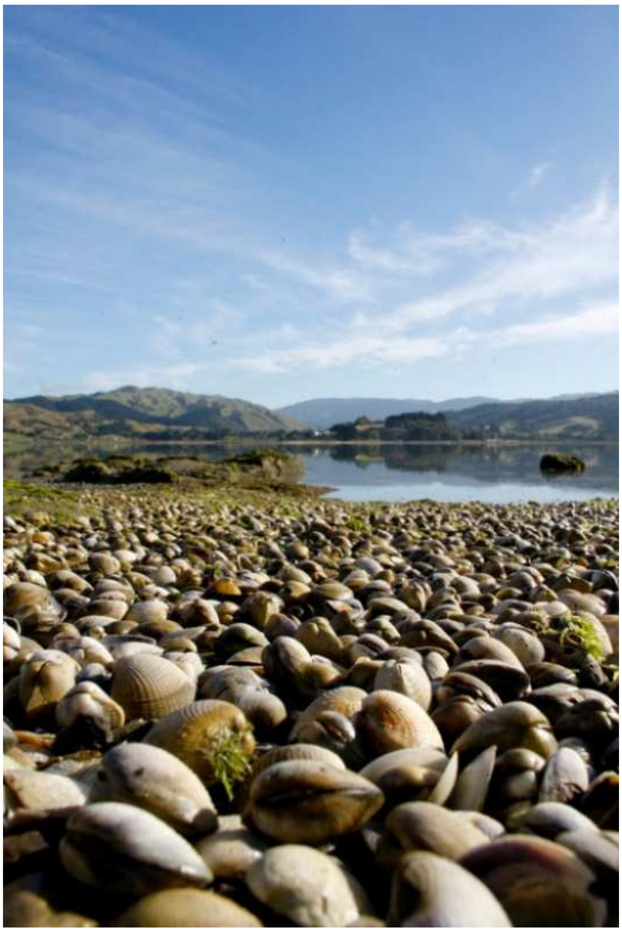
Community survey of cockles (*Austrovenus stutchburyi*) in the intertidal zone of Pāuatahanui Inlet, Wellington, November 2019

Prepared for Guardians of Pāuatahanui Inlet

June 2020



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Matt Duncan, cockles exposed by the low tide in Pāuatahanui Inlet (2011, 2nd place - Scenic Impressions, Guardians of Pāuatahanui Inlet photographic competition).

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Executive summary

The Guardians of Pāuatahanui Inlet and community volunteers have carried out ten triennial surveys of cockles (*Austrovenus stutchburyi*) in Pāuatahanui Inlet (Porirua Harbour) since 1992. These surveys provide an important time-series of data to monitor trends in cockle densities and their size structures over space and time, in the intertidal zone. Localised changes in the demographics of cockles may provide indications of changes to environmental factors and the ecosystem health of Pāuatahanui Inlet.

All the GOPI surveys use the same design and methods, allowing site, transect, and tide level comparisons between surveys. This report summarises the results of the tenth survey undertaken between the 24th of November 2019 and 15th of January 2020. Of the 30 transects, 29.5 were fully sampled and comprised 354 of the 360 quadrats available. Transect 30 has not been sampled since 2010.

This report updates the 2016 survey report and provides an in-depth context and discussion of surveys.

Key findings of the 2019 Pāuatahanui Inlet cockle survey:

- The total survey counts of cockles increased 40.9% between 2016 and 2019.
- Most transects had higher or markedly higher total counts of cockles than in 2016.
- The highest number of cockles recorded per 0.1 m^2 quadrat was 279, substantially higher than for previous surveys.
- Mean cockle density over the intertidal survey area was 38.1 per 0.1 m^2 (99% CI 34.6–41.7) was higher than in 2013 (33.6 per 0.1 m^2, 99% CI 30.9-36.2); however, not significantly different. Mean cockle density in 2019 was significantly higher than in 2016 (28.8 per 0.1 m2, 99% CI 25.9–31.6), and higher than for previous GOPI surveys since 1992.
- The cockle population size estimates have increased 32.2% (both Methods 1 and 2) since 2016 and were the highest since 1976.
- Most sites showed similar or increasing trends in total numbers of cockles.
- The percentage of juvenile cockles in the population increased markedly between 1992 and 2004 from 1% to 16 % and has remained high, varying without trend between 15.6 % in 2010 and 17.4% in 2016. In 2019, the percentage of juvenile cockles declined to 15.6%.

The increase in population size of cockles in the intertidal zone of Pāuatahanui Inlet in 2019 and recovery of the population from the decline between 2013 and 2016 show the cockle population is in an improving state. The consistently high percentages of juvenile cockles since 2004 (12.4–17.4% of the total populations) suggest successful settlement of larvae and good survival of spat, or potentially some immigration of juvenile cockles from subtidal areas.

Population size of cockles declined below the long-term trend in 2016, putatively caused by the 2016 floods. The 2013, 2016, and 2019 population size frequencies suggest that all sizes of cockles were affected in 2016. Juvenile cockles are expected to be more vulnerable to changing environmental conditions such as increasing mud. However, the percentage of juvenile cockles was highest in 2016 (17.4% of the total population) and may have been driven by an extraordinarily large cockle spat settlement event.

High percentages of cockles (more than 50%) are above spawning size (larger than 18 mm in length) that should maintain larval production in the Pāuatahanui Inlet.

Changes in the environmental conditions in Pāuatahanui Inlet, particularly the increase in terrestrial sediments considered deleterious to cockles, do not appear to have affected the intertidal cockle population.

1 Introduction

Estuaries provide substantial ecosystem services and are highly vulnerable to anthropogenic (man-made) effects. Porirua Harbour, encompassing Pāuatahanui Inlet and the Onepoto Arm, is the largest and most significant estuary in the Wellington region. Pāuatahanui Inlet is ranked second for conservation importance in the Wellington region after the Manawatu River (Todd, Kettles et al. 2016). More information on the importance of estuaries and Pāuatahanui Inlet is given in the 2010 cockle survey report (Michael 2011).

Ngāti Toa have had a long and close relationship with Te Awarua-o-Porirua and the harbour is integral to the identity of Ngāti Toa. The ecological significance of Pāuatahanui Inlet has been long recognised by the community. In 1991, a local community group founded the Guardians of Pāuatahanui Inlet (GOPI). In the same year, a Pāuatahanui Inlet Advisory Group was established by Porirua City Council (PCC) and the Greater Wellington Regional Council (GWRC) to seek community input into an action plan to protect the inlet. This advisory group included Ngāti Toa and community groups such as GOPI and Forest and Bird. The Pāuatahanui Inlet Action Plan, Towards Integrated Management was established by PCC and GWRC. The advisory group became The Pāuatahanui Inlet Community Trust in 2002. PCC and GWRC commissioned a Pāuatahanui Restoration Plan between 2002 and 2004. In recognition of the ecological significance of the entire harbour, including the Onepoto Arm, the Porirua Harbour and Catchment Community Trust (PHT) was established in 2011 and a Porirua Harbour and Catchment Strategy and Action Plan finalised in 2012. The Pāuatahanui Inlet Community Trust was disbanded in 2015, with its role integrated in to PHT (For more information see the GOPI website, http://www.gopi.org.nz/home/items-of-current-interest/porirua-harbour-and-catchment-strategy-and-action-plan/).

