67%) cockles in 2013–14 (Table 20). This total estimate corresponded with a population density of 140 cockles per m^2. Although the total population size and density were similar to the two preceding surveys, there was marked decrease in the number of large cockles (≥ 30 mm shell length) in the current survey. There were 13.61 million (CV: 11.82%) cockles in this size class the previous year (and a similar number in 2009–10) compared with less than a quarter of this estimate in 2013–14 (4.44 million, CV: 19.47%). The mean density of large cockles in the 2013–14 survey was also considerably lower (less than a third) than in the most recent previous surveys, with 22 cockles per m^2. There was also an earlier marked decline in the cockle population at Okoromai Bay, as both the total number and the number of cockles in the large size class decreased notably in 2006–07; both population measures showed increases in subsequent surveys, e.g., in 2009–2010, before declining again in 2013–14.

The decrease in the number of large cockles was also evident in the length-frequency distributions and shell lengths in the recent surveys (Table 21, Figure 15). In 2013–14, the mean shell length was 21.38 mm, and this metric and the mode of 12 mm shell length were considerably lower than the 27-mm mean and 30-mm modal lengths in the two previous surveys. Similarly, recruits (≤15 mm shell length) constituted a large proportion of the cockle population in this assessment, while large cockles made a small contribution to the overall population compared with the surveys in 2009–10 and 2012–13.

3.5.1 Cockles at Okoromai Bay

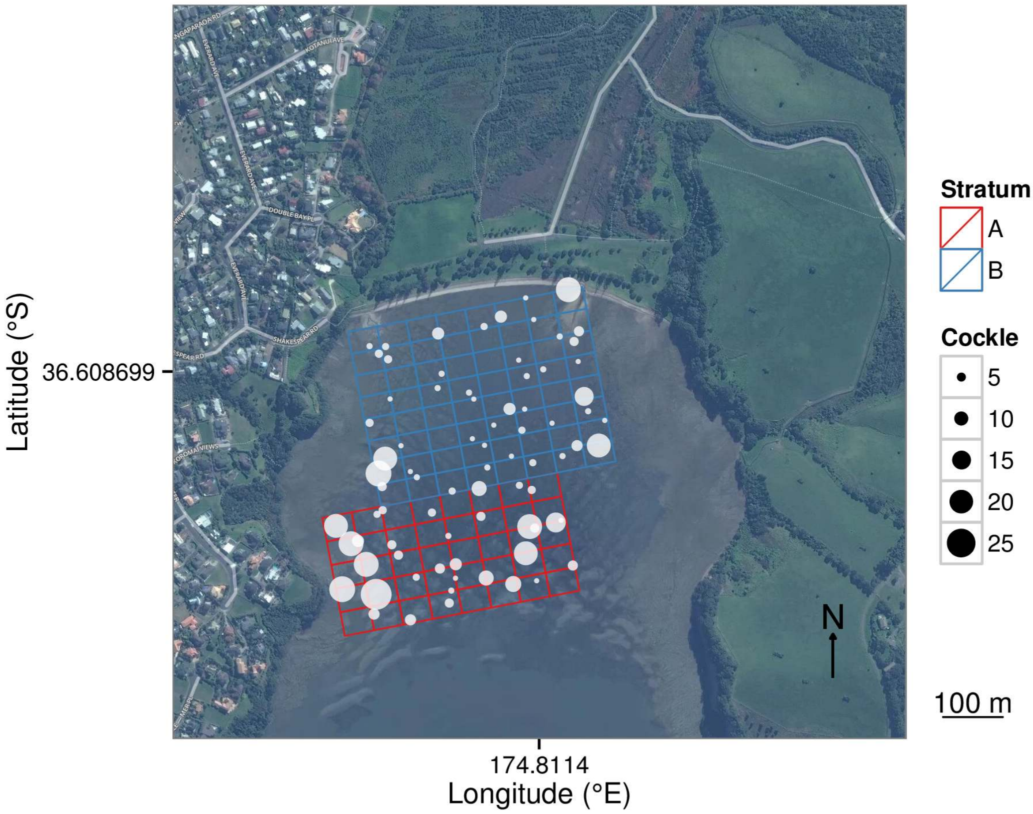

Figure 14: Map of sample strata and individual sample locations for cockles at Okoromai Bay, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 19: Estimates of cockle abundance at Okoromai Bay, by stratum, for 2013–14. 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	8.0	40	297	16.83	210	16.29
B	11.8	64	209	10.95	93	20.15

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	20.0	90.05	450	4.26	24.38	122	7.51
2001–02	24.0	27.26	114	7.78	8.66	36	11.77
2002–03	20.0	26.86	134	5.10	7.05	35	9.30
2003–04	20.0	27.96	140	11.48	12.01	60	15.04
2004–05	20.0	34.50	172	7.44	13.80	69	6.18
2006–07	20.0	17.39	87	9.08	7.03	35	15.88
2009–10	20.0	29.62	148	9.60	13.07	65	10.74
2012–13	20.0	28.50	142	10.61	13.61	68	11.82
2013–14	19.8	27.78	140	12.67	4.44	22	19.47

Table 21: Summary statistics of the length-frequency (LF) distribution of cockles at Okoromai Bay. LF distributions 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	27.37	30	6–47	9.81	47.08
2012–13	27.79	30	5–45	6.83	47.75
2013–14	21.38	12	7–39	28.09	15.91

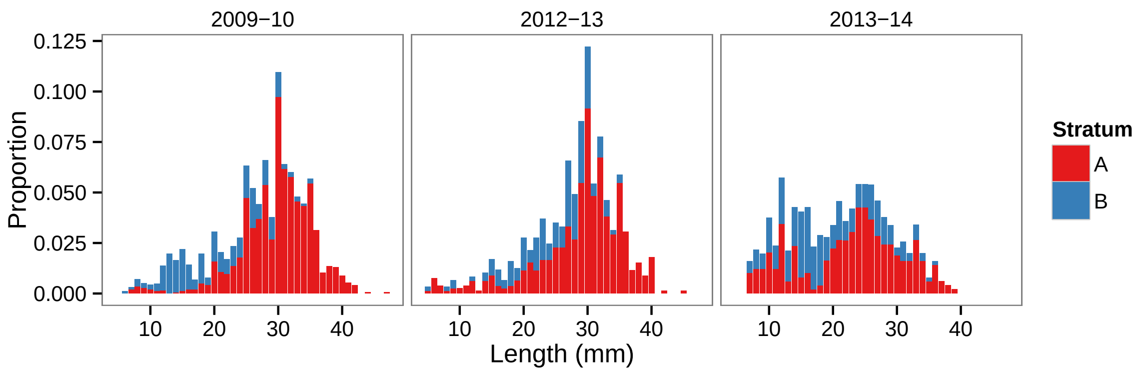

Figure 15: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Okoromai Bay. LF distributions were estimated for all strata in each survey to give the distribution of total LFs.

3.6 Pataua Estuary

Pataua Estuary is north of Whangarei and largely consists of extensive intertidal flats on either side of a tidal channel. Close to the estuary entrance, the intertidal areas are less sheltered, with elevated areas and sandbanks on the southern side and a narrow bank on the northern side of the channel. This estuary has been surveyed four times, including the present survey in 2013–14 (see Appendix B, Tables B-1, B-2). The most recent previous survey was conducted in 2005–06.

The sampling extent in 2013–14 was extended relative to previous surveys to include the extent of the cockle beds in strata A and B (e.g., Figure 16, Table 22). These two strata were located on the mudflats of the estuary. The remaining two strata C and D were located along the channel, close to the estuary entrance, and were sampled for pipi. Both pipi strata were sampled using a second phase to reduce the CV of abundance estimates.

The sediment in the cockle strata (strata A and B) was dominated by fine sand (grain size <250 µm), with some very fine sand (<125 µm) and medium sand (<500 µm) (see details in Appendix C, Table C-3). Sediment organic matter content varied between 1.5% and 4.8% in these strata. Sediment cores in pipi strata C and D were made up of coarser sediment, with medium and coarse grain sands (<500 µm and <2000 µm, respectively) making up the bulk of the substrate. These samples also had a lower percentage of organic matter than sediment in the cockle strata, ranging from 0.9% to 1.3%.

Cockles were abundant in strata A and B, and distributed throughout both strata, except for the channel areas (Figure 16, Table 22). There were an estimated 212.13 and 134.24 million cockles in these strata, with corresponding population densities of 1776 and 958 cockles m^2. There were few cockles in the other strata. The estimated total cockle abundance across all strata was 346.39 million cockles (CV: 5.94%), which represents an increasing trend from previous studies (Table 23). The estimated cockle density also increased from 832–1182 cockles m^2 in previous surveys to 1317 cockles m^2 in 2013–14. Although the increased sampling extent in the current study contributed to this increase, the population estimate based on the sampling extent of previous surveys also revealed an increase, with a total of 188.94 million cockles (CV: 7.56%) and a population density of 1813 cockles m^2. Nevertheless, the abundance of large cockles (≥30 mm shell length) declined both in number and density from previous surveys, despite the extended survey extent in the present study. The density of large cockle sdecreased by nearly an order of magnitude; the density in 2013–14 was estimated at 25 cockles m^2 (CV: 15.94%), compared with 190 cockles m^2 (CV: 10.72%) in the previous survey in 2005–06. For the sampling extent of previous surveys, the population density of large cockles was 42 cockles m^2 (CV: 17.92%).

The reduction in the number of large cockles was also reflected in the length-frequency distribution, with a shift in the mode from 25 mm shell length in 2005–06 to 20 mm shell length in 2013–14 (Table 24, Figure 17). The decrease of large cockle in the recent survey was also evident in the small proportion of this size class within the population, which was 1.59% compared with 18.38% of cockles in this size class in 2005–06. In contrast, the proportion of recruits increased from 7.45% in the preceding survey to 31.81% in the current study.

Pipi were present in all strata, but were only at high densities in strata C and D (Figure 18, Table 25). Average densities in these strata were 583 pipi m^2 in stratum C and 320 pipi m^2 in stratum D. The estimated total population estimate across strata was 6.42 million pipi (CV: 16.51%) in 2013–14 (it was 4.47 million pipi (CV: 22.95%) when based on the sampling extent of previous surveys) (Table 26). This estimate was higher than estimates for the two previous surveys, but all three surveys had considerably lower estimated abundances than the survey in 2002–03, when the population size was estimated at 16.58 million (CV: 14.00%) pipi.

At the same time, large pipi (≥50 mm shell length) contributed few individuals to the population overall, with an estimated population size comparable to estimates in the two preceding surveys, with 0.47 million pipi (CV: 60.35%) in this size class in 2013–14. The density of large pipi was 2 individuals m^2 (CV: 60.35%), and this estimate was similar to that for the smaller sampling extent of previous surveys of 3 pipi m^2 (CV: 59.71%).

The length-frequency distribution of the pipi population in 2013–14 was multi-modal, with predominantly smaller pipi in stratum B, and larger pipi in the remaining strata (Table 27, Figure 19). Despite the larger size mode in the current study, the length-frequency distribution contained fewer large individuals ($\geq$50 mm shell length) than previous surveys, and was truncated relative to earlier surveys (Figure 19); pipi in the earlier surveys were about 70 mm shell length (in 2003–04 and 2005–06) compared with the maximum shell length of 58 mm in 2013–14.

While the proportion of large pipi within the population was small, reflecting a marked decline of large size pipi in 2013–14 (6.27% compared with 38.20% in 2005–06), the proportion of recruits ($\leq$20 mm shell length) showed a marked increase to 29.82% in the current survey compared with 2.65% in the preceding assessment.

3.6.1 Cockles at Pataua Estuary

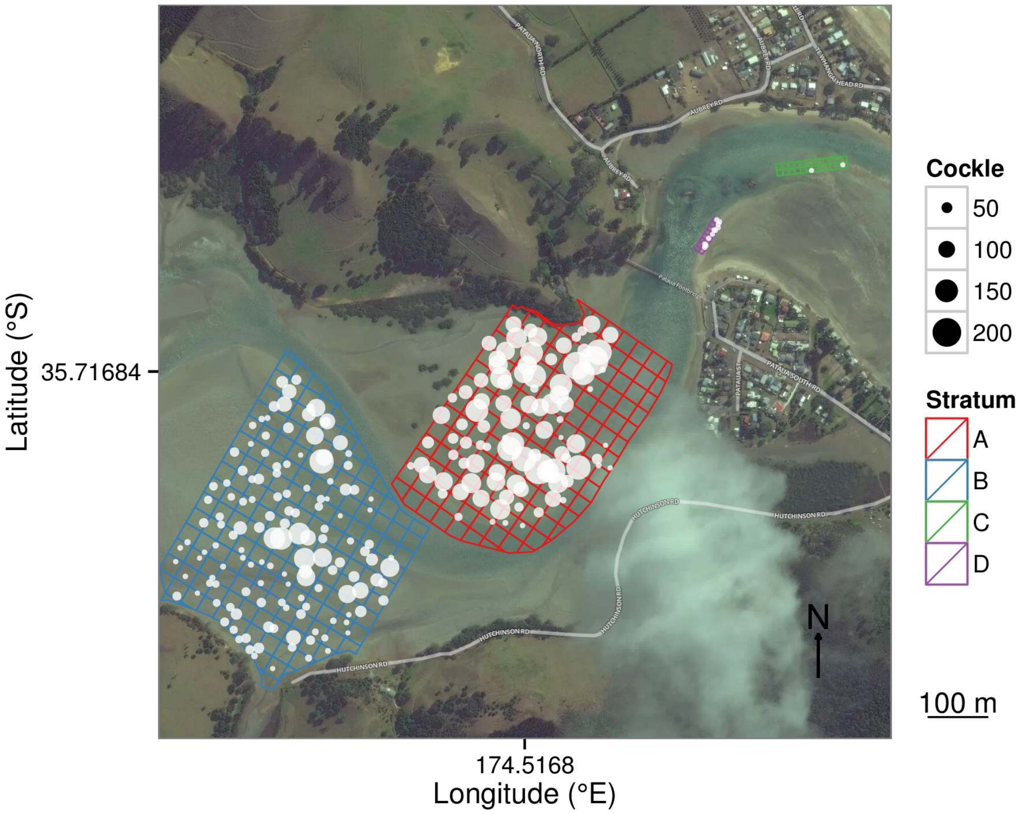

Figure 16: Map of sample strata and individual sample locations for cockles at Pataua Estuary, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 22: Estimates of cockle abundance at Pataua Estuary, by stratum, for 2013–14. 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	11.9	133	8 340	212.13	1 776	8.14
B	14.0	153	5 172	134.24	958	8.35
C	0.2	48	2	0.00	1	69.95
D	0.1	32	20	0.02	18	28.51

Table 23: Estimates of cockle abundance at Pataua Estuary for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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	10.7	88.64	832	4.45	21.63	203	9.83
2003–04	10.4	123.54	1 182	3.02	13.56	130	12.61
2005–06	10.4	108.08	1 034	5.18	19.87	190	10.72
2013–14	26.3	346.39	1 317	5.94	6.48	25	15.94
2013–14*	10.4	188.94	1 813	7.56	4.33	42	17.92

Table 24: Summary statistics of the length-frequency (LF) distribution of cockles at Pataua Estuary. LF distributions 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	22.76	22	6–42	10.68	10.97
2005–06	24.47	25	6–43	7.45	18.38
2013–14	17.97	20	4–58	31.81	1.59

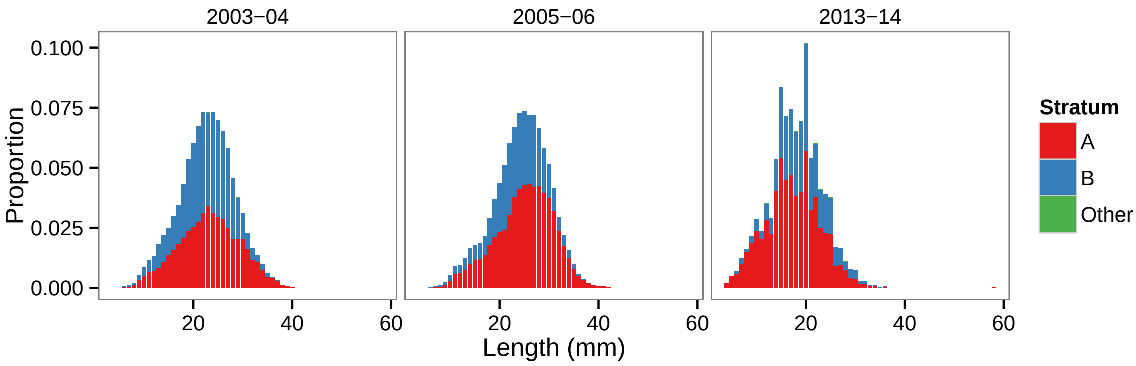

Figure 17: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Pataua Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.6.2 Pipi at Pataua Estuary