In 2014, in response to the National Policy Statement for Freshwater Management, the Te Awarua-o-Porirua Whaitua committee, comprised of Ngati Toa, community members, and local and regional council officers, and elected officials, was established. The committee were tasked with recommending ways to improve the management of land and water within Te Awarua-o-Porirua catchment to achieve an improvement in water quality and ecology. The Ngati Toa Statement (http://www.gw.govt.nz/assets/Whaitua/ngatitoataopwhaituastatement.pdf) and the Te Awarua-o-Porirua Whaitua Implementation Programme (WIP) (www.gw.govt.nz/assets/Whaitua/Porirua-WIP-web.pdf) containing these recommendations were finalised in April 2019. Implementation of the Statement and WIP are ongoing.

Concerns about ecosystem health, environmental threats, and sustainable development, have led to increased efforts to monitor and assess the status of estuarine ecosystem health. Determining estuarine health is difficult, as it requires knowledge of the complex ecosystem interactions, and good time-series data. Increasingly, ecological indicators or indicator species provide simple measures of changes in ecological processes or components of ecosystems. The GOPI surveys of intertidal cockles undertaken by community volunteers provide an important time-series of information for monitoring the health of Pāuatahanui Inlet. Significant, long-term decreases in the abundance and size structure of cockles, a keystone species in this intertidal habitat, is likely to represent changes to the ecological structure and probable loss of ecosystem function.

The biology of cockles (*Austrovenus stutchburyi*) was summarised in the 2010 cockle survey report (Michael 2011), and further information is available from Fisheries New Zealand (Ministry for Primary Industries) (Fisheries New Zealand 2019). An overview of some of the early surveys of Pāuatahanui

Inlet (1971 and 1976–1980) is contained within this report. Since 2008, cockle survey reports (Michael 2008, 2011; Michael & Wells 2014, 2017) represent a living document that is a depository for information on cockles in Pāuatahanui Inlet. This report updates the 2016 cockle survey report (Michael & Wells 2017) with the results of the 10th GOPI cockle survey, carried out in November 2019.

1.1 The Guardians of Pāuatahanui Inlet cockle surveys

The Guardians of Pāuatahanui Inlet and community volunteers have undertaken surveys of the cockle population in the Inlet since 1992. NIWA has assisted by analysing the survey data and updating reports containing the summaries of results. Greater Wellington Regional Council provides logistical and practical support for the surveys and funds the report preparation. All survey reports are available, as downloadable PDFs, on the GOPI website http://www.gopi.org.nz/cockle-survey-2.

1.1.1 Survey history

The first GOPI intertidal cockle survey was undertaken in 1992 (Figure 1–1), sampling most of the survey sites sampled in 1976 (Figure 1–2) by Richardson et al. (1979), this time with the assistance of community volunteers, and overseen by NIWA (Grange 1993). That survey found a decrease in the numbers of cockles in the Inlet since 1976 (see Figure 3–3) and indicated that there were fewer adults (larger than 10 mm shell length) in the population. The most pronounced decreases were around the south-western shores of the Inlet at Brown's Bay adjacent to the early residential development of Whitby (Estcourt and Grange 1976). Differences in population size and cockle density may also have been due to other factors such as heightened natural mortality and differences in the two survey designs.

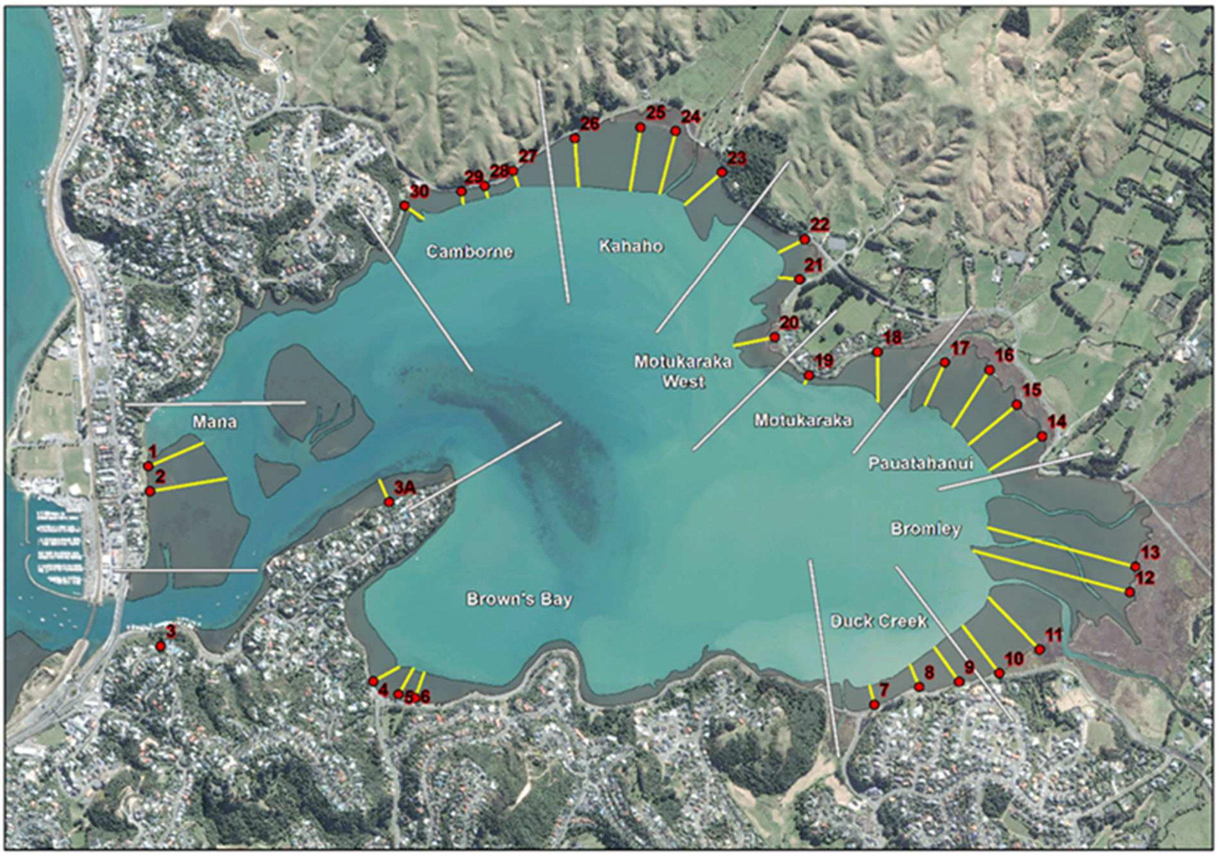

Figure 1-1: Location of the 31 transects in Pāuatahanui Inlet sampled for intertidal cockle densities and population size structure by the Guardians of Pāuatahanui Inlet (GOPI), 1992–2019.