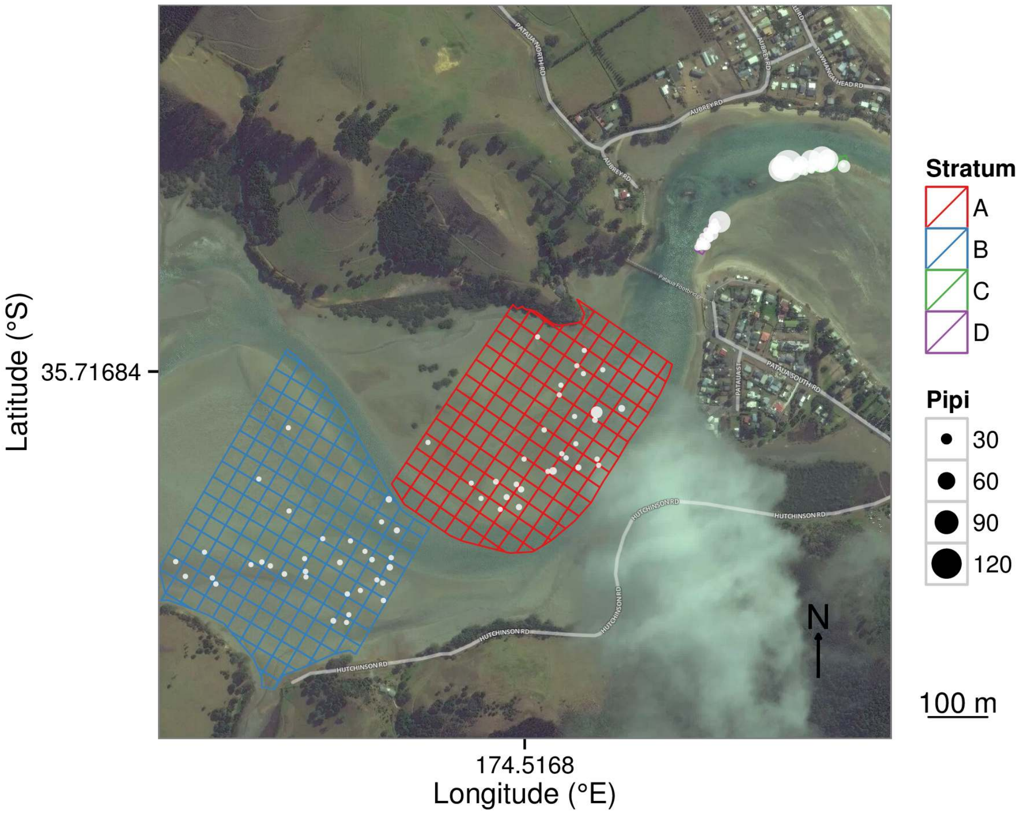

Figure 18: Map of sample strata and individual sample locations for pipi at Pataua Estuary, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 25: Estimates of pipi abundance at Pataua Estuary, by stratum, for 2013–14. 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	11.9	133	108	2.75	23	34.15
B	14.0	153	75	1.95	14	19.67
C	0.2	48	988	1.40	583	21.66
D	0.1	32	361	0.33	320	22.57

Table 26: Estimates of pipi abundance at Pataua Estuary for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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	10.7	16.58	156	14.00	0.02	<1	>100
2003–04	10.4	2.21	21	11.72	0.43	4	11.25
2005–06	10.4	1.18	11	9.73	0.45	4	45.99
2013–14	26.3	6.42	24	16.51	0.47	2	60.35
2013–14*	10.4	4.47	43	22.95	0.32	3	59.71

Table 27: Summary statistics of the length-frequency (LF) distribution of pipi at Pataua Estuary. LF distributions 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	33.96	23	15–72	4.46	19.28
2005–06	42.47	25	15–71	2.65	38.20
2013–14	31.28	19	7–58	29.82	6.27

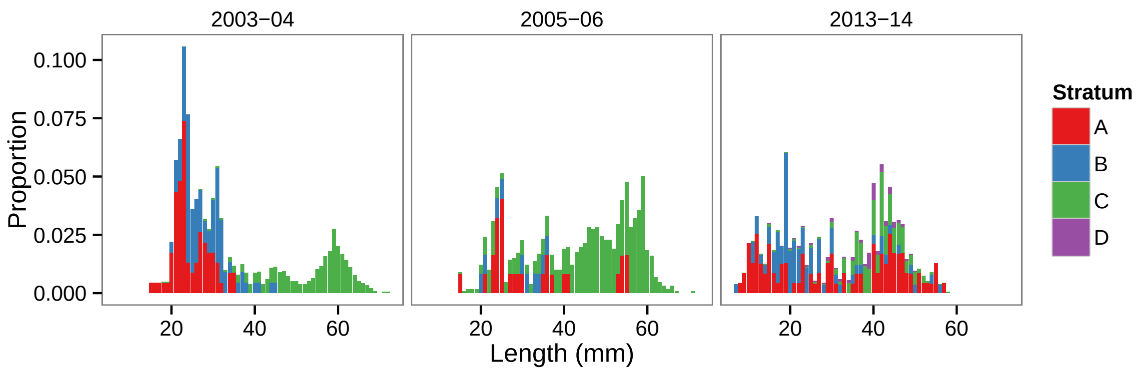

Figure 19: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Pataua Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs.

3.7 Tairua Harbour

Tairua Harbour is on the eastern side of Coromandel Peninsula. This site has been included in the bivalve assessments since 1999–00 (see Appendix B, Tables B-1, B-2). There have been seven surveys prior to the current study, most recently in 2010–11. The size of the sampling extent has varied throughout the survey series, with the 2013–14 study involving the largest sampling extent, encompassing a total of 359 sampling points (Figure 20).

Previous bivalve surveys in Tairua Harbour have focused on two areas north and south of the main channel. The current survey used the same sampling strata as the preceding survey in 2009–10, although some of the strata sizes varied. The northern area included an extensive intertidal sandflat, with four strata (A, B, E, and F) on this side of the main channel. Stratum A on the northern side extended along the channel, corresponding with the distribution of pipi. The fourth stratum north of the channel (stratum F) was close to the harbour entrance; this stratum was added to the sampling extent in the 2009–10 survey. In addition to the strata north of the main channel, there were two strata (C and D) on the southern side, at Pauanui. These strata were situated along the southern side of the main channel and along a side channel (close to the beach), respectively. The two strata were next to each other at the harbour entrance. The 2013–14 survey generally followed the sampling layout from the 2009–10 survey, with adjustments to the location and size of the strata for the pipi sampling, based on the location of the pipi beds.

Sediment samples at Tairua Harbour were taken within all of the strata and in adjacent areas (see details in Appendix C, Table C-3). The sediment was characterised by a low organic content of less than 4%. The proportion of fines (grain size <63 µm) was also small in most samples; the highest proportion of fines was 11–12% in three of the samples (in stratum E). Fine and medium sand (grain sizes >125 and >500 µm) were the prevalent sediment grain size fractions across the different strata.

The cockle population in Tairua Harbour in 2013–14 was distributed throughout most of the strata, with high-density areas in strata B and E (Figure 20, Table 28). While these two strata supported the largest number of cockles across the sampling extent, population densities were also high in strata C and D. The population density was comparatively low in stratum F, and there were few cockles in stratum A. The total population estimate for cockles in Tairua Harbour was 62.60 million (CV: 9.31%) cockles in this survey, with an average population density of 667 individuals per m^2 (Table 29). These estimates were an increase from the previous survey; however, the sampling extent was also considerably larger than in 2010–11.

The larger sampling extent was also relevant for the population estimate of large cockles ($\geq$30 mm shell length), which was lower in 2013–14 than in the previous survey; it was 0.80 million (CV: 14.22%) individuals with a mean density of 9 cockles per m^2 compared with 0.87 million (CV: 47.47%) cockles at a mean density of 15 cockles per m^2 in 2010–11. Corresponding estimates based on a more comparable (i.e., smaller) sampling extent included a total of 43.70 million (CV: 10.44%) cockles and 0.75 million (CV: 14.61%) large individuals.

Cockle sizes in the Tairua Harbour population were generally small, with a mean shell length of 19.12 mm (Table 30, Figure 21). Mean shell lengths were similar in the three most recent surveys, with a single large cohort of small-sized individuals. As the population only encompassed this cohort, there was no evidence of the small-sized individuals in 2006–07 (and 2010–11) subsequently contributing to a larger size class within the population. In all three recent surveys, recruits ($\leq$15 mm shell length) comprised between 21.98 and 30.86% of the cockle population, with the lowest value in the current survey.

Pipi in Tairua Harbour were present throughout all strata, but high-density areas were confined to two strata, C and F, that were within the main channel and/or close to the entrance of Tairua Harbour (Figure 22, Table 31). These two strata contained the highest numbers of pipi with 24.20 million (CV: 22.31%) pipi in stratum F, and 13.04 million (CV: 15.59%) pipi in stratum C. Population densities were similar in the two strata, at 1200 pipi per m^2. The number of pipi and population densities were low in the other strata. The total pipi population in Tairua Harbour was estimated at 43.10 million (CV: 13.62%) individuals, with an average population density of 459 individuals per m^2 (Table 32).

Although this total estimate was an increase from the 25.80 million (CV: 11.26%) pipi in 2010–11, the sampling extent was markedly smaller in this previous survey. Based on a smaller sampling extent, the estimate for 2013–14 was 46.75 million (CV: 13.65%) pipi. The population density in 2010–11 of 445 pipi per m^2 (CV: 11.26%) was comparable with the current estimate.

In contrast, there was a considerable decrease in the number of large pipi ($\geq$50 mm shell length) in 2013–14, with an estimated 0.44 million (CV: 28.85%) pipi at a mean density of 5 pipi per m^2 in this size grouping (or 0.40 million large pipi at a mean density of 6 pipi per m^2 for the smaller sampling extent). Although the large size class consistently included a relatively low number of pipi within the total Tairua Harbour population, the current estimate was one of the lowest in the survey series (i.e., since 1999–00), especially given the larger sampling area.

Similarly, there was a reduction in the proportion of small pipi, i.e., recruits ($\leq$20 mm shell length) in the population, with 9.39% of the pipi population included in this size class (Table 33, Figure 23). The mean shell length was 31.39 mm, with a single cohort at a modal size of 35 mm shell length.

3.7.1 Cockles at Tairua Harbour

Figure 20: Map of sample strata and individual sample locations for cockles at Tairua Harbour, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 28: Estimates of cockle abundance at Tairua Harbour, by stratum, for 2013–14. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	0.4	44	6	0.02	4	56.38
B	2.5	63	1 868	21.17	840	19.67
C	1.1	77	2 334	9.27	859	10.56
D	0.8	63	1 440	5.38	648	11.27
E	2.5	63	2 101	23.81	945	15.06
F	2.0	49	255	2.97	147	52.44

Table 29: **Estimates of cockle abundance at Tairua Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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	3.7	61.70	1 668	8.07	17.57	475	11.26
2000–01	3.9	56.07	1 438	4.93	10.65	273	8.87
2001–02	3.9	19.04	488	6.80	4.58	117	11.43
2002–03	3.9	32.76	840	5.14	5.56	143	9.25
2005–06	3.9	23.68	607	4.74	4.71	121	8.60
2006–07	4.8	53.82	1 121	6.47	4.28	89	9.02
2010–11	5.8	25.52	440	10.69	0.87	15	47.47
2013–14	9.4	62.60	667	9.31	0.80	9	14.22
2013–14*	7.2	43.70	606	10.44	0.75	10	14.61

Table 30: Summary statistics of the length-frequency (LF) distribution of cockles at Tairua Harbour. LF distributions 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	19.61	20	3–60	30.86	7.96
2010–11	18.25	20	5–50	32.55	3.41
2013–14	19.12	20	5–49	21.98	1.16

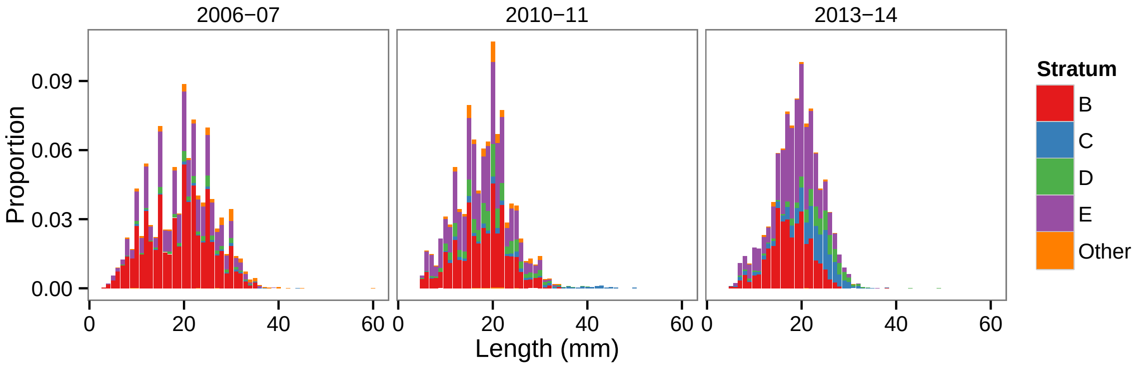

Figure 21: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Tairua Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.7.2 Pipi at Tairua Harbour

Figure 22: Map of sample strata and individual sample locations for pipi at Tairua Harbour, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 31: Estimates of pipi abundance at Tairua Harbour, by stratum, for 2013–14. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	0.4	44	266	0.72	171	49.48
B	2.5	63	218	2.47	98	36.82
C	1.1	77	3 283	13.04	1 208	15.59
D	0.8	63	477	1.78	214	13.84
E	2.5	63	78	0.88	35	47.01
F	2.0	49	2 080	24.20	1 203	22.31

Table 32: Estimates of pipi abundance at Tairua Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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	3.7	9.41	254	6.56	3.81	103	8.21
2000–01	3.9	8.35	214	6.25	2.11	54	11.02
2001–02	3.9	4.28	110	11.30	0.84	22	12.32
2002–03	3.9	4.98	128	6.73	0.43	11	16.30
2005–06	3.9	3.01	77	9.00	0.71	18	17.87
2006–07	4.8	6.33	132	6.72	2.10	44	6.39
2010–11	5.8	25.80	445	11.26	0.84	14	24.83
2013–14	9.4	43.10	459	13.62	0.44	5	28.85
2013–14*	7.2	46.75	648	13.65	0.40	6	28.99

Table 33: Summary statistics of the length-frequency (LF) distribution of pipi at Tairua Harbour. LF distributions 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	41.63	50	4–80	11.67	33.67
2010–11	30.75	30	8–68	13.00	3.25
2013–14	31.39	35	5–72	9.39	0.88

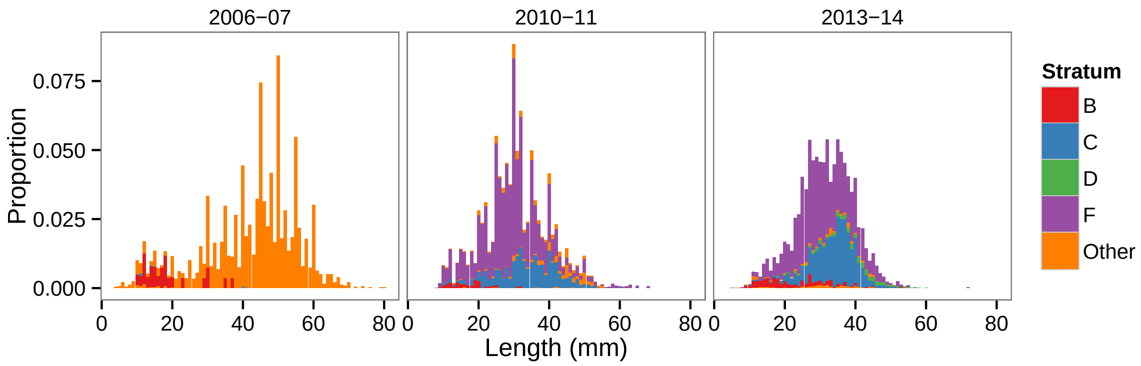

Figure 23: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Tairua Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.8 Umupuia Beach

Umupuia Beach is east of Auckland, in Tamaki Strait. This beach has been closed to the recreational take of cockles since 1 October 2008.

In this survey series, Umupuia Beach has been included in 11 previous shellfish surveys since 1999–00, including the preceding survey in 2012–13 (see Appendix B, Table B-2). Most of the recent surveys encompassed the same sampling extent, except for the current study that sampled a slightly smaller area (c. 340 000 m^2 compared with 360 000 m^2 in preceding surveys). The sample extent and allocation of strata in 2013–14 followed the earlier surveys, dividing the beach into four different strata (Figure 24, Table 34). Cockles and pipi were targeted in a total 162 sampling points across the four strata. A second sampling phase to reduce the CV of cockle abundance estimates was conducted in the seaward strata (A and B).

Sediment samples within and outside the sampling extent documented the variability in the sediment properties at Umupuia Beach (see details in Appendix C, Table C-3). Sediment organic content ranged from 1.0 to 8.4%, and the proportion of fines (grain size <63 µm) also varied across samples. The proportion of fines was relatively low in some samples (i.e., less than 8%), but high in other areas, with a maximum of 77% of the sediment consisting of fine particles in the sample adjacent to stratum A. In general, the sediment grain size was characterised by very fine or fine sand (grain sizes >63 to >125 µm).

There were no pipi at Umupuia Beach in the 2013–14 sampling.

The cockle population showed a patchy distribution across the different strata, with generally low densities at most sampling points. There was a high-density concentration of cockles in the middle of the beach, close to the low tide mark within strata A and B. These two strata had a similar number of cockles, and contributed the largest number of cockles to the total population estimate of 168.28 million (CV: 16.85%) individuals (Table 35). The population density at Umupuia Beach was 497 cockles per m^2. Both population metrics were higher than estimates in the previous surveys, and followed a continuous increase since 2009–10. In both the current and the 2012–13 surveys, large cockles made up a significant number of the overall population, with over 40 million individuals in this size class.

Comparing the proportion of large cockles and length-frequency distributions between these two recent surveys revealed a reduction in the former measure, with 26.00% of the population in the large size category in 2013–14 compared with 38.34% in 2012–13 (Table 36, Figure 25). At the same time, the proportion of recruits ($\leq$15 mm shell length) increased from 17.04% in the previous survey to 32.24% in 2013–14.

The length-frequency distributions illustrate the two size classes in the cockle population at Umupuia Beach (Figure 25). While there were two distinct modes of recruits and large cockles in the two recent surveys, there were few individuals at intermediate sizes. In contrast, the earlier survey in 2010–11 had a large single mode of medium-sized cockles (i.e., 20 mm shell length).