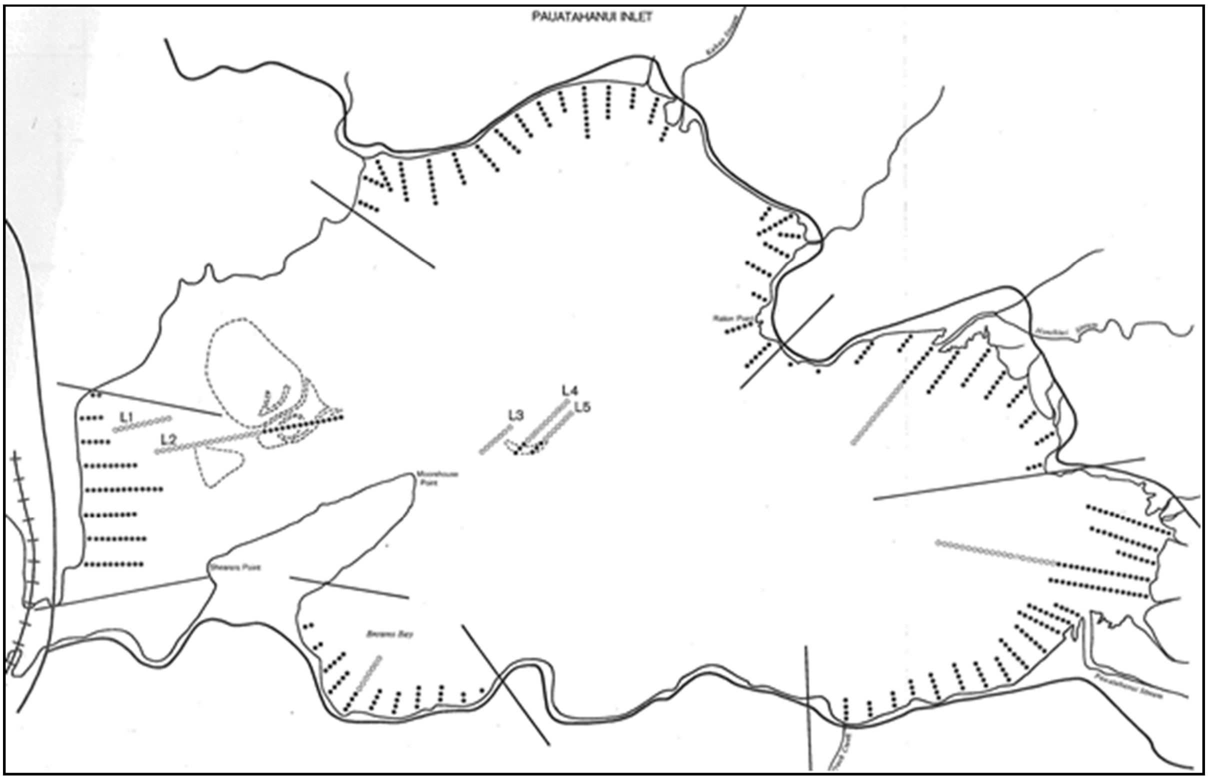

Figure 1-2: 1976 survey stratification of Pāuatahanui Environmental Programme (Healy 1980). Pāuatahanui Inlet was divided into seven sectors, and intertidal and subtidal zones were sampled in five sectors. Straight lines delineate sectors, filled circles show the location of intertidal transects, and open circle the location of subtidal transects. Figure reproduced from Richardson et al. (1979).

A second GOPI survey, undertaken in November 1995, sampled the same sites using the same methodology as the 1992 survey, and aimed to document any changes in the population. Those results indicated that the population decline had continued (Grange et al. 1996). Subsequent triennial surveys, since November 1998 (Grange & Crocker 1999; Grange & Tovey 2002; Horn et al. 2005; Michael 2008; Michael 2011; Michael & Wells 2014; Michael & and Wells 2017) used the same sites and methods as the 1992 and 1995 surveys (see section 2).

1.1.2 Population size and density

The population size of the intertidal cockles in Pāuatahanui Inlet declined between 1976 and 1995, increased in 1998, and declined again in 2001 (see Figure 3–3 and Table 3–2). The trend in population size between 2001 and 2013 showed a continuous increase.

Total population size increased 87% between 1995 and 2013. However, the population size of cockles declined 14% between 2013 and 2016 (see Figure 3–3 and Table 3–2).

In 2016, cockle counts per quadrat were mostly lower than in 2013 and ranged from zero to a maximum of 176 per 0.1 m^2 (higher than in any of the previous surveys).

The 2016 survey showed the first downward trend in the cockle population size since 2001 (Michael & Wells 2017).

1.1.3 Juvenile Abundance

A greater overall abundance of juveniles (10 mm in length and smaller, Richardson et al. 1979) was recorded by the 1998 and 2001 surveys compared with the 1992 and 1995 surveys. The 2004 estimate was twice that in 1998 and 2001. The 2007 survey found similar numbers of juvenile cockles to 2004. The numbers of juvenile cockles increased further in 2010.

Assuming recruitment the intertidal cockle population and juvenile mortality remained near long-term mean (average) levels, there was negligible net migration of juveniles to subtidal areas, and growth rates were typically fast, the higher recruitment of juveniles observed in 2010 probably led to the increase in the cockle population observed in 2013. The numbers of juvenile cockles declined slightly in 2013.

2 Methods

Community volunteers have undertaken intertidal surveys of the cockle population in Pāuatahanui Inlet since 1992, and most recently in 2019. These surveys sampled the same transects (Figure 1–2) and used similar methods.

When using volunteers for sampling it is important to include a substantial training for volunteers before they are sent to the estuary to sample cockles, for health and safety, and to allow for comparisons with other sampling sites and other survey years. The Pāuatahanui cockle count uses a method of training-the-trainers, where training occurs for all transect team leaders. Team leaders then share that knowledge with the 3–4 other people on their sampling teams. All transect leaders have the phone number of the scientific advisor, which was John Wells until 2016 when Warrick Lyon replaced him in 2019, so any additional queries can be phoned in. Team leaders guided volunteers, monitored sampling and the recording of data. Volunteers were each provided with sheets that explained the sampling methods and were shown the location of sites (Appendices A and B for instruction and sampling sheets), the team leader's check list (Appendix C), and tally sheets to record cockle lengths (Appendix D).

The survey comprised 31 fixed transects (see Figure 1–2). Transect 30 has not been sampled since 2010, because this area is now a launching place for jet skis and the beach shows relatively high degradation caused by the vehicle traffic so would not be comparable to previous years. Transects were located using numbered stakes deployed before the survey and transects were orientated towards landmarks on the opposite shore of the Inlet (see Appendix B for details). The details used to locate each of these transect markers are given in Appendix E. Transects were grouped by site (Table 2–1). Each transect was sampled at four tidal heights (high (HT), upper-mid (UMT), lower-mid (LMT), and low (LT) tides), and those tidal heights were determined by a set-number of adult paces from the location marker (see Appendix E) and marked with a stake to provide a reference for sampling. Samples were taken from three haphazardly placed quadrats (0.1 m^2), on or about 5 m either side of transects (recorded as A, B, and C), at each tide height.

Table 2-1: The grouping of transects sampled within each site in Pāuatahanui Inlet.

Site	Transects	Site	Transects
Mana	1–3	Pāuatahanui	14–17
Seaview Road	3a	Motukaraka	18–19
Brown's Bay	4–6	Motukaraka West	20–22
Duck Creek	7–9	Kakaho	23–26
Bromley	10–13	Camborne	27–30

These replicate quadrats were sampled to a depth of about 7 cm and the entire sample was sieved. In 2019, the survey used kitchen colanders as for all previous surveys, with mesh sizes of 3–5 mm (John Wells and Neil Bellingham, GOPI, pers. comm.). Volunteers flushed sediments and fines through the sieves using seawater. These colanders retained cockles down to 2 mm in length (see Figure 2–2).

Volunteers sorted all live cockles into containers, measured them for length (along the anterior posterior axis) (Figure 2-2) to the nearest millimetre using rulers, and returned them to the intertidal seabed. They used sampling sheets (Appendix D) to record tallies of lengths from each sample. For images of these activities see the 2010 cockle survey report (Michael 2011).

2.1 Density and population estimates

2.1.1 Cockle counts and density

Cockle counts from quadrats and tallies from multiple quadrats are used to estimate cockle densities at each site, transect, and tidal height. Cockle densities from the 2019 survey are compared with those from the previous nine GOPI surveys (1992–2016). The fixed sampling locations have been consistent over time, and changes in cockle density are compared at the spatial scales of transect, site and tidal height, as well as by survey for Pāuatahanui Inlet.

2.1.2 Population estimates

Two methods are used to estimate the population size of cockles in Pāuatahanui Inlet. Method 1 uses the mean density calculated from the counts of all 0.1 m^2 quadrats (up to 372 samples) scaled to the size of the intertidal area (as if a single stratum), which was assumed to be about 1 km^2 (Healy 1980) to remain consistent with previous surveys. This method uses a NIWA built program SurvCalc (Francis and Fu 2012) to estimate population size. The coefficients of variation (CVs) are estimated as the standard deviation of the unweighted means of all transects (in any one year) divided by the square root of the number of transects.

Method 2 is similar to Method 1 in that it considers the intertidal area of Pāuatahanui Inlet as a single stratum; however, it uses each quadrat count as an independent sample. Method 2 estimates mean cockle density from the three quadrats at each tidal height and from the means of each of the four tidal heights to give the mean cockle density for each transect. The transect mean cockle density is adjusted (weighted) for transect length (Figure 2–1) using the proportion of the total transect length (length of all transects combined) as a proxy for proportion of survey area. The estimate of mean population size is the sum of the weighted averages from all transects (up to 31 transects in total). The coefficients of variation (CVs) are estimated as the standard deviation of the unweighted means of all transects (in any one year) divided by the square root of the number of transects. Method 2 is likely to overestimate the variance in the estimate of population size, as the variance is sensitive to transect length and to changes in the distribution of cockle density over time.

2.1.3 Significance tests

Significant differences in cockle counts between surveys were tested using cockle counts in each quadrat in each survey. Quadrats were assumed independent samples, and the large numbers of quadrats sampled (348–372, Table 3–1) give greater power to detect differences. The multiple comparisons amongst surveys used the Holm-Sidak test, considered to have high power to detect differences amongst paired comparisons. We discuss the methods used to estimate population size and to compare survey estimates in section 4.1.2.

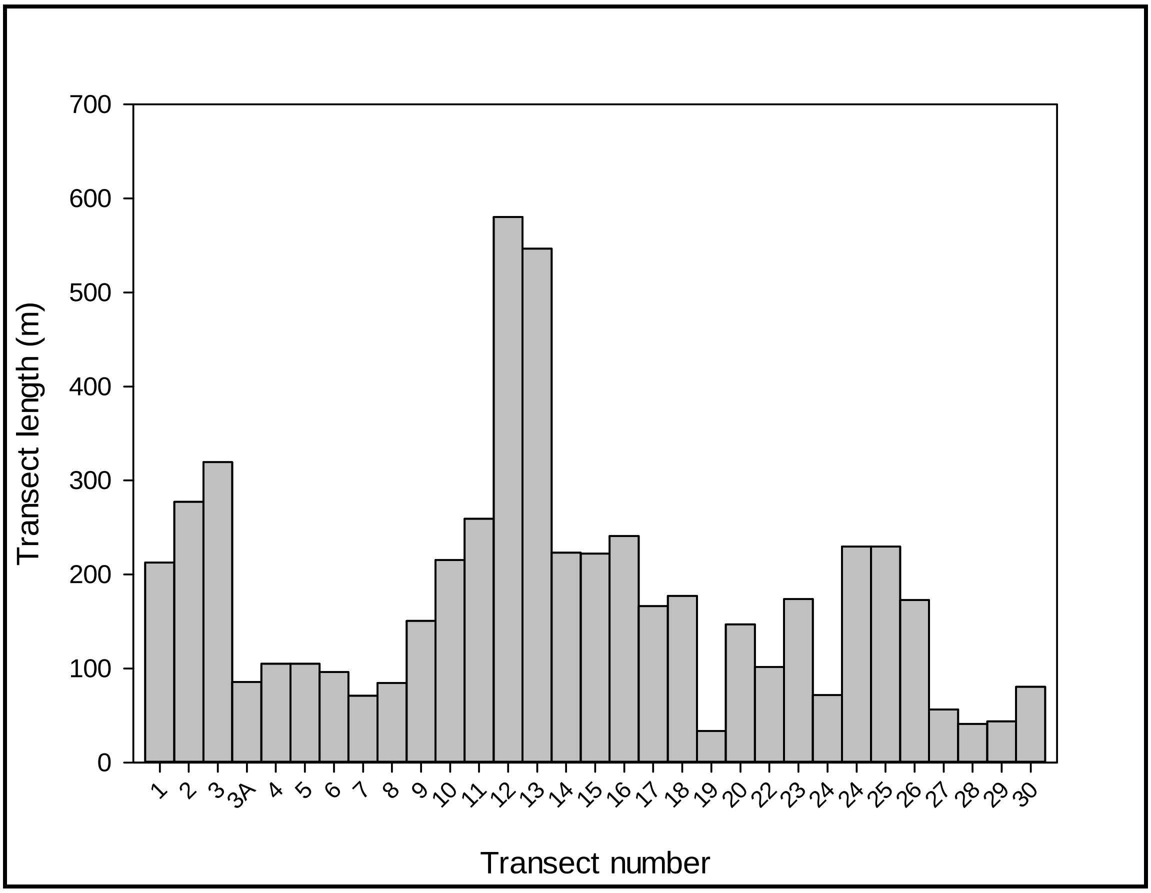

Figure 2-1: Approximate transect lengths estimated from distances between high and low water from a map of the intertidal zone.