In summary, the cockle population showed little change in the two recent surveys. Both the estimated total number of cockles and the number of large cockles in these assessments have continuously increased from low values in 2006–07. In view of the temporary closure of Umupuia Beach since October 2008, it is possible that these increases result from the reduction in fishing pressure.

3.8.1 Cockles at Umupuia Beach

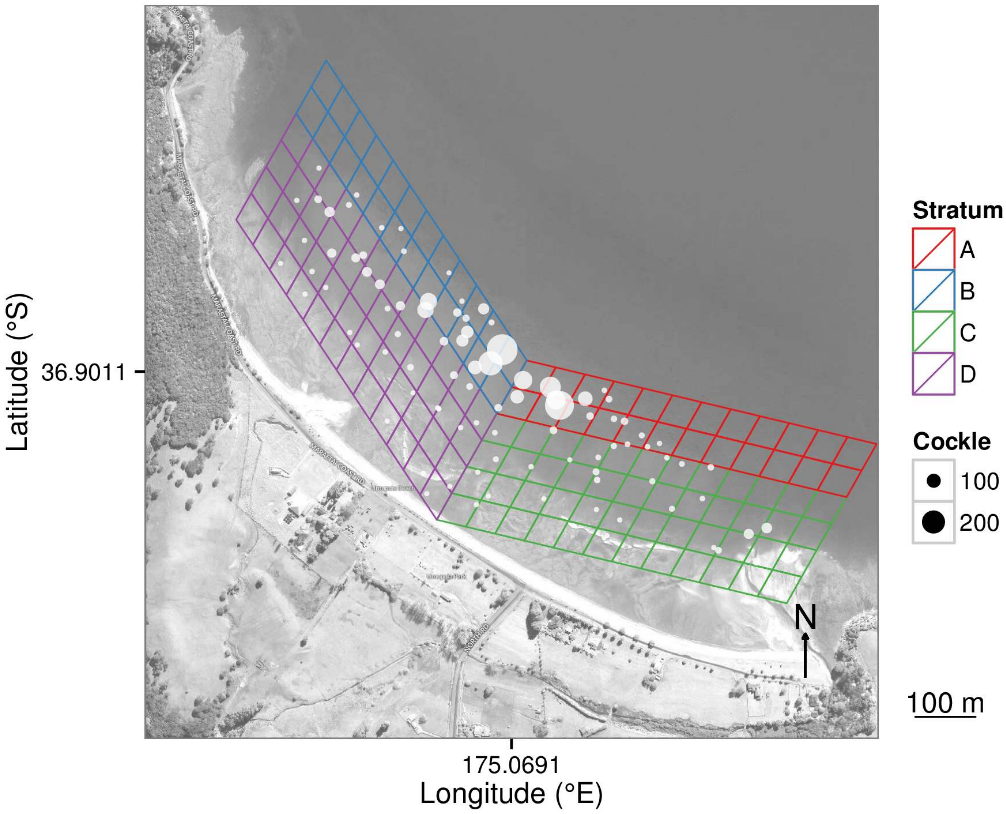

Figure 24: Map of sample strata and individual sample locations for cockles at Umupuia Beach, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 34: Estimates of cockle abundance at Umupuia Beach, by stratum, for 2013–14. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	5.8	35	1 058	50.01	856	35.24
B	5.4	31	1 066	53.05	974	34.96
C	11.7	48	338	23.30	199	26.91
D	10.9	48	652	41.91	385	24.97

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
1999–00	25.0	84.41	338	5.51	18.59	74	11.32
2000–01	36.0	177.48	493	5.50	66.98	186	11.78
2001–02	36.0	66.22	184	7.00	29.49	82	13.34
2002–03	36.0	64.43	179	5.26	24.96	69	11.14
2003–04	36.0	29.94	83	9.53	21.62	60	16.21
2004–05	36.0	41.49	115	6.95	30.72	85	11.29
2005–06	36.0	26.86	75	9.99	14.53	40	22.57
2006–07	36.0	11.59	32	13.84	5.07	14	31.16
2009–10	36.0	61.58	171	11.30	1.89	5	20.67
2010–11	36.0	103.08	286	9.96	9.32	26	16.95
2012–13	36.0	125.18	348	14.17	47.99	133	14.52
2013–14	33.9	168.28	497	16.85	43.92	130	17.80

Table 36: Summary statistics of the length-frequency (LF) distribution of cockles at Umupuia Beach. LF distributions 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 (%)
2010–11	21.87	20	3–47	12.70	9.07
2012–13	24.87	30	2–40	17.04	38.34
2013–14	22.24	14	5–42	32.24	26.00

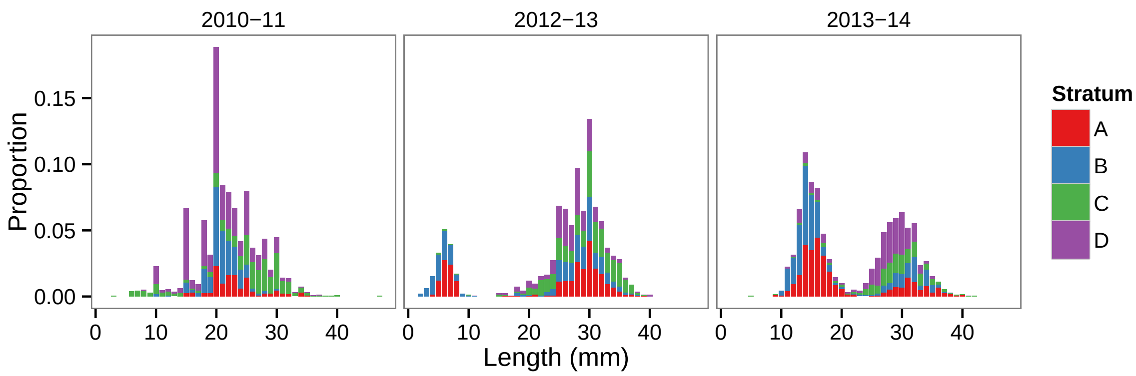

Figure 25: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Umupuia Beach. LF distributions were estimated for all strata in each survey to give the distribution of total LFs.

3.9 Waikawau Beach

Waikawau Beach is a small beach in Hauraki Gulf, on the western side of Coromandel Peninsula, south of Coromandel. This beach was included in four earlier surveys, most recently in 2005–06 (see Appendix B, Tables B-1, B-2).

The most recent earlier survey assessed the bivalve populations in five strata and detected only three cockle across these strata (Walshe et al. 2007). Pipi were present in four strata, with sample sizes ranging from 3 to 124 individuals per stratum.

In 2013–14, there were no pipi beds present at Waikawau Beach, and most of the beach did not contain habitat deemed suitable for bivalves. It was characterised by large pebbles and cobbles that were encrusted with sessile epifauna, and there was no sedimentary habitat across most of the beach (Figure 26). The only area that did contain sediment was along the river at the northern end of the beach, where the sediment was very fine, resembling clay (see Figure 26). This sediment appeared to be too fine to be suitable habitat for pipi, which have a narrow tolerance of sediment mud content (generally less than 3%), and reside predominantly in sandy habitats (Anderson 2008).

The preceding survey in 2005–06 sampled 350 pipi at Waikawau Beach. The estimated size of the pipi population was 0.67 million individuals (CV: 20.1%). The mean and modal shell lengths were 49 and 57 mm, respectively. For large pipi ($\geq$50 mm shell length), the estimated population size in this earlier survey was 0.46 million individuals (SE: 0.10), and the mean densities across the four strata that contained pipi varied from 1.1 to 38.8 pipi per m^2.

The substantial and large-scale changes at Waikawau Beach have resulted in the loss of sedimentary habitat since the last survey eight years ago. In this time, the pipi population at Waikawau Beach also disappeared.

Figure 26: Top left: View across areas that included pipi sampling strata in previous surveys at Waikawau Beach, including in 2005–06. Top right: Close-up of cobble substrate in previous pipi stratum B (GPS unit for scale is 10 cm long). Bottom left: Waikawau River with steep sediment banks on either side at the northern end of Waikawau Beach. Bottom right: Close-up of fine-sediment substrate along Waikawau River at the northern end of the beach.

3.10 Waiotahi Estuary

Waiotahi Estuary is in Bay of Plenty, and the intertidal areas within this estuary are north and south of the tidal channel. Close to the estuary entrance, the intertidal areas are narrow and consist of steep banks, compared with more extensive sandflats further upstream. Including the current study, there have been seven surveys in Waiotahi Estuary since 2000–01, with the most recent previous bivalve assessment in 2009–10 (see Appendix B, Tables B-1, B-2). Throughout the surveys, the size of the sampling extent has remained relatively similar, except for the current survey which involved a larger area. The 2013–14 survey at Waiotahi Estuary involved five strata that varied in size, with 257 sampling points across all strata (Figure 27, Table 37). Strata A and B encompassed large areas of intertidal sandflat, while strata C–E were largely in the channel of the estuary. A second sampling phase was conducted in stratum D to reduce the CV of pipi abundance estimates.

Sediment at Waiotahi Estuary was characterised by a low organic content (3%), with considerable variation in the proportion of fines (grain size $<$63 µm) (see details in Appendix C, Table C-3). There were no or less than 1% of fines in some of the sediment samples, but this proportion increased to 32% in a sample in stratum B. In other areas of stratum B, some parts of stratum A and in adjacent areas, the proportion of fines was also relatively high at $>$10%. The largest proportion of the sediment grain size across samples was fine sand (grain size $>$125 µm).

Cockles were most abundant in strata A and B, and the population estimate for these strata was 19.48 million (CV: 17.93%) and 21.03 million (CV: 14.26%) cockles, respectively (Table 37). The population density was 778 cockles per m^2 in stratum A and 700 cockles per m^2 in stratum B. Stratum D contained considerably fewer cockles, with a population estimate that was about 20% of the estimates in the previous two strata. Strata C and E contained few or no cockles. The overall population estimate for Waiotahi Estuary was 45.05 million cockles (CV: 10.40%) of all sizes, at a mean density of 401 cockles per m^2; there were no large cockles in this estuary in 2013–14 (Table 38). Both the total population estimate and the population density of cockles of all sizes reflected an increasing trend since 2004–05; the total population estimate in 2013–14 was over twice the value of the most recently conducted, previous survey in 2009–10. The concomitant increase in population density in 2013–14 confirmed that this population increase was not linked to potential changes in the sampling extent between recent surveys.

Nevertheless, while the cockle population overall showed an increase, the number of large cockles ($\geq$ 30 mm shell length) continued to decline, with no cockles in this size class in 2013–14. Population estimates for large cockles have been consistently low in all of the previous surveys, and this size class has only been a minor component of the overall cockle population in Waiotahi Estuary. The length frequency distributions corresponded with this finding, and the mean cockle shell length in the 2013–14 survey was 11.70 mm; this size was a decrease from the mean shell length of 18.13 mm in the previous survey in 2009–10 (Table 39). At the same time, the proportion of recruiting cockles, defined as $\leq$ 15 mm shell length, has increased from 20.52% in this previous survey to 84.98% in 2013–14.

In general, small size classes (i.e., $\leq$20 mm shell length) have dominated the cockle population in Waiotahi Estuary (Figure 28). Considering the most recent surveys, the large mode of recruiting individuals in stratum A in 2005–06 was not evident in a corresponding proportion of larger-sized individuals in the subsequent survey in 2009–10. Similarly, the large mode of small-sized cockles in stratum B in the 2009–10 survey was not present as a larger size class in the subsequent sampling in the current survey; instead, most of the cockles present in 2013–14 were in the 8-mm shell length mode.

Pipi in Waiotahi Estuary were sampled in the same five strata as the cockle population, involving 257 sampling points (Figure 29). Most of the pipi population was concentrated in the estuary channel in strata C and D, especially in the latter stratum. In stratum C, pipi were localised in one area adjacent to stratum D.

Estimated pipi population densities were 2857 pipi per m^2 (CV: 17.27%) in stratum D, and 1298 pipi per m^2 (CV: 25.75%) in stratum C (Table 40). There were few pipi in other strata, with one small, localised area containing pipi in stratum E, on the northern side of the estuary channel.

The total population estimate for pipi in Waiotahi Estuary in 2013–14 was 105.68 million pipi (CV: 13.74%), with a corresponding mean density of 941 pipi per m^2 (Table 41). For large pipi (defined as $\geq$50 mm shell length), the population estimate in 2013–14 was 90 000 (0.09 million) pipi.

The small proportion of large individuals in the pipi population in 2013–14 was consistent with findings in previous surveys (Table 41). Nevertheless, the current estimates for this size class showed a marked decrease from values in the preceding survey in 2009–10, when there were an estimated 3.56 million (CV: 23.50%) large pipi in this estuary. At the same time, the total pipi population estimates did not show a similar decline, but estimates were similar to those in the 2009–10 survey.

Over the study period, population estimates for pipi of all sizes and for large pipi fluctuated across the seven surveys since 2000–01. Nevertheless, the small number of large pipi in 2013–14 was the lowest estimate for this size class in this data series.

The decrease in the number of large pipi in Waiotahi Estuary in 2013–14 was reflected in the length-frequency distributions (Table 42, Figure 30). The mean shell length in the most recent survey was 23.00 mm, with large-size pipi comprising 0.06 % of the population. Recruits (defined as $\leq$20 mm shell length) constituted over a third of the pipi population in Waiotahi Estuary. The relatively large cohort of medium-sized pipi in the 2009–10 survey was not evident in the length-frequency distributions in 2013–14, with a small cohort of medium-sized pipi and few large individuals.

Owing to concerns by members of the local hapū that accumulations of pine needles in the sediment may impact the pipi population (L. Reha, pers. comm.), the presence of pine needles in the sampling cores was monitored during the field sampling. There was no evidence of pine needles in any of the cores sampled at Waiotahi Estuary.

3.10.1 Cockles at Waiotahi Estuary

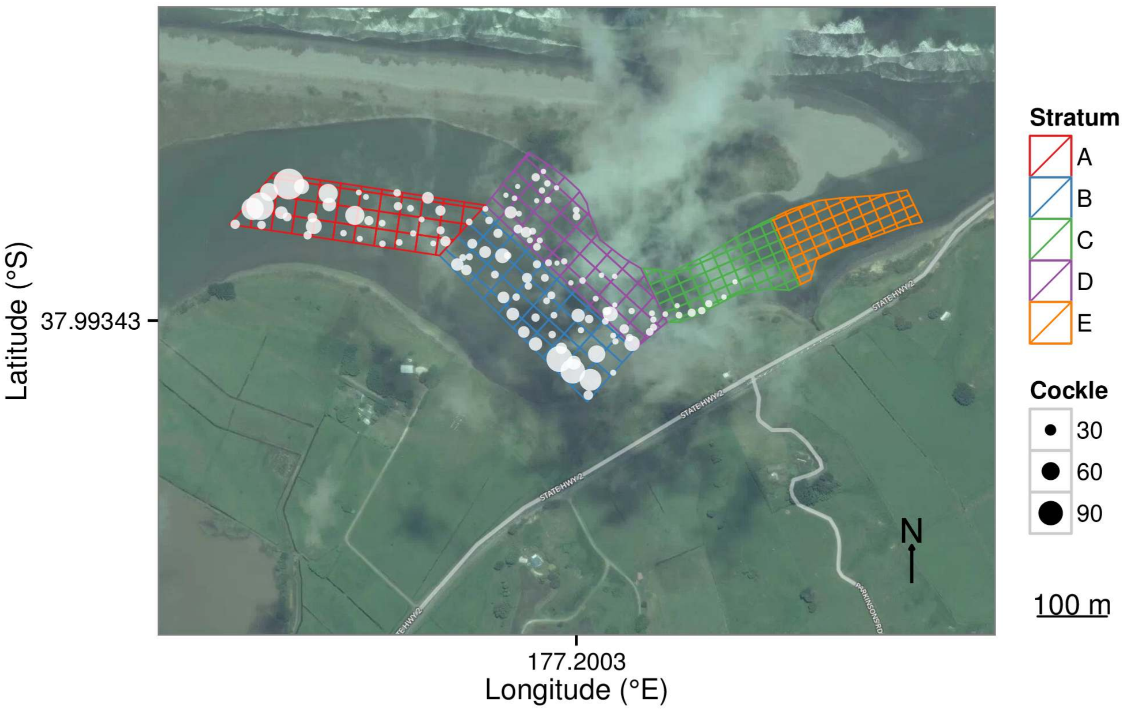

Figure 27: Map of sample strata and individual sample locations for cockles at Waiotahi Estuary, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 37: Estimates of cockle abundance at Waiotahi Estuary, by stratum, for 2013–14. Presented are the number of points and the number of cockles sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

Stratum		Sample		Population estimate		
	Area (ha)	Points	Cockle	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	35	961	19.48	778	17.93
B	3.0	40	988	21.03	700	14.26
C	1.6	57	52	0.41	26	41.46
D	2.7	74	396	4.13	152	20.40
E	1.4	51	0	0.00	0	

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

Year	Extent (ha)	Population estimate			Population ≥ 30 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	8.5	36.67	431	8.08	0.52	6	23.26
2003–04	8.5	5.77	68	9.16	0.09	1	48.45
2004–05	9.5	1.13	12	12.12	0.04	<1	>100
2005–06	9.5	5.88	62	10.53	0.09	<1	74.1
2009–10	9.5	20.17	212	15.50	0.06	<1	70.21
2013–14	11.2	45.05	401	10.40	0.00	0	

Table 39: Summary statistics of the length-frequency (LF) distribution of cockles at Waiotahi Estuary. LF distributions 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	14.99	12	7–39	62.07	1.53
2009–10	18.13	20	5–35	20.52	0.33
2013–14	11.70	10	2–28	84.98	0.00

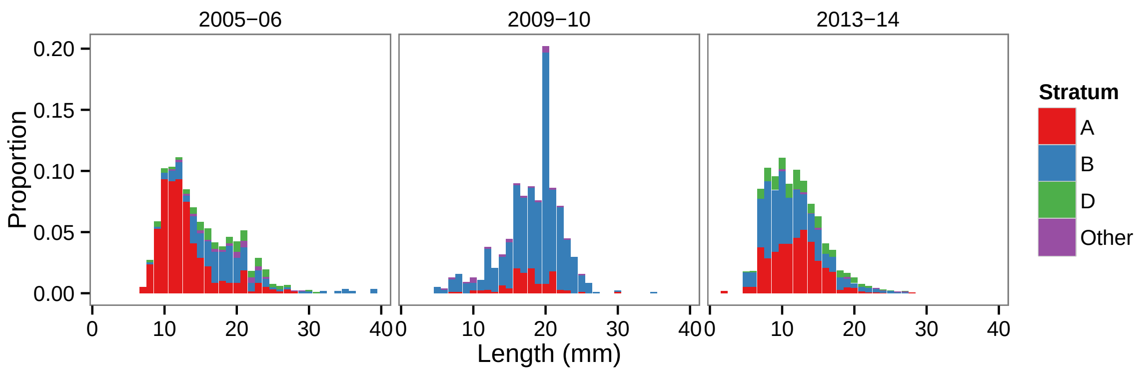

Figure 28: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Waiotahi Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.10.2 Pipi at Waiotahi Estuary

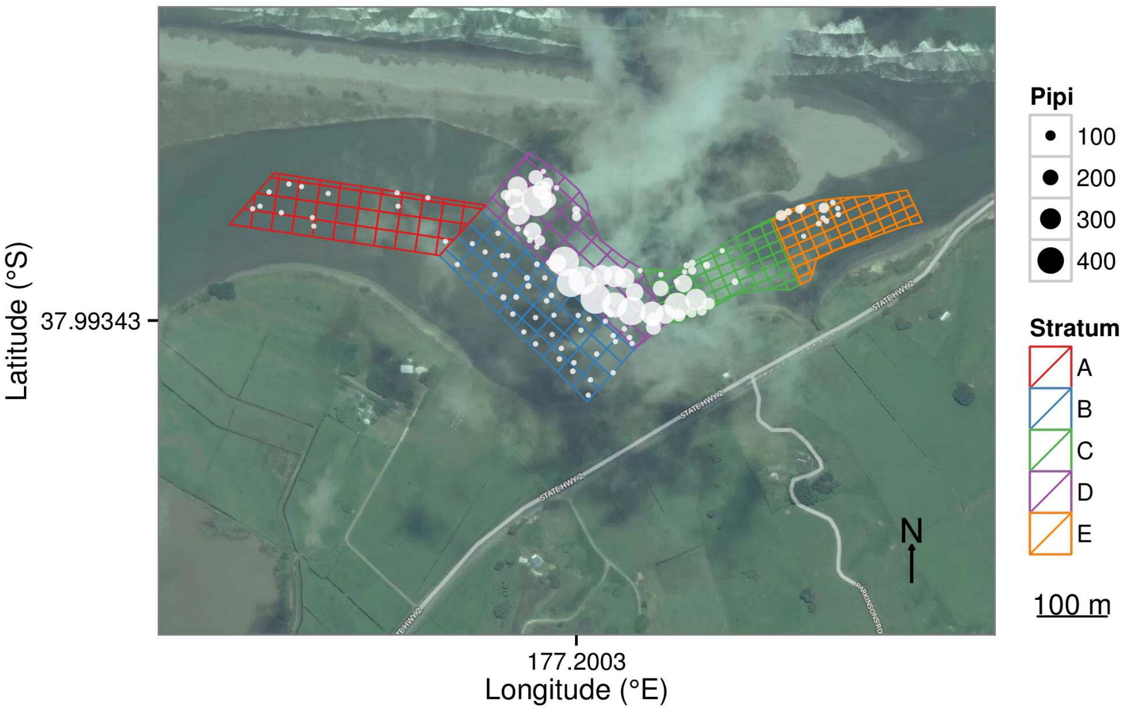

Figure 29: Map of sample strata and individual sample locations for pipi at Waiotahi Estuary, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 40: Estimates of pipi abundance at Waiotahi Estuary, by stratum, for 2013–14. Presented are the number of points and the number of pipi sampled, the mean total estimate, the mean density, and the coefficient of variation (CV).

	Stratum	Sample		Population estimate		
	Area (ha)	Points	Pipi	Total (millions)	Density (m^{-2})	CV (%)
A	2.5	35	20	0.41	16	26.15
B	3.0	40	180	3.83	127	16.17
C	1.6	57	2 612	20.57	1 298	25.75
D	2.7	74	7 464	77.86	2 857	17.27
E	1.4	51	385	3.01	214	41.28

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

Year	Extent (ha)	Population estimate			Population ≥ 50 mm		
		Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
2002–03	8.5	183.91	2 164	5.14	1.46	17	22.43
2003–04	8.5	47.91	564	5.70	0.20	2	27.81
2004–05	9.5	41.41	436	5.00	0.81	9	17.14
2005–06	9.5	40.61	427	9.30	1.24	13	28.09
2009–10	9.5	96.71	1 018	12.48	3.56	38	23.50
2013–14	11.2	105.68	941	13.74	0.09	<1	65.16

Table 42: Summary statistics of the length-frequency (LF) distribution of pipi at Waiotahi Estuary. LF distributions 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	33.94	37	7–61	15.90	3.06
2009–10	29.68	40	3–63	26.09	3.93
2013–14	23.00	20	4–112	45.08	0.06

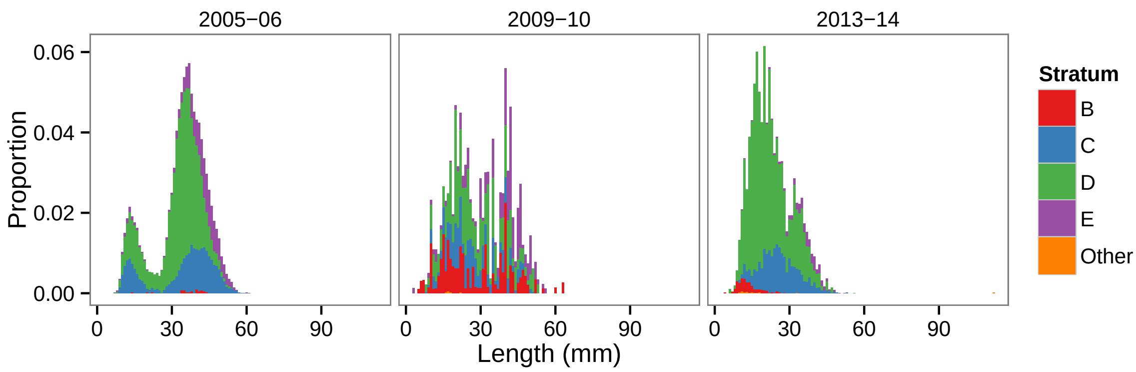

Figure 30: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Waiotahi Estuary. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

3.11 Whangateau Harbour

Whangateau Harbour is north of Auckland, just south of Cape Rodney. This inlet is characterised by extensive intertidal sandflats interspersed with elevated banks. The main channel has a number of side branches that intersect the tidal areas. This harbour has been closed to recreational shellfish collections since March 2010, with a second three-year closure period implemented in March 2013.

Assessments of bivalve populations in Whangateau Harbour, as part of the current survey series, have been conducted since 2001–02 (see Appendix B, Tables B-1, B-2). There were seven previous surveys, most recently in 2012–13. This inlet is also included in the cockle monitoring programme by the Hauraki Gulf Forum. Past MPI surveys have focused on three strata for the cockle population, with the sampling of pipi concentrated in a stratum located at the main channel. As the distribution of the pipi bed has varied across surveys, the location of the pipi stratum (along the main channel) has changed accordingly. In the 2013–14 survey, the sampling extent was expanded considerably from previous surveys, including the extension of previous strata and the addition of two new cockle strata (Figure 31, Table 43). The latter were directly adjacent to stratum A that has been consistently sampled for cockles in recent surveys. Stratum A was extended to the main channel in the current survey. Similarly, stratum C from the previous surveys was also extended to reach the channel. Across this sampling extent, cockles and pipi were targeted in 395 sampling points.

For the sediment sampling, samples were taken across all strata and also in adjacent areas. Although Whangateau Harbour consisted of a variety of intertidal habitats, sediment properties were generally similar across the areas sampled (see details in Appendix C, Table C-3). The sediment organic content was low, ranging from 0.6 to 2.8%, and the proportion of fines (grain size <63 μm) was also low with a maximum value of 4.7%. Fine sand (grain size >125 μm) and medium fine sand (>250 μm) dominated the sediment grain size distribution.

Cockles in Whangateau Harbour were prevalent in strata A, C, F, and G, with highest cockle numbers in strata A and C (Figure 31, Table 43). There were no cockles in stratum D. Within stratum A, cockles were concentrated in the high intertidal area, and decreased towards the water line, i.e., towards a side channel that branched off the main channel. There was also an elevated sandbank between the two channels, with few cockles in this part of stratum A. In stratum C, the cockle distribution was relatively even and densities were generally high throughout this stratum.

The total cockle population estimate in Whangateau Harbour in the current survey was 545.24 million (CV: 6.49%), with an average population density of 492 individuals per m^2(Table 44). The total population estimate was an increase from the previous survey, but the sampling extent in 2013–14 was almost twice the size of the area sampled in 2012–13. Across this sampling extent, the estimated cockle population density in 2013–14 was lower than that in 2012–13. For a sampling extent similar to that of previous surveys, the total cockle population estimate was 482.99 million (CV: 6.79%), with an average population density of 641 individuals per m^2.

The population density of large cockle ($\geq$30 mm shell length) was also lower in the current survey, with a mean density of 40 cockles per m^2 compared with 48 cockles per m^2 in the previous survey. The total estimate for this size class in 2013–14 was 44.13 million (CV: 13.45%) individuals. Based on the comparable sampling extent, the estimate of large cockles was 30.24 million (CV: 15.57%) individuals, and the population density was 40 large cockles per m^2.

Length-frequency data showed a consistent pattern across the three recent surveys. The cockle population comprised a single cohort of medium-sized individuals at a modal shell length of 19.97 mm that was the same across these population assessments (Table 45, Figure 32). Large cockles contributed 6 to 8% of the total population compared with recruits ($\leq$15 mm shell length) contributing 22.70 to 26.18% in the three most recent surveys, including the current study.

Pipi in Whangateau Harbour were concentrated in a few localised areas, including at high densities in the main channel in stratum D and in two areas in stratum A (Figure 33, Table 46). Stratum A also contained pipi at low densities across most of the upper shore area. There were an estimated 35.87 million (CV: 28.78%) pipi in this stratum, which was most of the total pipi population estimate of 38.20 million (CV: 27.07%) pipi in Whangateau Harbour (Table 47). In comparison, stratum D had the highest pipi population density of 376 pipi per m^2 (CV: 20.67%) compared with 75 pipi m^{-2} (CV: 28.78%) in stratum A. A second sampling phase was necessary in stratum D to obtain a CV below the target of 20%. The population density of pipi across all strata was 34 pipi per m^2. Large pipi ($\geq$50 mm shell length) were only a minor proportion of the population with only 0.67 million (CV: 24.04) individuals, reflecting $<$1 large pipi per m^2 (Table 47). The estimates were similar when based on a sampling extent comparable to that of previous surveys, with a total of 41.52 million (CV: 27.41%) pipi, including 0.67 million (CV: 24.04) large pipi.

The length-frequency distributions also showed that the mean and modal shell lengths of 21.22 mm and 21 mm were well below the large-size threshold of 50 mm (Table 48, Figure 34). While the former metric was similar to the mean shell length of pipi in the previous year, the modal size was larger in 2013–14 compared with the 12 mm shell length in 2012–13. Nevertheless, both recent surveys lacked the second cohort of large-size pipi that were present in 2010–11. Instead, the length-frequency distributions revealed a single, large cohort of small-sized pipi in the surveys in 2012–13 and 2013–14.

The prevalence of small-sized pipi was evident in the relatively large proportion of recruits ($\leq$20 mm shell length) across surveys, with 50.19% of the pipi population in this category in 2013–14. In contrast, large pipi contributed little to the total population in the two recent surveys, with 1.23% of the total pipi population in this size class in 2013–14.

3.11.1 Cockles at Whangateau Harbour

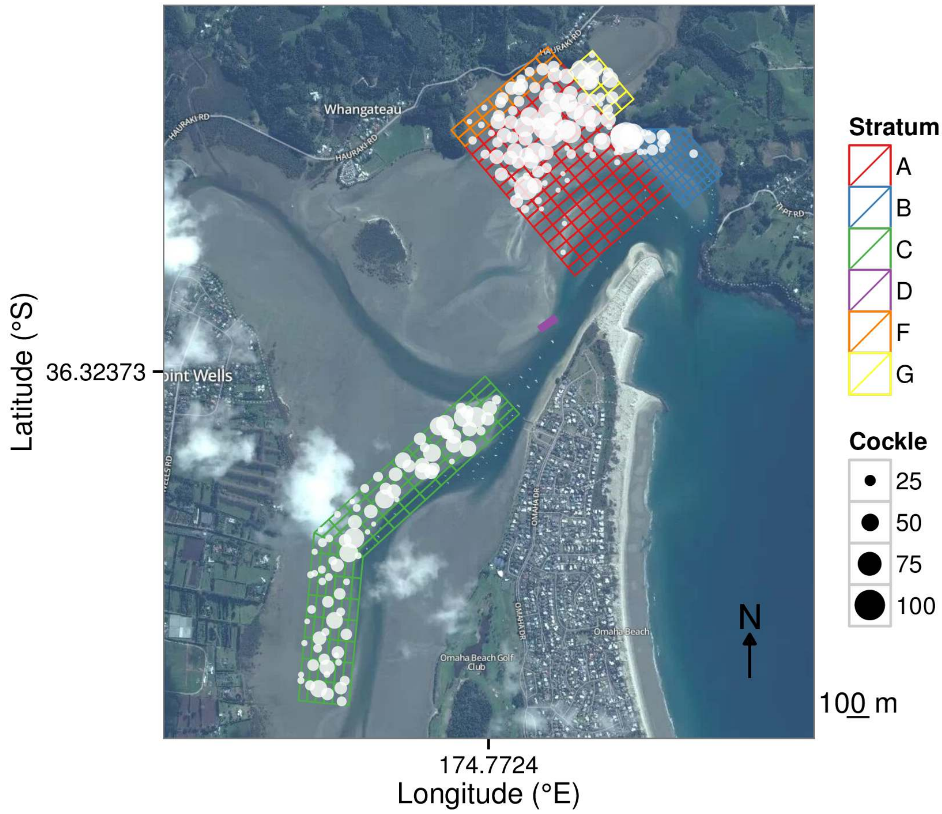

Figure 31: Map of sample strata and individual sample locations for cockles at Whangateau Harbour, with the size of the circles proportional to the number of cockles found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 43: Estimates of cockle abundance at Whangateau Harbour, by stratum, for 2013–14. 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	48.0	127	2 240	239.83	500	11.09
B	9.1	77	415	13.92	153	34.00
C	43.0	109	2 014	225.20	523	9.20
D	0.3	54	0	0.00	0	
F	6.0	16	282	29.96	499	18.51
G	4.5	12	342	36.33	807	21.94

Table 44: Estimates of cockle abundance at Whangateau Harbour for all sizes and large size (≥30 mm) cockles. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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 (%)
2001–02	64.2	253.26	395	6.51	62.36	97	22.91
2003–04	64.2	376.68	587	5.80	56.85	89	17.93
2004–05	64.2	349.04	544	8.52	59.52	93	18.58
2006–07	64.2	266.04	415	8.24	35.20	55	28.55
2009–10	64.5	230.55	357	7.16	16.16	25	25.49
2010–11	64.2	239.27	373	5.06	19.77	31	16.05
2012–13	64.2	363.72	567	5.87	30.84	48	14.55
2013–14	110.9	545.24	492	6.49	44.13	40	13.45
2013–14*	75.4	482.99	641	6.79	30.24	40	15.57

Table 45: Summary statistics of the length-frequency (LF) distribution of cockles at Whangateau Harbour. LF distributions 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 (%)
2010–11	20.05	20	4–46	26.18	8.26
2012–13	20.28	20	3–39	22.70	8.48
2013–14	19.97	20	5–44	24.64	6.09

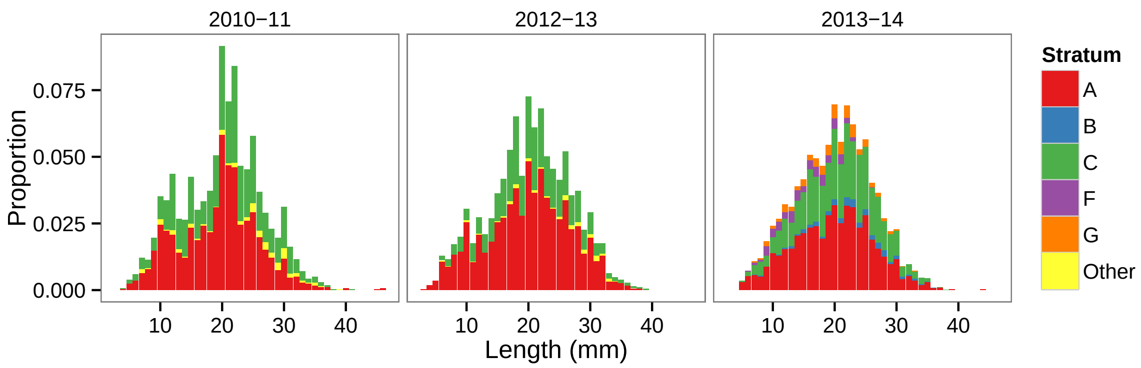

Figure 32: Weighted length-frequency (LF) distribution of cockles for the present and previous surveys at Whangateau Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in 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.