2.2 Size structure of cockle populations

Shell length of cockles is defined as the longest distance along the anterior–posterior axis (Figure 2–2) and recorded as the lower whole millimetre. Cockle lengths from each quadrat were aggregated to provide estimates of population size structure by tidal heights, transects and sites, as well as by survey for Pāuatahanui Inlet. These data were summarised as histograms and cumulative percentage frequency curves so that they could be compared visually for spatial and temporal differences (e.g., differences between sites for each tidal height). In addition, cockle size structures are compared amongst surveys.

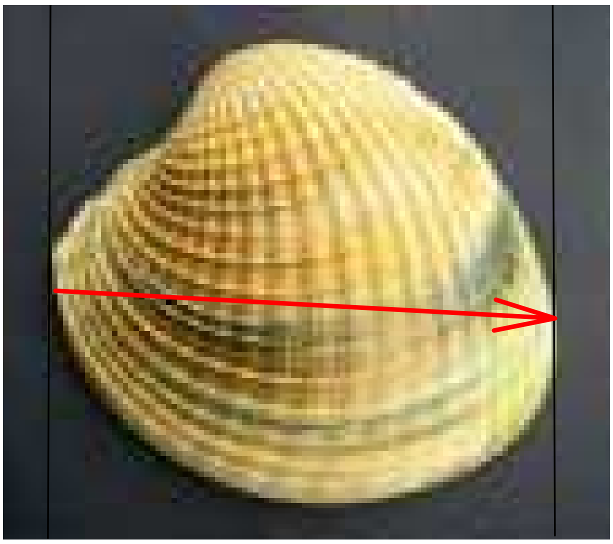

Figure 2-2: Cockle showing the length measurement along the anterior–posterior axis.

The size structure of populations was further divided into juveniles (defined as individuals 10 mm or smaller in length Larcombe (1971) and Richardson et al. (1979) and adults.

3 Results

The GOPI community cockle survey was undertaken on Sunday 24th of November 2019. All transects other than 1-3, 3a, 13 and 28 were completed on the day and at least one of the quadrats (mostly low tide) were not completed for transects 12, 18, 19, 24 and 27. All remaining quadrats were sampled between the 25th of November 2019 and the 15th of January 2020. Of the 31 transects (numbered 1–30 and 3A), 29 were fully sampled. Only half the quadrats were sampled for transect 13 (high tide and lower mid-tide quadrats only) and transect 30 (the jet ski club) was not sampled at all. Between 28 and 30 transects were sampled between 2010 and 2016 (Table 3–1).

More quadrats (354) and transects (29.5) were sampled in 2019 than in 2016 (336 and 28 respectively), and fewer than in 2013 (360 and 30 respectively). Some of the shellfish in the 0–10 mm size range identified as cockles may have been misidentified nutshells (*Nucula hartvigiana*) and vice versa. Significant misidentification of cockles could bias the numbers of juvenile cockles. To minimise this, transects that could be expected to have a considerable population of nutshells were sampled by experienced volunteers who could be relied on to know the difference.

Appendix F gives the numbers of cockles sampled in each quadrat in 2019 to provide a record of these data. Total survey counts of cockles increased 70.5% between 2001 and 2013, decreased 20.8% between 2013 and 2016, and increased 40.9% between 2016 and 2019 (see Table 3–1).

The total numbers of cockles sampled at each transect between 1998 and 2016 showed temporal variation, with total counts generally increasing over successive surveys until 2013 (Figure 3–1). In 2016, total survey counts were much more variable with some transects recording relatively high total counts while others near historical lows. In 2019, total counts were mostly higher than the long-term average (see red stars representing the 2019 counts against all survey means and 99% confidence intervals in blue, Figure 3–1).

Total cockle counts over surveys from 1998 to 2019 show marked spatial trends (Figure 3–1). Consistently high counts were recorded from Mana and Bromley to Motukaraka West. Consistently low counts were recorded from Brown's Bay, Duck Creek and Camborne sites.