3.11.2 Pipi at Whangateau Harbour

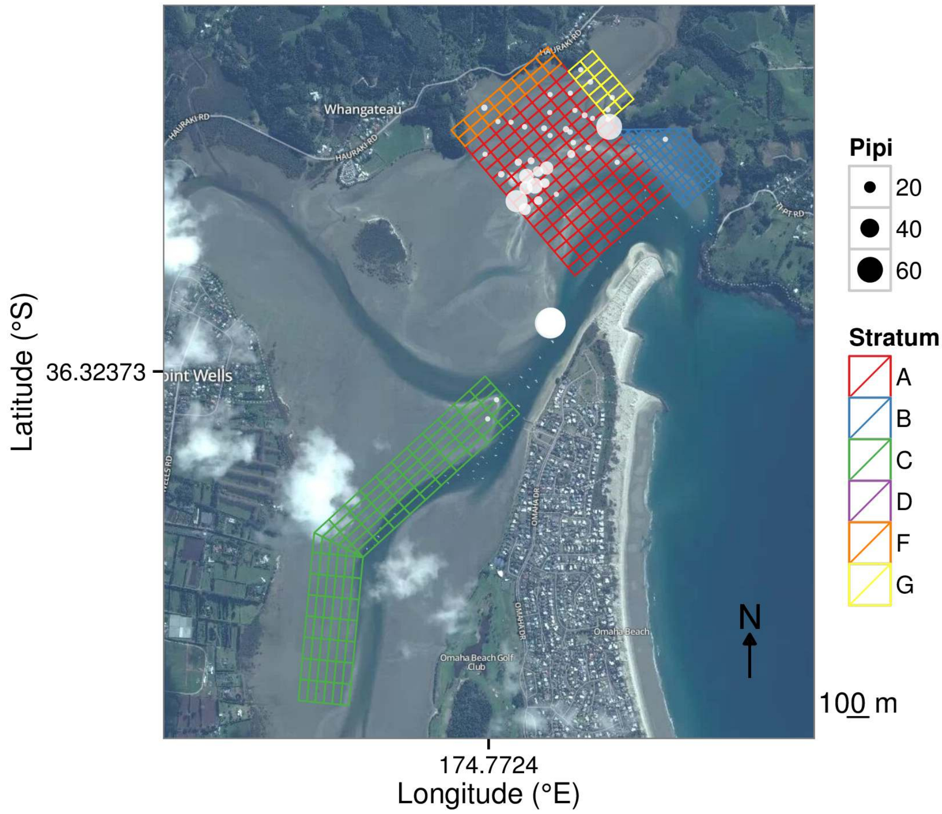

Figure 33: Map of sample strata and individual sample locations for pipi at Whangateau Harbour, with the size of the circles proportional to the number of pipi found at each location. The grid within each stratum was used to stratify the sampling, with one sample randomly allocated within each cell per sampling phase.

Table 46: Estimates of pipi abundance at Whangateau Harbour, by stratum, for 2013–14. 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	48.0	127	335	35.87	75	28.78
B	9.1	77	1	0.03	<1	>100
C	43.0	109	2	0.22	<1	70.38
D	0.3	54	716	1.01	376	20.67
F	6.0	16	4	0.42	7	>100
G	4.5	12	6	0.64	14	46.06

Table 47: Estimates of pipi abundance at Whangateau Harbour for all sizes and large size (≥50 mm) pipi. Columns include the mean total estimate, mean density and coefficient of variation (CV). Asterisk indicates 2013–14 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 (%)
2001–02	64.2	1.83	3	31.83	0.31	<1	>100
2003–04	64.2	0.48	<1	10.18	0.42	<1	13.95
2004–05	64.2	6.85	11	22.46	0.58	<1	13.77
2006–07	64.2	10.56	16	33.78	0.05	<1	>100
2009–10	64.5	17.58	27	33.35	0.11	<1	>100
2010–11	64.2	9.31	15	17.74	1.57	2	22.33
2012–13	64.2	19.58	30	16.89	0.60	<1	41.69
2013–14	110.9	38.20	34	27.07	0.67	<1	24.04
2013–14*	75.4	41.52	55	27.41	0.67	2	24.04

Table 48: Summary statistics of the length-frequency (LF) distribution of pipi at Whangateau Harbour. LF distributions 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 (%)
2010–11	29.38	16	9–70	38.48	16.88
2012–13	19.86	12	7–67	62.16	3.06
2013–14	21.22	21	7–69	50.19	1.23

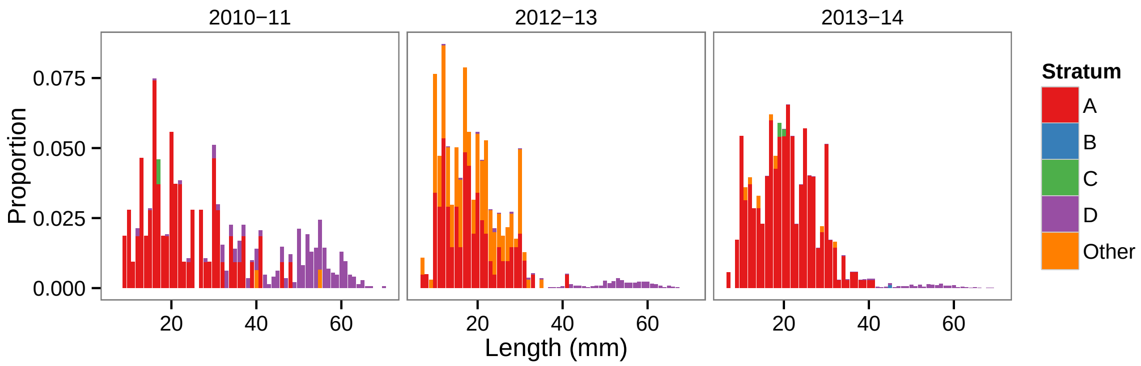

Figure 34: Weighted length-frequency (LF) distribution of pipi for the present and previous surveys at Whangateau Harbour. LF distributions were estimated for all strata in each survey to give the distribution of total LFs. Strata from previous surveys that did not correspond to strata sampled in the present survey, as well as strata contributing less than 10 % for all length classes and years, were grouped into a single stratum labelled Other.

4. SUMMARIES

4.1 Cockle populations

Considering the cockle populations at all sites included in the 2013–14 survey, the estimated total cockle abundance ranged from 4.41 million individuals at Grahams Beach to 545.24 million cockles at Whangateau Harbour (Table 49). These values provide some indication of the size of the cockle populations that are (or have been) subjected to non-commercial fishing pressure at each site, but differences in the sampling extent make comparisons across surveys difficult. This limitation also meant that the estimated population densities did not necessarily reflect the estimated population abundances. For example, the highest cockle density was found at Pataua Estuary, with an estimated 1317 cockles per m^2, but this site did not have the highest population abundance.

Patterns in the total population size and the population size of the large cockles ($\geq$30 mm shell length) at the same site did not always match, as a number of populations were characterised by small-sized individuals. There were only two sites, Cockle Bay and Umupuia Beach, where large cockles comprised a substantial proportion of the total population (Table 49). These two sites had the highest densities of large cockles with 132 cockles per m^2 at Cockle Bay, and 130 cockles per m^2 at Umupuia Beach. At other sites, the cockle population was dominated by small individuals that were abundant and present at relatively high densities. For example, at Waiotahi Estuary, the total population estimate was 45.05 million cockles at a density of 401 cockles per m^2, while there were no large cockles within this population.

Within individual strata sampled, the range of total population densities in the present survey was comparable with that found in previous surveys (Figure 35). The distribution of cockle densities within strata containing cockle beds was bi-modal; half of the strata had densities $<$500 individuals per m^2 with the other half of the strata containing densities above this value (Figure 35). The present survey included slightly more strata with high cockle densities (i.e., more than 500 individuals per m^2) compared with previous surveys. In addition, only one previous assessment, the 2006–07 survey, included a stratum with a higher cockle population density than the maximum density in the present study. The comparatively high cockle densities determined in the present survey may be related to the specific sites included in this study, and the addition of strata and changes to strata used previously.

Comparing length-frequency distributions over time showed that the cockle populations at the study sites underwent a shift towards smaller-sized individuals (a smaller shell-length mode), i.e., from the early surveys between 1999–00 and 2002–03 to more recent assessments between 2009–10 and 2013–14 (Figure 36). This shift towards a prevalence of small cockles was caused by a reduction in the number of large cockles in the population (Figure 37). For example, at Tairua Harbour the density of large cockles dropped sharply and remained low in recent years compared with high densities of this size class in earlier surveys. At Cockle Bay, Okoromai Bay, and Pataua Estuary, this decline was evident in the 2013–14 survey. All of the sites showed a substantial decrease in large cockle densities over the study period, except for Umupuia Beach. This beach was the only site within the present survey where the density of large cockles showed an increase compared with their density in 2008–09, indicating recovery from a decline in previous years.

Table 49: Estimates of cockle abundance for all sites on which more than ten cockles were found in the 2013–14 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 (%)
Cockle Bay	33.40	212	8.14	20.84	132	9.5
Grahams Beach	4.41	16	19.20	0.12	<1	>100
Little Waihi Estuary	21.45	126	14.77	0.34	2	59.9
Okoromai Bay	27.78	140	12.67	4.44	22	19.47
Pataua Estuary	346.39	1 317	5.94	6.48	25	15.94
Tairua Harbour	62.60	667	9.31	0.80	9	14.22
Umupuia Beach	168.28	497	16.85	43.92	130	17.8
Waiotahi Estuary	45.05	401	10.40	0.00	0	
Whangateau Harbour	545.24	492	6.49	44.13	40	13.45

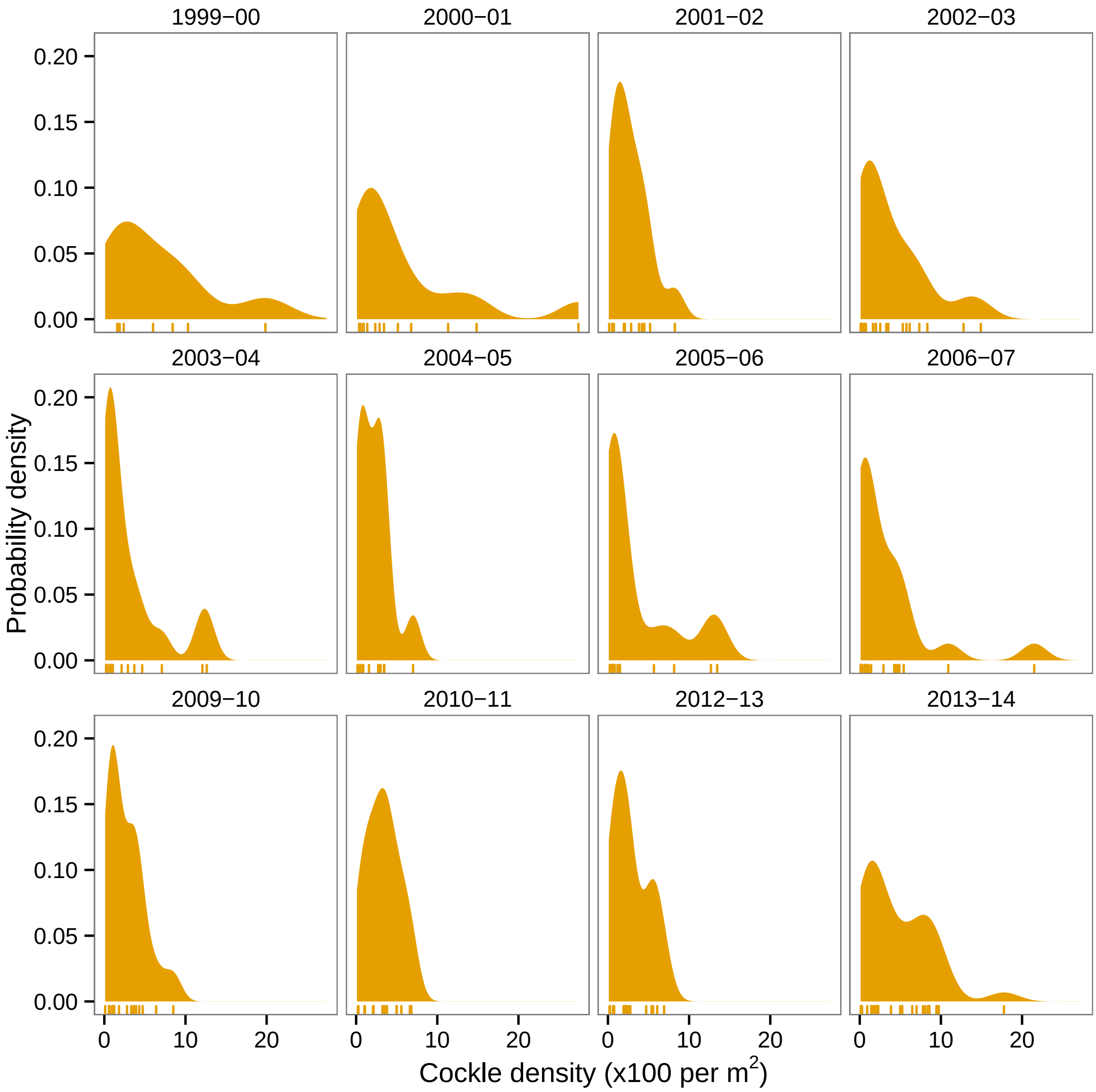

Figure 35: Cockle densities over time at sites included in the 2013–14 survey, estimated independently for all strata. Only strata with more than ten cockles per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

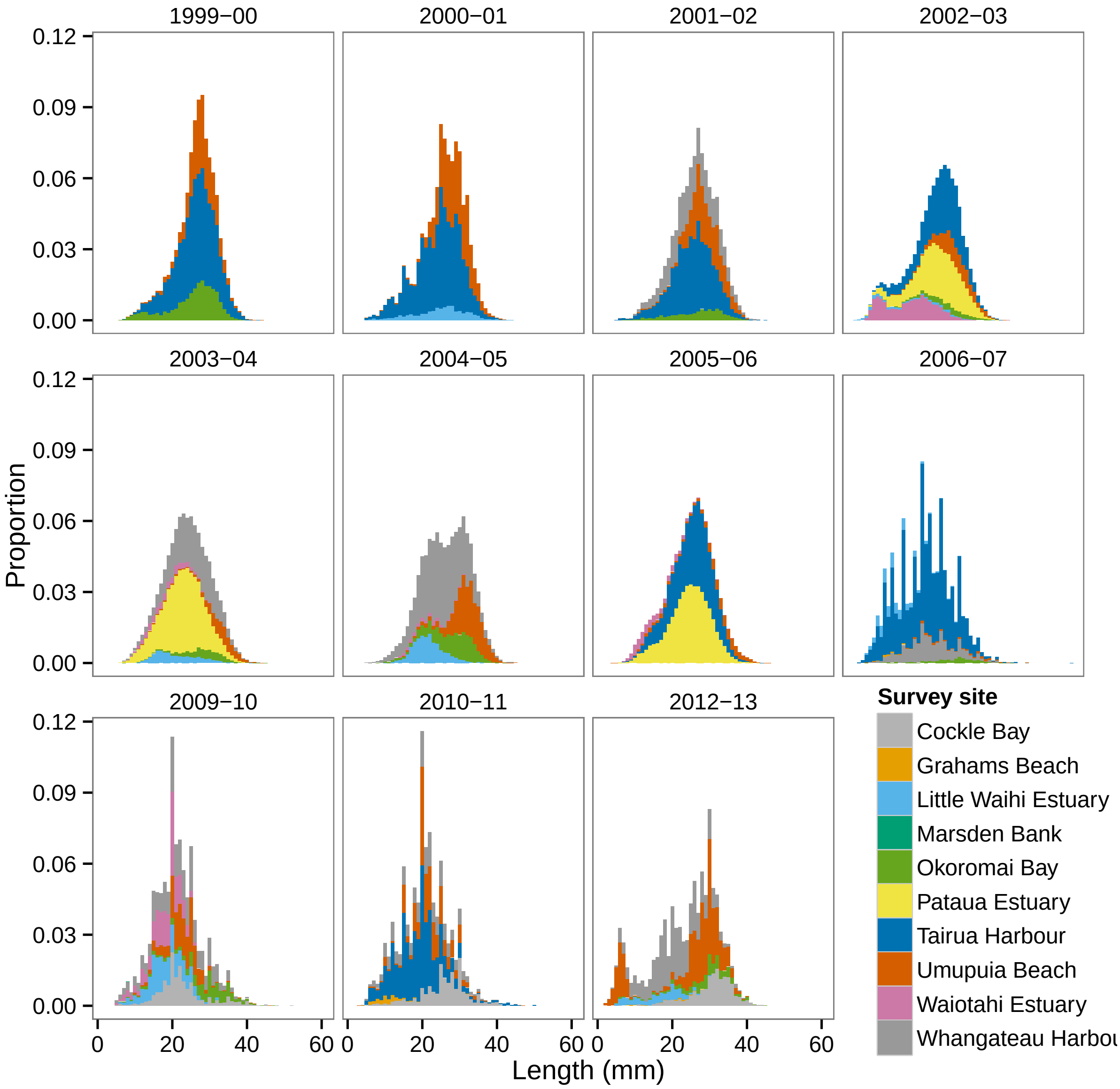

Figure 36: Weighted length-frequency (LF) distributions of cockles over time at sites included in the 2013–14 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