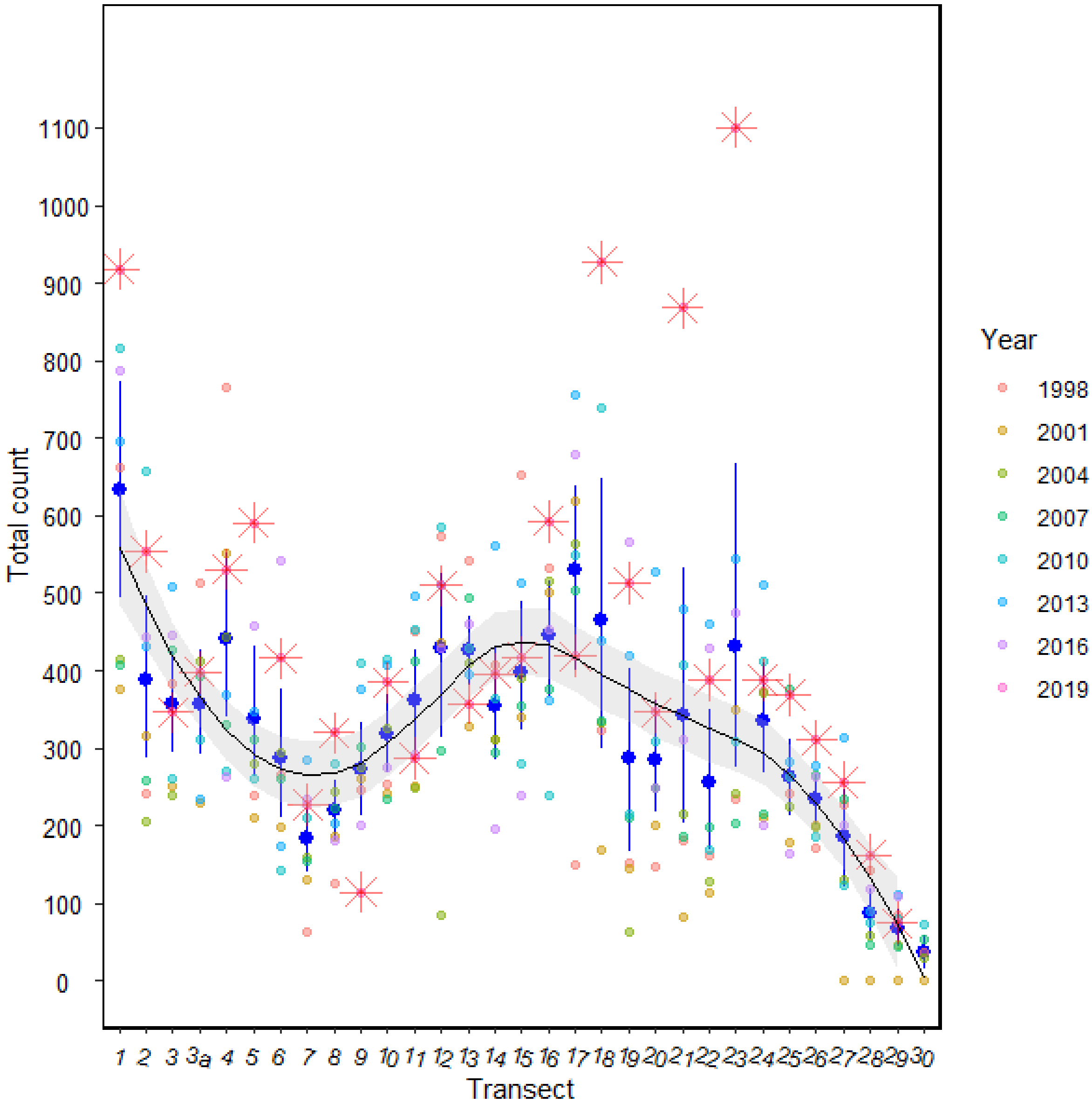

Figure 3-1: The total numbers of cockles (adults and juveniles combined) sampled from each transect in surveys between 1998 and 2019. Counts shown as coloured filled circles, 2019 counts shown as red stars, means for all years (dark blue filled circles) and 99% confidence intervals as blue lines. The spatio-temporal trend in the total numbers of cockles across Pāuatahanui Inlet are shown using a Loess smoother with the mean shown as a black line and ±1 SE shown in grey shading. Transect 30 has not been sampled since 2010, transects 3a and 18 were not sampled in 2016, and only half the quadrats in transect 13 were sampled in 2019.

In 2019, most transects had higher or markedly higher total counts than in 2016 (Figure 3–2), while in 2016, total counts were either similar or markedly lower (Figure 3–2).

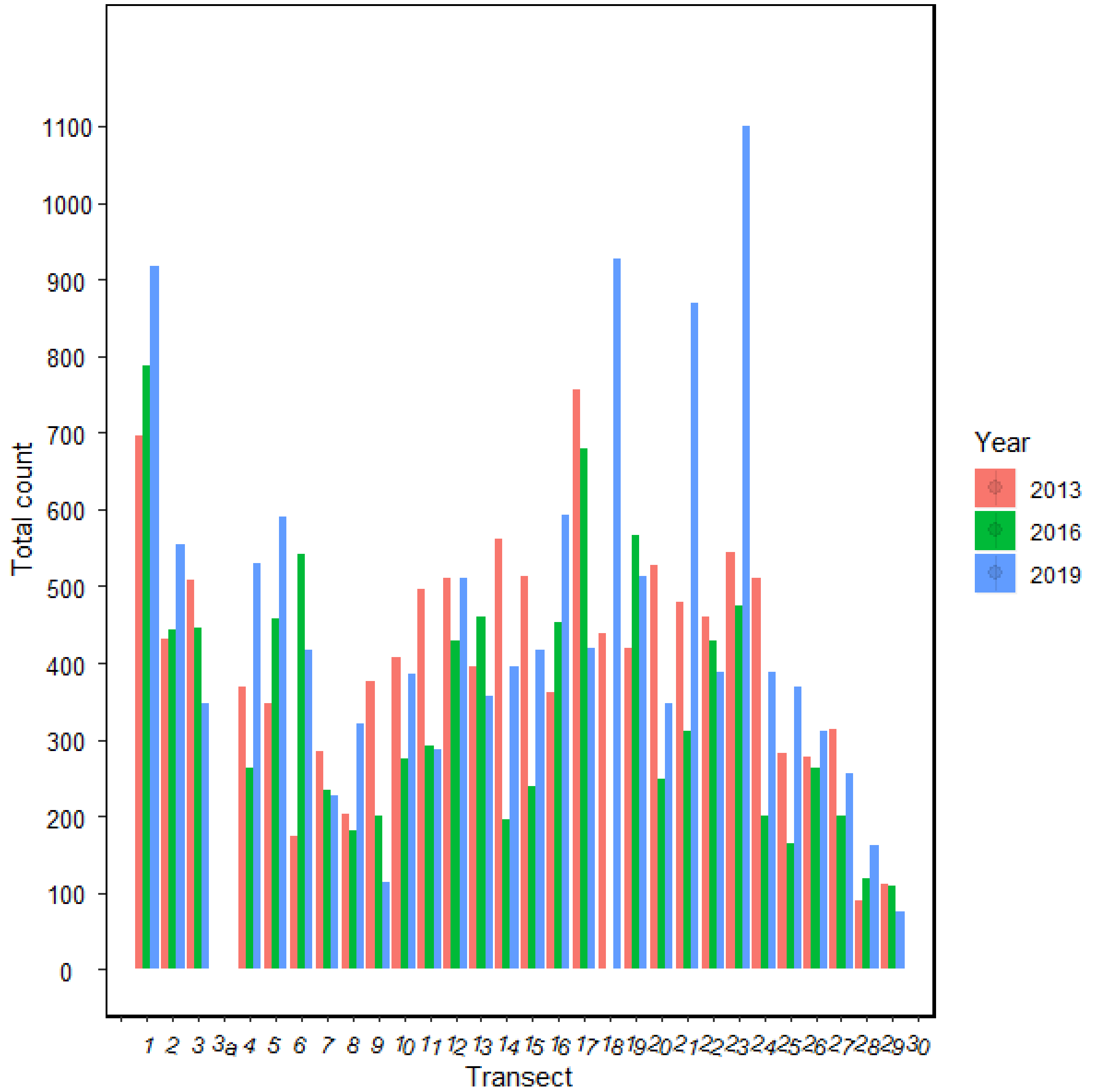

Figure 3-2: The total numbers of cockles (adults and juveniles combined) sampled from each transect in the 2013, 2016 and 2019 surveys. Transects 3a, 18, and 30 were not sampled in 2016. Transect 30 has not been sampled since 2010, transects 3a and 18 in 2016, and only half the quadrats in transect 13 were sampled in 2019.

3.1 Cockle densities and population size

3.1.1 Cockle densities

In 2019, cockle counts per quadrat ranged from zero to 279 per 0.1 m2 (at transect 1, upper-mid tide, Mana). The maximum count was higher than for 2016, 176 per 0.1 m^2 (at transect 17, low tide, Pāuatahanui) and 2013, 153 per 0.1 m^2 (at transect 17, lower-mid tide). The maximum count was also higher than for previous maximum densities recorded in 2010 (150 per 0.1 m^2 at transect 1, upper-mid tide, Mana), in 2007 (112 per 0.1 m^2 at transect 1, low-mid tide Mana), and in 2004 (95 per 0.1 m^2 at transect 1, upper-mid tide, Mana).