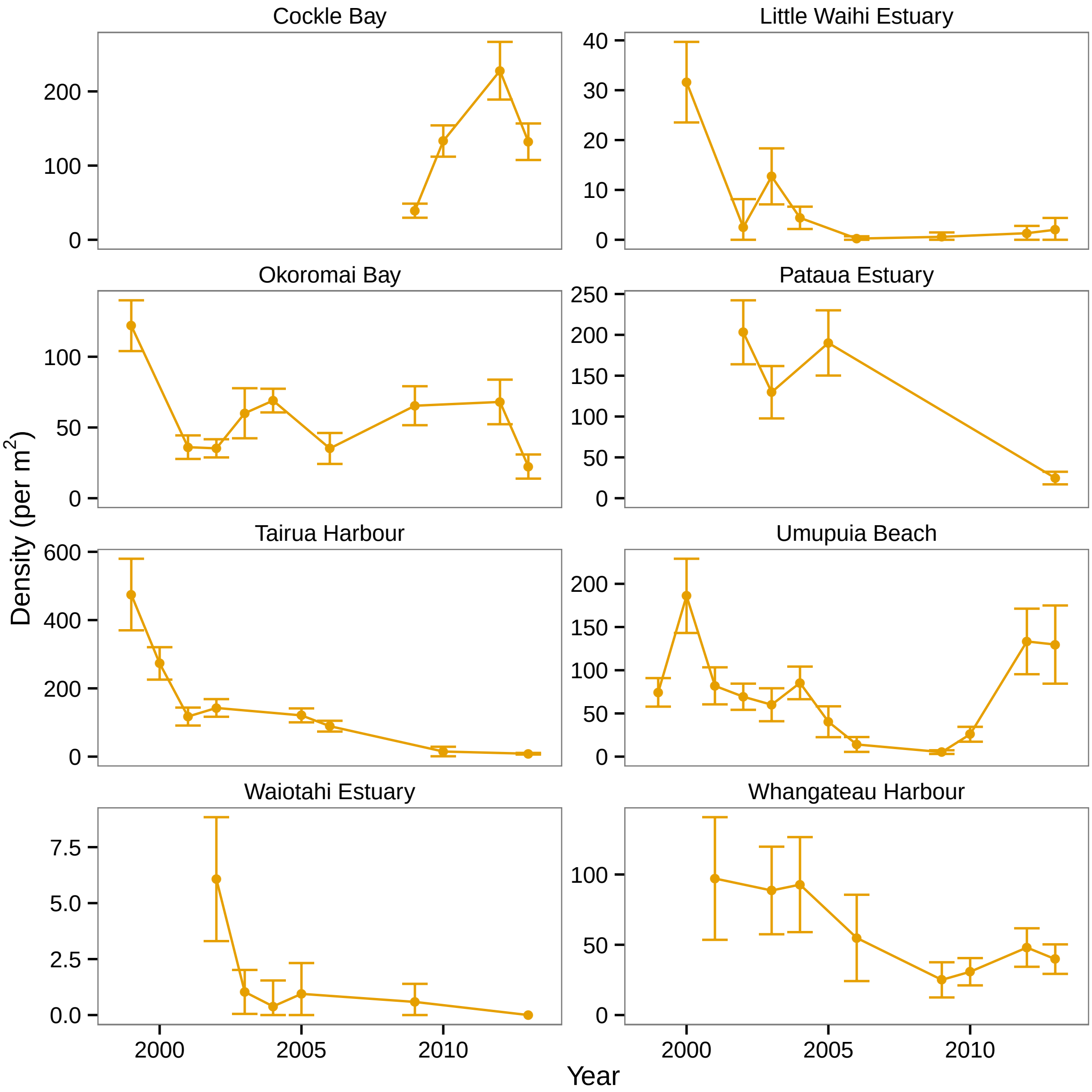

Figure 37: Estimated density of large cockles (≥30 mm shell length) for all sites where cockles in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large cockles across years within each year's survey strata, bars indicate 95% confidence intervals.

4.2 Pipi populations

Pipi abundance in the 2013–14 survey was highest at Little Waihi Estuary (113.46 million), and this site also had the highest abundance and highest density of large-size pipi ($\geq$50 mm shell length), with 4.55 million large pipi at a density of 27 pipi per m^2 (Table 50). All other sites had comparatively few large pipi, with densities of less than 1 individual per m^2 at five of the seven sites that contained pipi beds. Low estimates of large pipi were also evident at sites where the total pipi population was characterised by abundant and dense pipi beds, such as Waiotahi Estuary and Tairua Harbour. Total population densities at Waiotahi Estuary and Tairua Harbour were 941 and 459 pipi per m^2, respectively, but the densities of large pipi were low with <1 and 5 individuals per m^2.

In the strata sampled in the current study, total pipi densities were comparable with previous surveys (Figure 38). Nevertheless, the length-frequency distributions revealed a slight shift towards a predominance of smaller pipi since the start of the study period in 1999–00 (Figure 39). This shift was due to a decrease in large pipi at sites where high densities of this size grouping were found previously (Figure 40). The shift towards a smaller size within the pipi population included Little Waihi Estuary, where the highest density of large pipi was found in the present survey. This site recorded densities of over 100 large individuals per m^2 previously, compared with the 27 large pipi per ^{2} in the present survey. Similarly, Tairua Harbour, Waiotahi Estuary, and Marsden Bank had high densities of large pipi in previous surveys, but populations at these sites have all undergone a substantial decline in large pipi abundance and density (Figure 40).

Table 50: Estimates of pipi abundance for all sites on which more than ten pipi were found in the 2013–14 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 ($\geq$50 mm shell length).

Survey site	Population estimate			Population $\geq$50 mm		
	Total (millions)	Density (m^{-2})	CV (%)	Total (millions)	Density (m^{-2})	CV (%)
Grahams Beach	11.60	43	21.72	0.06	$<$1	$>$100
Little Waihi Estuary	113.46	664	14.61	4.55	27	31.3
Marsden Bank	3.23	21	51.83	0.00	0	
Pataua Estuary	6.42	24	16.51	0.47	2	60.35
Tairua Harbour	43.10	459	13.62	0.44	5	28.85
Waiotahi Estuary	105.68	941	13.74	0.09	$<$1	65.16
Whangateau Harbour	38.20	34	27.07	0.67	$<$1	24.04

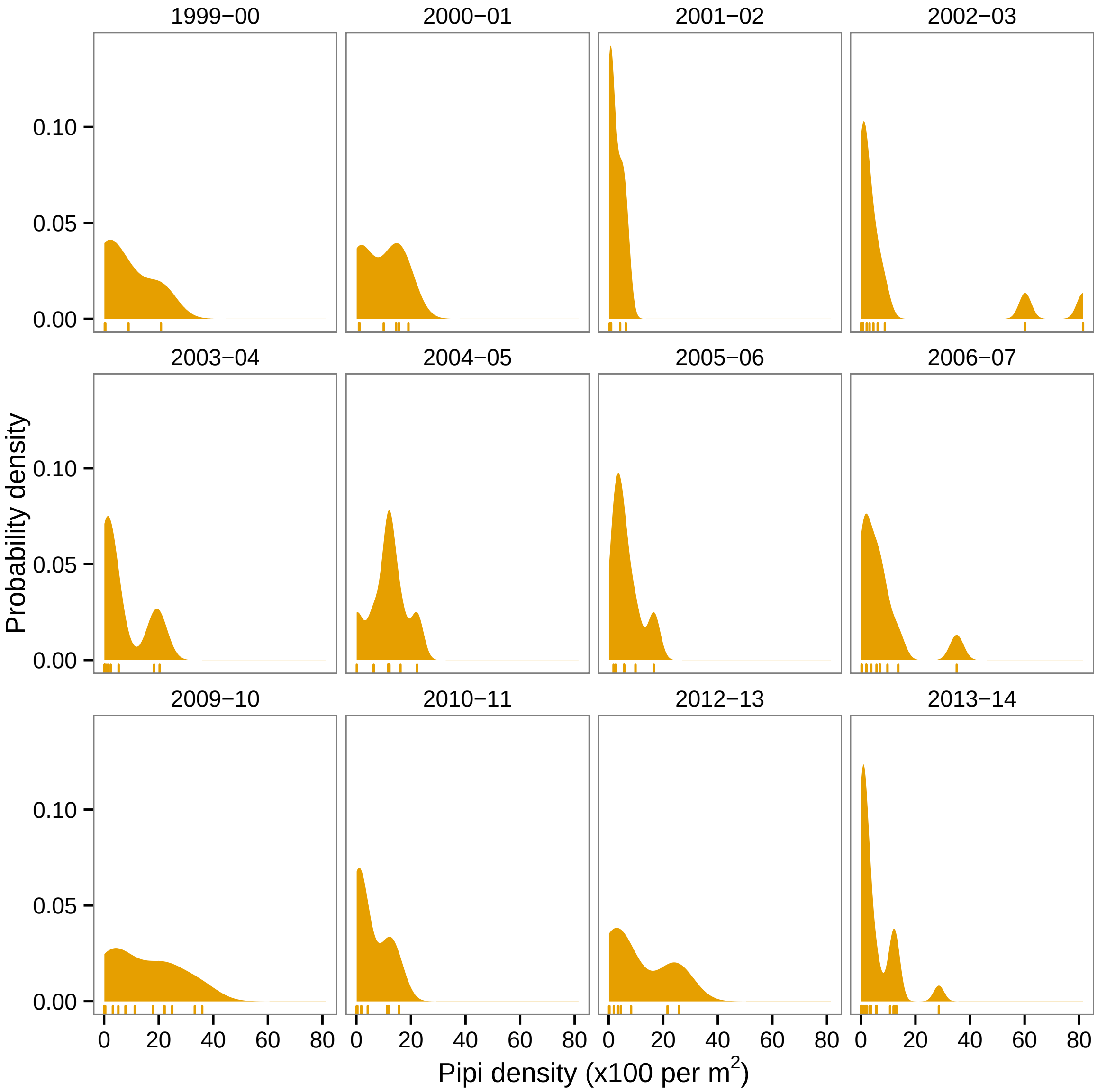

Figure 38: Pipi densities over time at sites included in the 2013–14 survey, estimated independently for all strata. Only strata with more than ten pipi per m^2 were included, the shading shows densities of individual strata. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

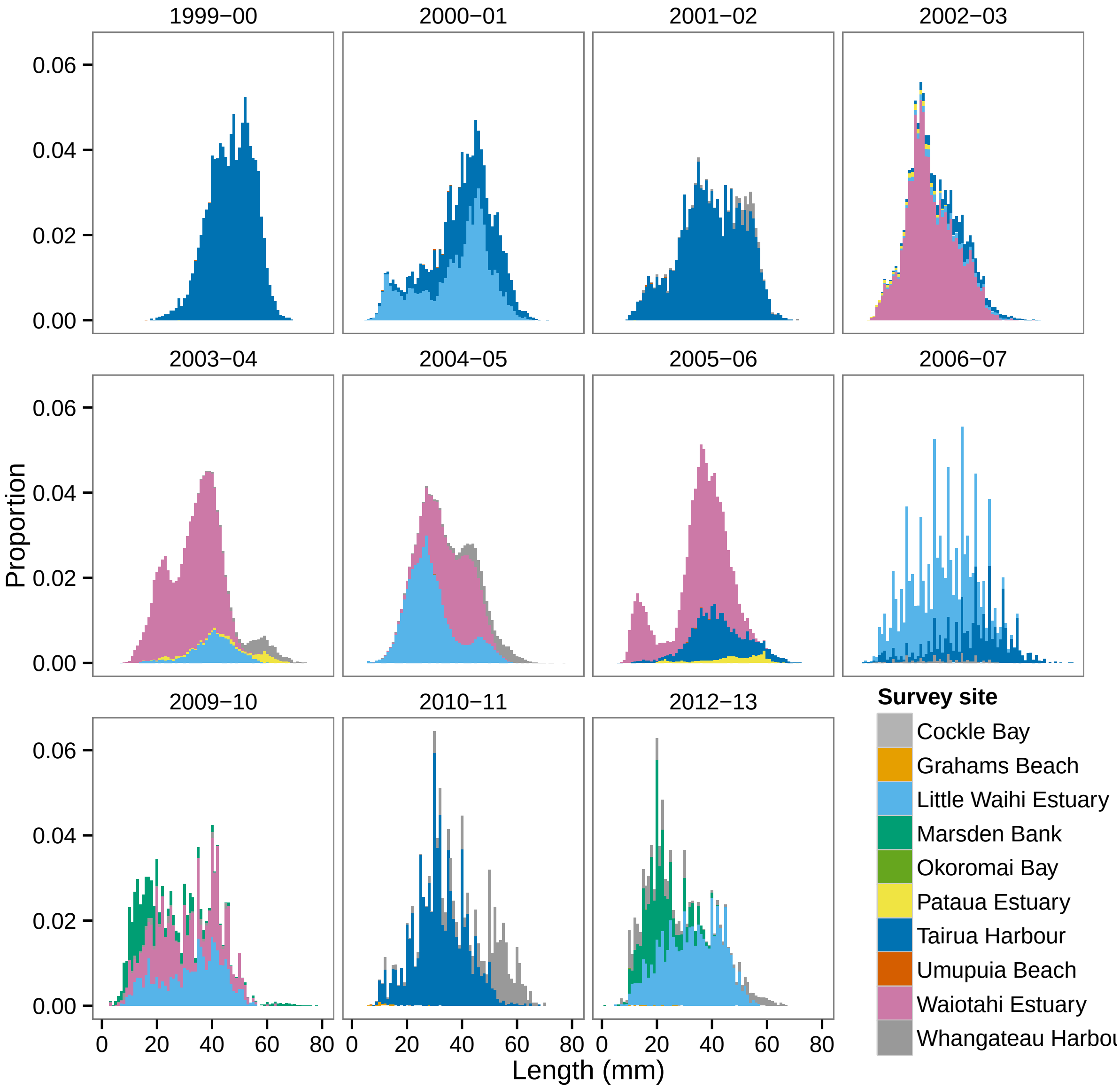

Figure 39: Weighted length-frequency (LF) distributions of pipi over time at sites included in the 2013–14 survey. LF distributions were estimated independently for all strata in each survey to provide the total LF distribution. (Note, not all sites were surveyed each year, and the sampling extent may vary across years.)

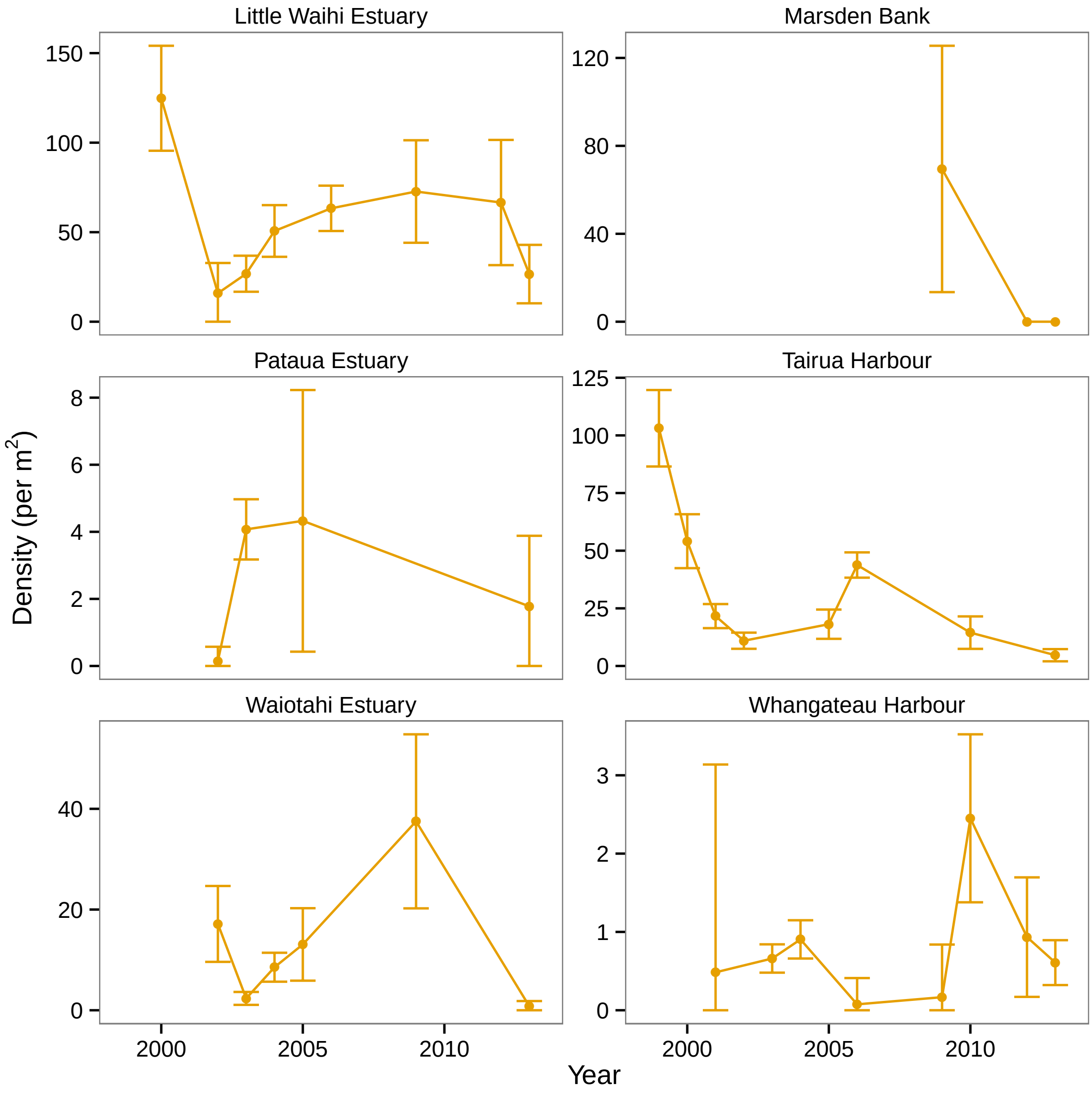

Figure 40: Estimated density of large pipi (≥50 mm shell length) for all sites where pipi in this size class were present in at least one survey. For each site, the figure shows the mean estimated density of large pipi across years within each year's survey strata, bars indicate 95% confidence intervals.