In 2019, no cockles were recorded from 10% of quadrats, substantially more than between 2007 and 2016. Mean cockle density in 2019 (38.1 per 0.1 m^2, 99% CI 34.6–41.7) was higher than in 2013 (33.6 per 0.1 m^2, 99% CI 30.9-36.2); however, not significantly different. Mean cockle density in 2019 was significantly higher than in 2016 (28.8 per 0.1 m^2, 99% CI 25.9–31.6), and higher than for previous GOPI surveys since 1992, see Table 3–1.

Figure 3–1 shows total counts of all sized cockles 1998–2019 by transect, and a smoothed trend (black line showing a spatial trend across Pāuatahanui Inlet, i.e., counts are averaged by transects across all years in sequence along the Inlet's coastline) showing whether on average each transect has recorded relatively high or low counts. In 2019, only transect 9 showed a count (shown in red star) substantially lower than its long-term average. Most transect counts were around the long-term average and counts from four transects (transects 1, 18, 21 and 23) were substantially higher.

3.1.2 Population size

Population estimates using Method 1 are consistently higher and often significantly higher than those using Method 2 (transect counts weighted by transect length), see Figure 3–3. Estimates from both methods show an upward trend from 2007 to 2013, a decrease between 2013 and 2016, and a marked increase between 2016 and 2019 (Table 3–1, Figure 3–3). The coefficients of variation (CVs) of the survey estimates has been consistently low, 3–6% (Table 3–1).

Pairwise multiple comparisons for significant differences among population estimates between years (Holm-Sidak method) undertaken at a significance level of 0.05 are given in Table 3–2. Cockle population size was significantly higher in 2019 than in all surveys since 1998, except for 2013 (Table 3–2). In 2019, the cockle population size estimates increased 32.2% (both Methods 1 and 2) since 2016 and increased 13.4 % and 10.8 % (Methods 1 and 2 respectively) since 2013 The precision of the estimates shown by the 99% confidence intervals (Figure 3–3) is expected to vary between surveys and is typical of time-series of survey data from populations with relatively patchy distributions.

Table 3-1: Cockle densities and population estimates for cockles in Pāuatahanui Inlet between 1976 and 2019. Estimates from Method 1 (unweighted data) and Method 2 (weighted data) given separately. The 2019 estimates given for all transects sampled (2019) and with the partly completed transect 13 removed (2019[1]). Maximum counts per quadrat (0.1 m^2) (Max number per quadrat), the total numbers of cockles, mean numbers of cockles per quadrat (Mean number per quadrat), cockle population (millions), coefficient of variation (CV), and the likely range of the cockle population size (millions) based on 99% Confidence Intervals (99%CI) given by survey.

Survey year	1976	1992	1995	1998	2001	2004	2007	2010	2013	2016	2019	2019[1]
Method 1												
No. transects	75	30	30	31	31	31	31	31	30	28	29	30
No. quadrats	NA	NA	NA	372	372	372	372	372	360	336	354	348
Max number per quadrat	280	168	191	273	118	95	112	150	153	176	279	279
Total numbers of cockles	15633	7976	6484	9264	7807	8124	8653	10290	12080	9569	13485	13127
Mean number per quadrat	52.3	22.2	18	25.7	19.9	21.8	23.3	28.6	33.6	28.8	38.1	37.7
Cockle population (millions)	523	222	180	257	199	218	233	277	336	288	381	377
C.V.	NA	NA	NA	0.06	0.06	0.05	0.04	0.05	0.04	0.05	0.05	0.05
Population range (millions)	438-608	187-257	146-214	227-287	177-221	198-238	214-252	250-302	309-362	259–316	346-417	342-413
Method 2												
Mean population (millions)	NA	NA	NA	316	240	236	270	335	369	309	409	388
C.V.	NA	NA	NA	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Population range (millions)	NA	NA	NA	310-321	236-244	233-239	266-274	329-340	364-374	304-314	403-415	383-393