5. DISCUSSION

The present survey found cockle and pipi population at densities comparable with previous surveys, and also showed a continued decline in large-size pipi and cockle densities at many of the surveyed sites, consistent with previous findings (Pawley 2011, Pawley & Smith 2014). Large size classes (defined as $\geq$30 mm shell length for cockle and $\geq$50 mm for pipi) were used to indicate the proportion of bivalves that are likely to be targeted within the cockle and pipi populations. On this premise, monitoring the large size classes potentially helps to identify declines in the bivalve populations at the surveyed sites. Nevertheless, establishing a direct relationship between population trends and fishing pressure is difficult, especially since the number and sizes of bivalves taken at the surveyed sites are unknown. This lack of information and the intermittent sampling at the sites (not every site is surveyed each year) mean that potential links between fishing effort and changes in the cockle and pipi populations remain unknown.

In addition, changes in the size and/or area of the sampling extent and survey strata at some sites make comparisons across surveys difficult. As the surveys focus on intertidal areas that have been identified as important for recreational and customary fisheries, they do not necessarily provide population estimates of the entire cockle and pipi populations at each site. Instead, sampling areas and strata are non-randomly assigned prior to sampling, and it is possible that shifts or extensions in the distribution of bivalve beds, especially cockle, are missed. Changes in the distribution of pipi beds could be related to a shift to deeper, subtidal areas (i.e., below 0.5 m water depth at low tide), making them inaccessible to sampling (and presumably fishing). Information about the location of individual sampling points in previous surveys was not available for the present survey, so that it was not always possible to accurately delimit the bivalve beds or to detect spatial shifts in abundance through time. This aspect was particularly relevant for the cockle beds, which are generally more extensive than the pipi beds, impeding a comprehensive, large-scale assessment of their population distributions prior to the field sampling.

The present study aimed to address these shortcomings by adding spatial information to individual samples. In addition, the field sampling extended some of the cockle strata when their size was considered insufficient to encompass the entire cockle bed. As it was unclear how large these beds were *a priori*, the extension of some of these strata (e.g., stratum A in Whangateau Harbour) went beyond current cockle habitat. Surveying sites like Whangateau Harbour over a considerably larger spatial scale but at a lower spatial resolution would improve the assessment of cockle population boundaries in the future.

In the previous survey in 2012–13, Pawley & Smith (2014) noted that the abundance of large-size cockle had notably increased from earlier declines at three sites following closures, including Cockle Bay, Umupuia Beach, and Whangateau Harbour. These three sites were also included in the present study. At Cockle Bay, the density of large cockles in 2013–14 decreased relative to the previous survey, caused primarily by a decrease in abundance across all sizes, resulting in a stable length-frequency distribution. This finding marked the first decline in the abundance of large cockles at this site since the seasonal closure was first introduced in 2008. At Whangateau Harbour, a decline in the density of large cockles relative to the previous survey was primarily related to the larger survey area, as the total population estimate was higher than in the previous year, and the length-frequency distribution was stable. The total abundance at Umupuia Beach increased relative to the previous survey, whereas the abundance of large cockles remained relatively stable. Based on the overall increases in large cockles at these sites, the closures to fishing appear to be effective, but the marked decline in abundance across age classes at Cockle Bay in 2013–14 also indicates that other factors influence cockle abundance at this and other sites.

Factors that influence the distribution and abundance of bivalves include population dynamics and environmental conditions, such as variable recruitment and changes in hydrodynamics that influence larval and juvenile dispersal. For example, the distribution of juvenile cockles is influenced by active and passive dispersal and post-settlement mortality, resulting in spatially complex recruitment patterns that influence the distribution and abundance of adult populations. For this reason, strong cohorts of juveniles and individuals do not necessarily result in strong adult populations (e.g., for pipi see, Cole et al. 2000).

In addition, the size of adult populations is also influenced by high adult mortality that may be caused by changes to the habitat (e.g., increased freshwater input, Tallis et al. 2004) and disease events involving infestations by parasites and mycobacteria as occurred at Whangateau Harbour in 2009 (Townsend et al. 2010). The importance of factors other than fishing was also evident at Marsden Bank, which underwent a substantial decline of pipi in spite of the closure at this beach.

In addition, environmental patterns, such as increased siltation, and large-scale disturbance events, such as storm runoff and erosion, can potentially lead to drastic changes in bivalve abundance. Both cockles and pipi are sensitive to changes in the sediment regime, and increased concentrations of suspended sediments can lead to declines in their densities, create physiological stress, reduce growth rates and impact on reproduction (Norkko et al. 2002, Gibbs & Hewitt 2004, Hewitt & Norkko 2007). In addition, both species 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 (Gibbs & Hewitt 2004, Thrush et al. 2005, Anderson 2008). Although cockles have a comparatively wide tolerance, evident in their broad distribution and presence (albeit at low densities) in sediments that contain up to 60% mud, they show highest abundances in sediments that contain less than about 11% mud (Thrush et al. 2005, Anderson 2008). Pipi have a narrow tolerance of sediment mud content, generally less than 3%, and reside predominantly in sandy habitats.

The present survey provided some broad-scale information on sediment organic content and grain size across the surveyed sites. These data showed that most sites were characterised by low sediment organic content (i.e., less than 5%) and a small proportion of fines, although the latter was high in some samples, most notably at Cockle Bay and Umupuia Beach (up to 42 and 77%, respectively). In addition, the field sampling revealed localised areas of consolidated clay below a thin layer of surface sediment (about 5 cm depth) at both sites, which made coring across the 15-cm sampling depth difficult within those areas (K. Berkenbusch pers. obs.). Although the broad spatial scale and the low replication of the sediment sampling prevented a systematic assessment of bivalve data in relation to sediment variables, these findings and observations highlight the potential value of including benthic habitat information in the bivalve population assessments. The current sediment sampling provided baseline information over a large spatial scale at each site, and these data allow the design of a targeted sediment sampling programme at higher spatial resolution involving particular sites and/or areas. In addition, these baseline data allow the assessment of sediment changes over time, allowing temporal comparisons of benthic habitat characteristics in conjunction with the bivalve population assessments.

In summary, data from this survey suggest that densities of large size cockles and pipi declined over much of the region. The cause of the declines are unknown, and it is not possible to distinguish the effects of fishing from environmental and demographic effects, such as variable recruitment and cohort strength. Nevertheless, the recovery of bivalves at some sites with closures implemented provides some indication that non-commercial fishing may be one of the factors influencing intertidal bivalve abundance.

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APPENDIX A: Northern North Island shellfish survey fact sheet

Ministry for Primary Industries
Manatū Ahu Matua

Northern North Island Shellfish Surveys

The Ministry for Primary Industries (MPI) has funded intertidal shellfish surveys in northern New Zealand since 1992. These surveys monitor the cockle and pipi populations to find out where these shellfish are and how many are there.

WHY SURVEY SHELLFISH?

Shellfish species such as cockles and pipis are treasured as kai moana and in recreational fisheries.

In the northern North Island region, cockle and pipi populations are still relatively widespread. At some sites, however, abundances may fluctuate over time due to harvest pressure, disease or environmental change.

For this reason, MPI commissions surveys to assess the shellfish populations.

WHERE ARE THE SURVEYS DONE?

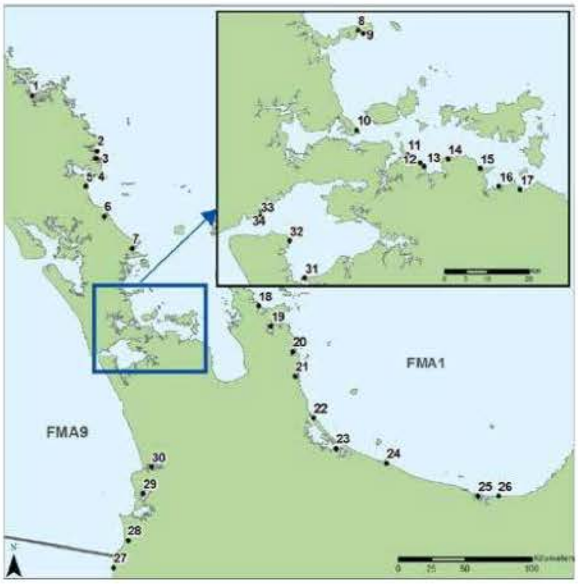
On sheltered muddy and sandy beaches throughout northern New Zealand.

Survey sites include beaches, harbours and bays in the Auckland Fisheries Management Area (FMA 1), with sites in the wider Auckland metropolitan area, Northland, Bay of Plenty, and Waikato.

The surveys have been ongoing since 1992, and usually include 12 sites each year.

Cockle *Austrovenus stuchburyi*

Pipi *Paphies australis*



Survey sites include (but are not limited in the future to): 1. Te Haumi Beach, 2. Ngunguru Estuary, 3. Pataua Beach, 4. Marsden Bank, 5. Ruakaka Estuary, 6. Mangawhai Estuary, 7. Whangateau Harbour, 8. Okoromai Bay, 9. Te Haruhi Bay, 10. Cheltenham Beach, 11. Eastern Beach, 12. Howick Beach, 13. Cockle Bay, 14. Beachlands, 15. Umupuia Beach, 16. Kauri Bay, 17. Kawakawa Bay, 18. Whangapoua Beach, 19. Whitianga Harbour. 20. Tairua Harbour, 21. Whangamata Harbour, 22. Bowentown Beach, 23. Otumoetai Harbour, 24. Little Waihi Estuary, 25. Ohiwa Estuary, 26. Waiotahi Estuary, 27. Waikawau Beach, 28. Marokopa Estuary, 29. Aotea Harbour, 30. Raglan (Whaingaroa) Harbour, 31. Clarks Beach, 32. Grahams Beach, 33. Cornwallis Beach, 34. Mill Bay.

Growing and Protecting New Zealand 1

Figure A-1: Fact sheet published by Ministry for Primary Industries to explain the shellfish sampling programme to members of the public (page one of two).

Northern North Island shellfish surveys

HOW ARE THE SHELLFISH SURVEYED?

At each survey site, cockles and pipis are counted and measured from random locations across each shellfish bed.

Afterwards, the shellfish are returned to where they were sampled from.

FOR FURTHER INFORMATION

For any questions regarding the surveys, or their results, please contact MPI **0800 00 83 33** or +64-4-894 0100.

WHAT DO THE RESULTS LOOK LIKE?

The counts and measurements tell us how many cockles and pipis are there. We also find out what their sizes are, and how many juveniles and adults are in the population.

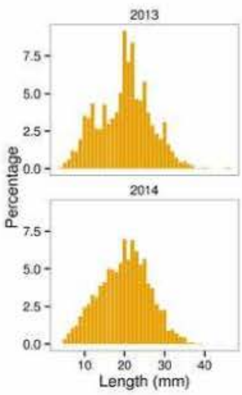
In addition, the survey results can be used for comparisons across years, providing information about population changes.

Shellfish sampling grid. Circles indicate the sampling points, and their size increases with the number of shellfish found.

HOW ARE THE RESULTS USED?

The surveys provide important information about changes to shellfish populations that inform fisheries management discussions with tangata whenua and the recreational sector on the sustainable management of these populations.

Past management measures have included seasonal, temporary and permanent closures, as well as changes to bag limits.



Comparison of shellfish lengths between surveys conducted in 2013 and 2014.

New Zealand Government

September 2014

Figure A-2: Fact sheet published by Ministry for Primary Industries to explain the shellfish sampling programme to members of the public (page two of two).

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

Table B-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
Aotea Harbour							■		■			
Bowentown Beach			■							■	■	
Clarks Beach						■						
Cockle Bay									■	■	■	■
Cornwallis Wharf			■									
Eastern Beach	■		■									
Grahams Beach								■		■	■	■
Howick Harbour							■					
Kawakawa Bay						■		■				
Little Waihi Estuary		■		■	■	■		■	■		■	■
Mangawhai Harbour	■	■	■	■	■					■		
Marokopa Estuary							■			■		
Marsden Bank									■		■	■
Mill Bay	■	■	■		■	■	■		■			
Ngunguru Estuary					■	■				■		
Ohiwa Harbour			■				■	■	■		■	
Okoromai Bay	■		■	■	■	■		■	■		■	■
Otumoetai Harbour		■		■			■	■	■			
Papamoa Beach	■											
Pataua Estuary				■	■		■					■
Raglan Harbour	■	■		■	■				■		■	
Ruakaka Estuary								■		■		
Tairua Harbour	■	■	■	■			■	■		■		■
Te Haumi Bay	■	■	■	■				■	■		■	
Umupuia Beach	■	■	■	■	■	■	■	■	■	■	■	■
Waikawau Beach	■	■				■	■					■
Waiotahi Estuary				■	■	■	■		■			■
Whangamata Beach	■	■	■	■	■	■		■		■		
Whangapoua Harbour				■	■	■	■			■		
Whangateau Harbour			■		■	■		■	■	■	■	■
Whitianga Harbour											■	

Table B-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 2013–14. 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
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	16.00	AKI2009-01
	2010–11	5 May	16.00	AKI2010-01
	2012–13	31 Jan	16.00	AKI2012-01
	2013–14	29 Mar	15.77	AKI2013-01
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
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	2004–05	5 Feb–8 Apr	60.37	AKI2004-01
	2006–07	19 Apr	62.94	AKI2006-01
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
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
	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
Ngunguru Estuary	2003–04	6 Mar–7 Mar	1.70	AKI2003-01

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Table B-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2004–05	6 Feb–7 Feb	1.80	AKI2004-01
	2010–11	23 Mar	1.80	AKI2010-01
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 Harbour	2000–01	27 Mar–2 Apr	5.60	AKI2000-01
	2002–03	3 Mar–5 Mar	5.60	AKI2002-01
	2005–06	15 Feb–28 Feb	4.60	AKI2005-01
	2006–07	13 Jun–14 Jun	4.60	AKI2006-01
	2009–10	1 Mar–17 Mar	5.60	AKI2009-01
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
Ruakaka Estuary	2006–07	21 Mar	7.00	AKI2006-01
	2010–11	22 Mar	11.01	AKI2010-01
Tairua Harbour	1999–00	1 Apr–1 May	3.70	AKI1999-01
	2000–01	15 Feb–16 Feb	3.90	AKI2000-01
	2001–02	23 May–24 May	3.90	AKI2001-01
	2002–03	23 Feb–28 Mar	3.90	AKI2002-01
	2005–06	14 Jan–15 Jan	3.90	AKI2005-01
	2006–07	3 May–1 Aug	4.80	AKI2006-01
	2010–11	20 Apr	5.80	AKI2010-01
	2013–14	13 Mar–22 Mar	9.38	AKI2013-01
Te Haumi Bay	1999–00	7 Mar–30 Mar	10.00	AKI1999-01
	2000–01	12 Mar	13.53	AKI2000-01
	2000–01	15 Jan–26 Jan	9.90	AKI2000-01
	2001–02	15 Mar–15 Apr	9.90	AKI2001-01
	2002–03	21 Jan–22 Apr	9.90	AKI2002-01
	2006–07	22 Mar	9.81	AKI2006-01
	2009–10	18 Feb	12.06	AKI2009-01

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Table B-2 – *Continued from previous page*

Survey site	Year	Sampling dates	Sampling extent (in ha)	Project
	2012–13	13 Dec	12.06	AKI2012-01
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 Beach	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
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
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 C: Sediment sampling

Table C-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
Cockle Bay	A	I	1	-36.89966	174.95157	2.2	3.0	40.6	34.7	13.3	3.8	4.6
	A	I	2	-36.90038	174.95419	1.9	4.4	45.7	34.6	9.3	2.3	3.7
	A	I	3	-36.89987	174.95299	1.9	41.5	34.1	18.0	3.1	1.5	1.8
	A	O	1	-36.90091	174.95260	1.9	2.5	17.2	28.4	18.1	5.0	28.9
	A	O	2	-36.89910	174.95091	2.1	1.6	10.9	43.7	14.4	4.7	24.6
	A	O	3	-36.89789	174.95659	1.2	1.7	36.4	50.5	1.7	1.1	8.6
	B	I	1	-36.89903	174.95439	1.2	2.4	28.6	42.3	16.6	1.1	8.9
	B	I	2	-36.89892	174.95648	1.1	3.2	44.6	46.7	2.6	1.3	1.6
	B	I	3	-36.89889	174.95339	1.4	0.0	33.5	30.3	5.2	3.3	27.7
Grahams Beach	A	I	1	-37.05520	174.66768	0.5	0.0	0.1	1.5	67.7	30.4	0.4
	A	I	2	-37.04688	174.66112	1.8	2.6	3.3	40.1	49.0	3.9	1.1
	A	I	3	-37.04829	174.66277		1.7	5.4	38.5	31.4	5.9	17.1
	A	I	4			1.5	0.0	2.3	43.8	45.4	5.0	3.6
	A	I	5			1.2	0.1	1.6	51.8	41.1	5.4	0.0
	A	I	6			0.8	0.0	0.2	10.1	48.4	40.9	0.4
	A	O	1	-37.04507	174.65923	1.5	0.0	0.2	15.2	78.7	4.0	1.8
	A	O	2	-37.04439	174.65889	0.8	0.3	0.5	22.9	67.7	8.4	0.1
	A	O	3	-37.05052	174.66263	0.5	0.0	0.2	4.2	63.2	31.3	1.1
Little Waihi Estuary	B	I	1	-37.75925	176.48166	1.7	2.7	6.4	61.6	28.0	0.9	0.4
	B	I	2	-37.75865	176.48077	1.6	3.5	5.1	71.2	18.9	0.9	0.5
	B	I	3	-37.75820	176.48054	1.3	1.5	0.3	18.7	57.7	21.5	0.4
	C	I	1	-37.75953	176.47933	2.3	11.5	9.2	31.0	25.7	12.0	10.5
	C	I	2	-37.75943	176.47923	1.0	4.3	4.9	35.2	25.7	16.9	13.0
	D	I	1	-37.76163	176.48199		1.9	6.5	56.2	26.0	8.8	0.7

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Table C-3 – *Continued from previous page*

							Sediment grain size fraction (%)					
Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	D	I	2	-37.76380	176.48055	2.0	8.2	9.9	36.3	31.9	11.6	2.1
	D	I	3	-37.76295	176.48150	1.5	2.8	2.6	50.8	36.3	7.1	0.4
	E	I	1	-37.76068	176.48333	0.8	2.3	3.4	29.3	39.5	24.5	1.0
	E	I	2	-37.76022	176.48273	1.5	3.4	5.3	36.7	28.6	18.3	7.7
	E	I	3	-37.75973	176.48211		3.0	4.0	36.8	38.6	17.7	0.0
Marsden Bank	A	I	1	-35.83992	174.50102	0.6	1.7	1.3	73.8	22.8	0.4	0.0
	A	I	2	-35.84073	174.50195	0.5	1.7	0.6	65.4	30.9	1.4	0.0
	A	I	3	-35.84049	174.50274	1.0	0.0	0.8	44.8	35.0	4.1	15.4
	A	I	4	-35.83982	174.50326	0.5	1.4	1.3	82.6	14.5	0.2	0.0
	A	I	5	-35.83862	174.50362	0.9	0.0	1.2	69.9	25.9	1.2	1.8
	B	I	1	-35.84259	174.50104	0.7	0.5	0.7	49.3	39.7	1.9	7.9
	B	I	2	-35.84255	174.50139	0.6	0.0	0.6	57.2	40.8	0.9	0.5
	B	I	3	-35.84186	174.50132	0.6	0.0	0.8	60.1	38.3	0.6	0.1
	B	I	4	-35.84118	174.50148	0.6	1.1	1.5	82.8	14.4	0.2	0.0
	B	I	5	-35.84139	174.50212	0.6	2.1	0.8	59.3	34.4	2.7	0.7
	B	I	6	-35.83930	174.50032	1.1	0.0	4.7	87.3	7.8	0.2	0.0
	B	O	1	-35.84336	174.50036	0.7	0.0	2.5	64.9	28.4	3.2	0.9
	B	O	2	-35.84301	174.50094	0.5	0.0	1.7	62.1	33.5	1.9	0.8
	B	O	3	-35.83931	174.50032	0.5	0.9	1.5	88.0	9.5	0.1	0.0
Okoromai Bay	A	I	1	-36.61161	174.80818	2.4	1.2	24.8	62.0	10.1	0.6	1.3
	A	I	2	-36.61171	174.80985	1.6	0.4	48.3	41.8	0.9	0.5	8.0
	A	I	3	-36.61106	174.81156	1.7	1.6	59.3	35.7	2.6	0.3	0.4
	A	O	1	-36.60786	174.80828	1.5	0.0	0.6	26.9	60.7	4.9	6.9
	A	O	2	-36.61007	174.80827	2.0	1.7	81.6	15.7	0.7	0.1	0.1
	A	O	3	-36.61266	174.80828	1.7	0.4	28.5	65.9	5.1	0.1	0.0
	B	I	1	-36.60912	174.80861	2.0	4.7	63.8	28.1	2.2	0.5	0.7
	B	I	2	-36.60874	174.81207	2.4	7.2	61.0	24.3	3.5	0.8	3.2
	B	I	3	-36.60886	174.81065	2.0	1.9	69.1	23.0	1.3	0.7	4.0
Pataua Estuary	A	I	1	-35.71515	174.51862	4.4	5.4	25.5	54.2	11.4	2.4	1.1

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Table C-3 – *Continued from previous page*

							Sediment grain size fraction (%)					
Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	A	I	2	-35.71660	174.51705	2.5	3.1	20.7	57.8	4.9	4.9	8.6
	A	I	3	-35.71872	174.51749	2.0	0.0	18.5	73.0	1.3	4.8	2.4
	A	I	4	-35.71760	174.51645	2.0	4.0	17.7	49.2	20.9	6.9	1.4
	A	O	1	-35.71586	174.51828	1.5	2.3	8.0	49.8	32.7	5.7	1.4
	A	O	2	-35.71591	174.51619	1.7	4.4	6.0	43.0	15.1	23.8	7.7
	A	O	3	-35.71694	174.51566	1.8	2.4	10.2	57.1	19.3	8.6	2.4
	B	I	1	-35.72028	174.51261	2.2	1.0	27.9	45.3	12.7	9.5	3.7
	B	I	2	-35.71769	174.51237	2.0	0.7	27.5	70.0	0.5	0.5	0.9
	B	I	3	-35.71874	174.51217	2.0	3.9	18.1	58.8	6.8	6.4	6.1
	B	I	4	-35.71894	174.51390	2.1	3.7	21.0	64.5	8.1	2.3	0.3
	B	O	1			2.2	1.9	10.5	17.0	9.4	14.2	47.0
	B	O	2			1.6	2.8	7.7	36.0	25.7	26.5	1.4
	B	O	3			4.8	3.4	46.0	47.1	2.6	0.9	0.0
	C	I	1	-35.71382	174.52205	1.4	0.1	0.7	19.7	47.9	29.2	2.5
	C	I	2	-35.71365	174.52234	1.2	0.0	1.5	39.8	29.3	25.0	4.4
	C	I	3	-35.71379	174.52174	1.1	3.7	2.2	33.9	32.3	21.8	6.1
	C	O	1	-35.71384	174.52238	0.9	1.5	0.0	2.7	20.9	73.0	1.9
	C	O	2	-35.71479	174.52022	1.2	0.0	2.7	26.7	20.0	26.3	24.3
	C	O	3	-35.71513	174.51999	1.3	0.5	0.5	9.3	23.6	36.7	29.5
	C	O	4	-35.71513	174.52017	1.1	0.0	0.1	2.7	16.5	64.3	16.4
	D	I	1	-35.71479	174.52022	1.1	2.6	2.1	17.8	28.6	44.9	4.0
	D	I	2	-35.71495	174.52008	1.1	2.3	0.3	6.0	21.7	50.3	19.5
	D	I	3	-35.71493	174.52007	1.2	0.0	1.0	18.7	36.0	42.1	2.1
Tairua Harbour	A	I	1	-37.00511	175.85720	1.1	1.9	0.1	10.5	60.4	27.0	0.2
	A	I	2	-37.00456	175.85836	1.1	0.0	0.1	4.9	39.8	55.3	0.0
	A	I	3	-37.00386	175.85969	1.3	1.3	0.3	23.8	50.0	24.6	0.0
	B	I	1	-37.00524	175.85492	2.1	3.0	9.2	64.5	20.5	1.8	1.0
	B	I	2	-37.00513	175.85516	2.1	0.1	7.6	60.1	24.5	6.7	1.1
	B	I	3			1.9	2.1	4.2	44.1	32.4	11.1	6.0

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Table C-3 – *Continued from previous page*

							Sediment grain size fraction (%)					
Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Fines	VFS	FS	MS	CS	Gravel
	B	O	1	-37.00695	175.85161	2.1	2.6	10.7	53.9	29.2	3.3	0.3
	B	O	2	-37.00491	175.85539	1.7	1.3	0.7	34.0	51.6	12.0	0.4
	B	O	3	-37.00457	175.85394	2.2	2.3	7.5	65.2	19.7	4.5	0.8
	C	I	1	-37.00682	175.85729	2.2	2.1	7.0	69.6	17.1	3.3	0.9
	C	I	2	-37.00611	175.85902	2.0	3.3	4.2	76.5	15.5	0.5	0.0
	C	I	3	-37.00569	175.86075	2.1	2.3	5.9	84.4	7.1	0.3	0.1
	D	I	1	-37.00624	175.86130	0.9	1.3	1.0	36.8	50.5	4.1	6.3
	D	I	2	-37.00733	175.86063	1.0	3.8	2.8	32.2	39.6	7.4	14.2
	D	I	3	-37.00787	175.86016	1.0	1.6	3.4	46.0	42.9	2.7	3.5
	E	I	1	-37.00718	175.85221	3.7	11.3	19.8	47.6	16.5	2.8	2.0
	E	I	2	-37.00633	175.85334	2.6	12.1	10.6	53.7	17.8	3.1	2.7
	E	I	3	-37.00664	175.85377	3.9	11.3	18.2	47.6	10.0	3.2	9.6
	F	I	1	-37.00347	175.85915	1.4	0.8	0.3	23.9	57.3	17.6	0.1
	F	I	2	-37.00330	175.86058	1.9	1.7	2.5	43.8	43.9	4.1	4.0
	F	O	1	-37.00277	175.85907	1.0	0.6	0.2	9.6	52.4	37.1	0.1
Umupuia Beach	A	I	1	-36.90177	175.07328	1.0	2.1	53.6	42.9	1.2	0.1	0.0
	A	O	1	-36.90105	175.06532	4.5	76.9	6.7	12.5	3.8	0.2	0.0
	A	O	2	-36.89950	175.06450	8.5	47.6	28.1	9.5	5.3	4.6	5.0
	A	O	3	-36.90011	175.06491	3.4	3.8	23.9	26.9	39.2	5.9	0.4
	B	I	1	-36.90010	175.06813	1.1	7.6	45.4	41.7	4.6	0.3	0.3
	C	I	1	-36.90372	175.07112	7.9	36.7	28.1	19.9	12.2	2.0	1.1
	C	I	2	-36.90318	175.07484	2.0	1.4	61.4	7.5	5.1	14.4	10.2
	D	I	1	-36.89966	175.06603	1.5	8.1	37.8	46.3	6.5	0.8	0.5
	D	I	2	-36.89958	175.06509	4.1	42.8	39.0	12.7	4.6	0.8	0.1
Waiotahi Estuary	A	I	1	-37.99186	177.19831		5.5	3.4	65.0	23.0	3.1	0.0
	A	I	2	-37.99226	177.19672	1.8	1.9	7.9	69.4	18.3	2.3	0.1
	A	I	3			1.8	10.6	14.6	59.3	13.0	2.3	0.2
	A	I	4				3.1	5.0	68.6	21.0	2.4	0.0
	A	O	2	-37.99401	177.19940	1.7	12.2	10.6	67.2	8.7	1.2	0.0

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Table C-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	3	-37.99323	177.19798	1.7	11.1	14.2	66.0	8.1	0.4	0.2
	B	I	1	-37.99350	177.19944	2.2	17.5	14.2	60.5	5.3	2.5	0.1
	B	I	2	-37.99324	177.19992	2.2	16.4	11.3	64.8	6.1	1.3	0.1
	B	I	3	-37.99377	177.19993	2.1	17.3	14.3	64.3	2.9	0.5	0.7
	B	O	1	-37.99247	177.19577	2.8	32.6	22.3	35.9	7.4	1.5	0.3
	C	I	1	-37.99299	177.20158	1.4	3.5	2.6	83.4	10.0	0.6	0.0
	C	I	2	-37.99293	177.20203	1.3	0.4	1.0	70.4	26.2	1.9	0.1
	C	I	3	-37.99336	177.20205	2.4	0.0	2.5	93.3	4.1	0.1	0.0
	C	O	1	-37.99256	177.20138	1.3	8.5	10.5	67.2	5.6	5.6	2.6
	C	O	2	-37.99327	177.20270	1.0	1.2	2.4	63.2	31.9	1.4	0.0
	D	I	1	-37.99205	177.19924	1.8	2.4	4.8	67.8	18.1	5.6	1.3
	D	I	2	-37.99256	177.20074	1.2	3.1	2.5	74.7	19.5	0.1	0.0
	E	I	1	-37.99197	177.20396	1.1	1.2	3.1	80.1	15.2	0.4	0.0
	E	I	2	-37.99247	177.20440	1.4	0.4	1.1	63.1	29.7	5.6	0.0
Whangateau Harbour	A	I	1	-36.31414	174.77888	1.1	0.4	2.2	48.9	41.9	3.5	3.1
	A	I	2	-36.31550	174.77695	0.6	1.2	0.1	16.7	65.2	9.7	7.1
	A	I	3	-36.31517	174.77391	0.8	0.2	2.1	65.2	13.5	1.2	17.7
	A	I	4	-36.31306	174.77318	1.1	0.9	7.1	56.9	30.8	2.4	1.9
	A	I	5	-36.31233	174.77526	0.8	0.2	5.8	69.8	21.5	2.0	0.8
	A	O	1	-36.31632	174.77221	1.3	1.4	5.1	65.7	24.7	1.6	1.5
	A	O	2	-36.31510	174.77109	1.0	0.1	1.5	51.2	29.4	4.9	13.1
	A	O	3	-36.31175	174.77389	1.1	0.7	8.9	54.4	33.4	2.3	0.2
	B	I	1	-36.31379	174.78031	2.8	4.7	27.5	53.5	13.4	0.7	0.2
	B	I	2	-36.31498	174.78170	1.3	0.0	3.1	64.7	31.5	0.6	0.0
	B	I	3	-36.31389	174.78171	1.2	0.6	5.8	53.6	37.1	0.6	2.2
	C	I	1	-36.33260	174.76468	0.8	0.0	3.8	80.7	14.3	0.6	0.7
	C	I	2	-36.32996	174.76478	0.9						
	C	I	3	-36.32701	174.77073	1.2	0.5	8.2	64.0	10.9	4.8	11.7
	C	I	4	-36.33651	174.76284	0.9	0.0	4.4	73.0	21.7	0.3	0.5

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Table C-3 – *Continued from previous page*

Survey site	Stratum	Location	Sample	Latitude	Longitude	Organic matter (%)	Sediment grain size fraction (%) Fines	VFS	FS	MS	CS	Gravel
	C	I	5	-36.33739	174.76331	0.9	0.1	7.2	69.7	20.5	0.5	2.1
	C	O	1	-36.33211	174.76245	1.0	0.5	5.7	79.0	14.6	0.1	0.0
	C	O	2	-36.32583	174.76710	0.8	2.7	4.6	57.0	34.3	0.9	0.3
	C	O	3	-36.32756	174.76447	1.0	0.0	4.6	62.8	20.5	3.6	8.5
	C	O	4	-36.33260	174.76189	1.1	1.5	9.6	78.7	10.1	0.1	0.0
	C	O	5	-36.33863	174.76251	0.9	2.5	6.8	62.4	26.9	0.7	0.7
	D	I	1	-36.32146	174.77577	0.6	0.0	0.3	44.3	53.5	1.8	0.1
	D	I	2	-36.32146	174.77574	0.6	0.0	0.2	55.0	43.4	0.5	0.8
	D	I	3	-36.32185	174.77507	0.7	2.4	1.9	74.3	19.7	0.8	0.9
	D	O	1	-36.32175	174.77503	0.8	1.1	1.0	69.7	27.8	0.4	0.0
	D	O	2	-36.32139	174.77566	0.6	0.0	0.2	41.1	52.9	4.3	1.5
	D	O	3	-36.31390	174.77167	0.9	2.5	4.1	49.1	37.5	6.4	0.5

APPENDIX D: Errata

For some of the previous surveys, there were discrepancies between information presented in the reports and the underlying data contained in the MPI beach database. Discrepancies that became evident in the current analyses and corrections (where possible) are listed below.

D.1 Cockle Bay

- The total area of the sampling extent in 2009–10 in the beach database was incorrectly reported as 32 ha (320 000 m^2), when it was 16 ha (160 000 m^2, i.e., 80 000 m^2 per stratum).

D.2 Grahams Beach

- Multiple strata are reported for this site in the beach database, and the stratum area for each stratum changes between years. Reports since 2006–07 only document one stratum at this beach.
- The value for total cockle abundance reported in Pawley & Smith (2014) for 2006–07 was 8.5 million cockles. Data in the beach database suggest a value of 4.9 million cockles.
- The value for total pipi abundance reported in Pawley & Smith (2014) for 2010–11 was 2.6 million pipi. Data in the beach database suggest a value of 3.75 million pipi.

D.3 Little Waihi Estuary

- The proportion of large ($\geq$50 mm shell length) pipi reported in Pawley & Smith (2014) for 2009–10 was 2.7%, leading to a density of 56 pipi m^{-2}. This value is inconsistent with the reported population estimate of 10 million large-sized pipi. Data in the beach database suggest that 4% of pipi were $\geq$50 mm shell length. This proportion is consistent with the estimate of 10 million pipi $\geq$50 mm, but resulted in a revised density of 73 pipi m^{-2}.

D.4 Marsden Bank

- The proportion of large pipi reported in Pawley & Smith (2014) for 2010–11 was 3.8%. This value is inconsistent with the reported abundance estimate of 10 million pipi and the density of 2.6 pipi m^{-2} in this size class given the reported total population estimate.
- The stratum size for the 2012–13 survey was indicated as 6.3 ha in the database. This area is about half the size of the previous survey extent, and less than half the size of the sampling extent in the current survey. Visual comparisons with maps provided in previous survey reports suggest this value is an error. (Note that density estimates in the current study for the 2012–13 survey were derived from information in the database and may, therefore, be incorrect.)