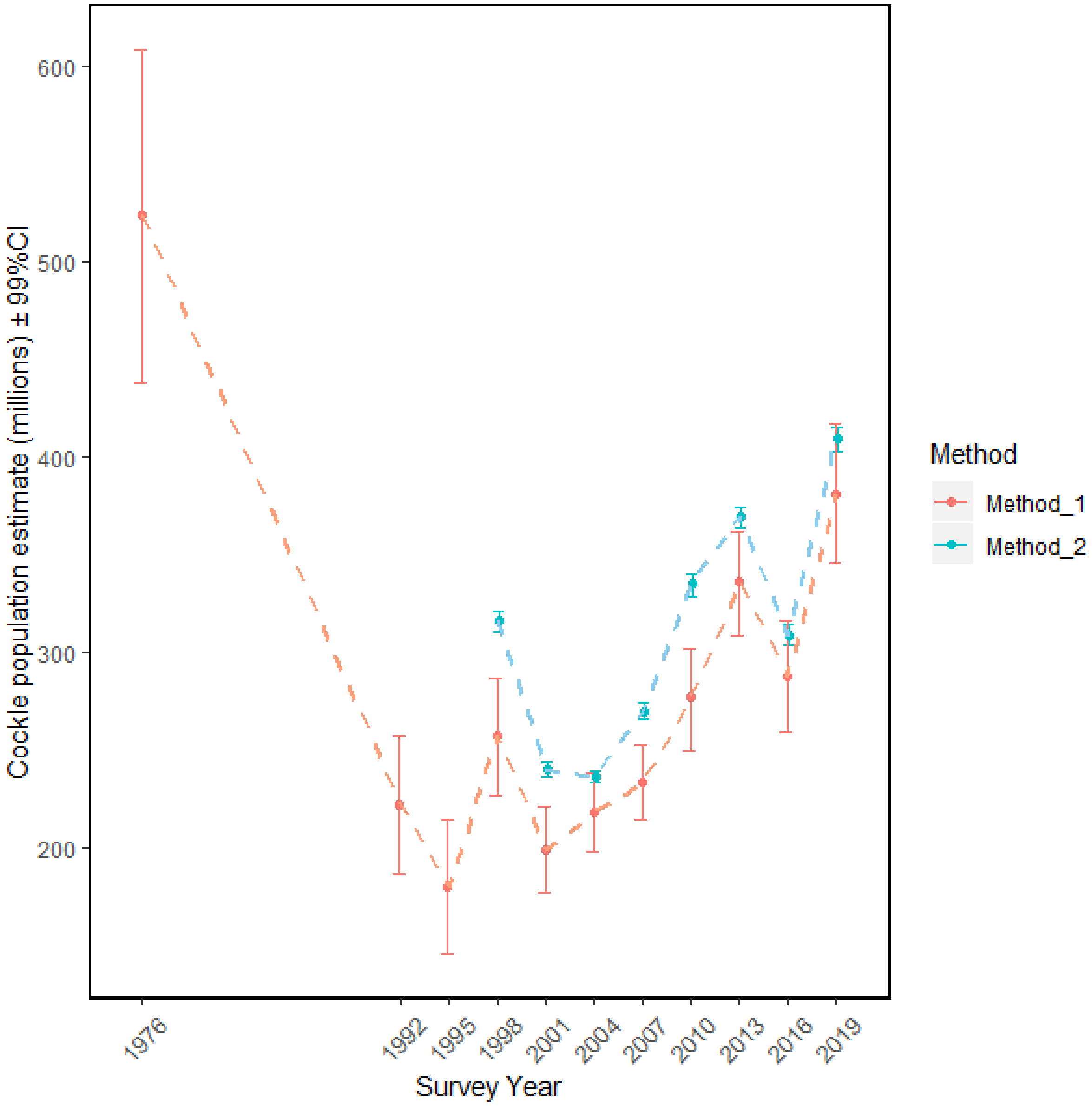

Figure 3-3: Estimates of total cockle population size and 99% confidence intervals for Pāuatahanui Inlet, 1976–2019. The initial survey in 1976 (Richardson et al. 1979) used a different survey design, surveys since 1992 carried out by the Guardians of Pāuatahanui Inlet have used the same survey design and methods. Estimates using previous method (Method 1) shown in sky blue and estimates using weighting factors for transect length (Method 2) are shown in salmon. Trends in population size shown as dashed lines. Data for surveys 1976, 1992, and 1995 not available to recalculate mean population size and 99% Cis using Method 1.

Table 3-2: The results from all pairwise multiple comparison procedures (Holm-Sidak method) undertaken for survey estimates 1998 to 2019 using cockle counts by quadrat, at a significance level of 0.05. Significant differences shown in bold and differences between survey years not significantly different given as "NS".

Survey years	1998	2001	2004	2007	2010	2013	2016
2001	0.025	-	-	-	-	-	-
2004	NS	NS	-	-	-	-	-
2007	NS	NS	NS	-	-	-	-
2010	NS	< 0.001	NS	NS	-	-	-
2013	0.004	< 0.001	< 0.001	< 0.001	NS	-	-
2016	NS	0.0158	NS	NS	NS	0.008	-
2019	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NS	< 0.001

3.1.3 Cockle densities by site

Figure 3–4 shows the numbers of cockles per quadrat and median numbers of cockles recorded at each site in 2013, 2016 and 2019. Trends in median densities varied by site. Median densities were broadly similar across the three surveys at Mana and Camborne sites; showed increasing trends at Seaview Road and Brown's Bay; and were broadly similar or increasing in trend with a decrease in median densities in 2016 at Duck creek, Pāuatahanui, Motukaraka and Motukaraka West, and Kakaho. Bromley showed no trend (Figure 3–4).

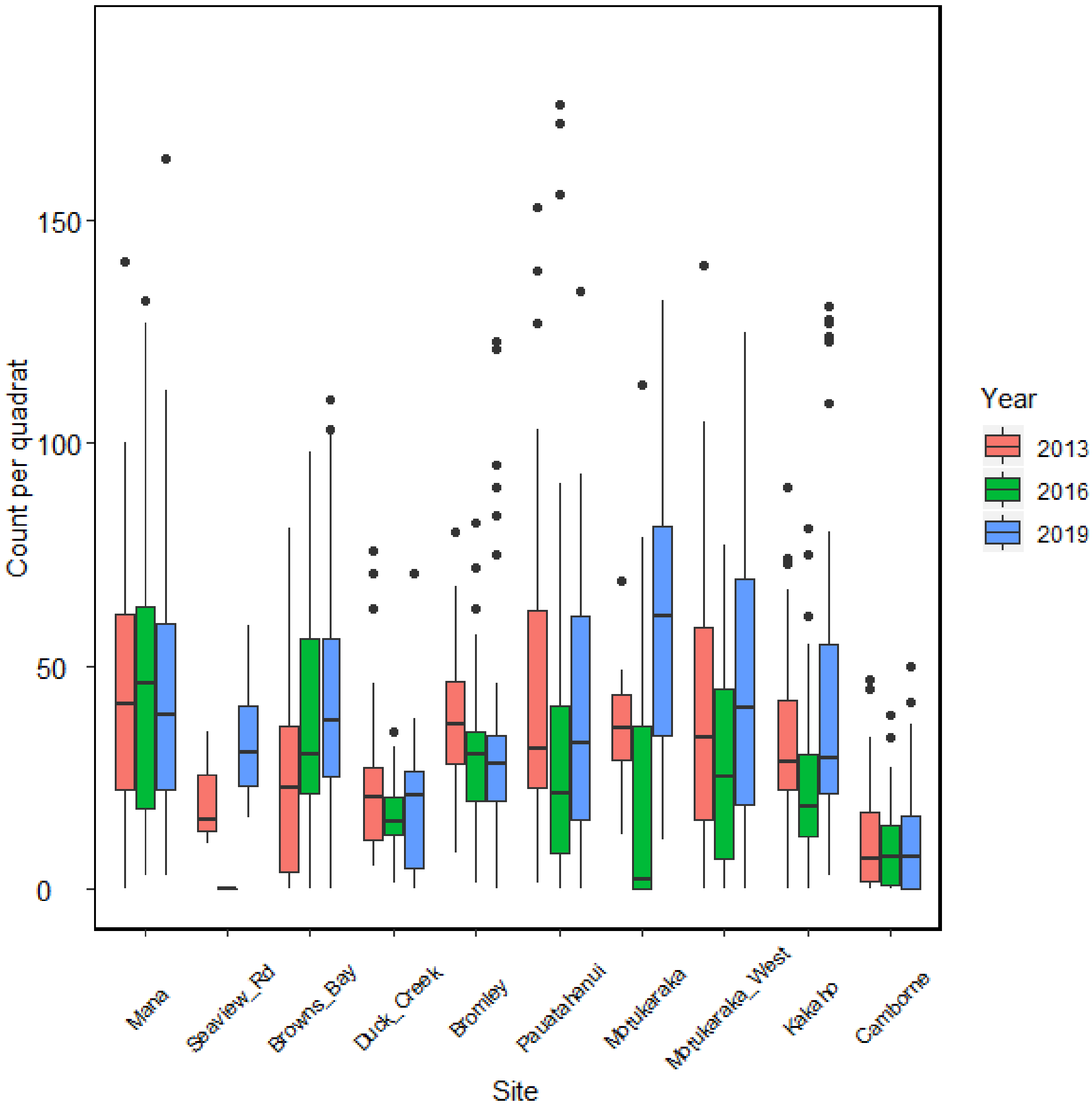

Figure 3-4: Box plots of the total numbers of cockles per quadrat (0.1 m²) by site in 2013, 2016 and 2019. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016 and transect 30 has not been sampled since 2010. Only half of Transect 13 sampled in 2019.

Boxplots the cockle numbers per quadrat by site and year show similar trends to the population estimates with medians generally increasing until 2013, declining in 2016 and increasing further in 2019 (Figure 3–5). The large numbers of outliers (represented by filled black circles) shows high variation in quadrat densities at each transect and year reflecting high small-spatial scale variation in the distribution of cockle densities.

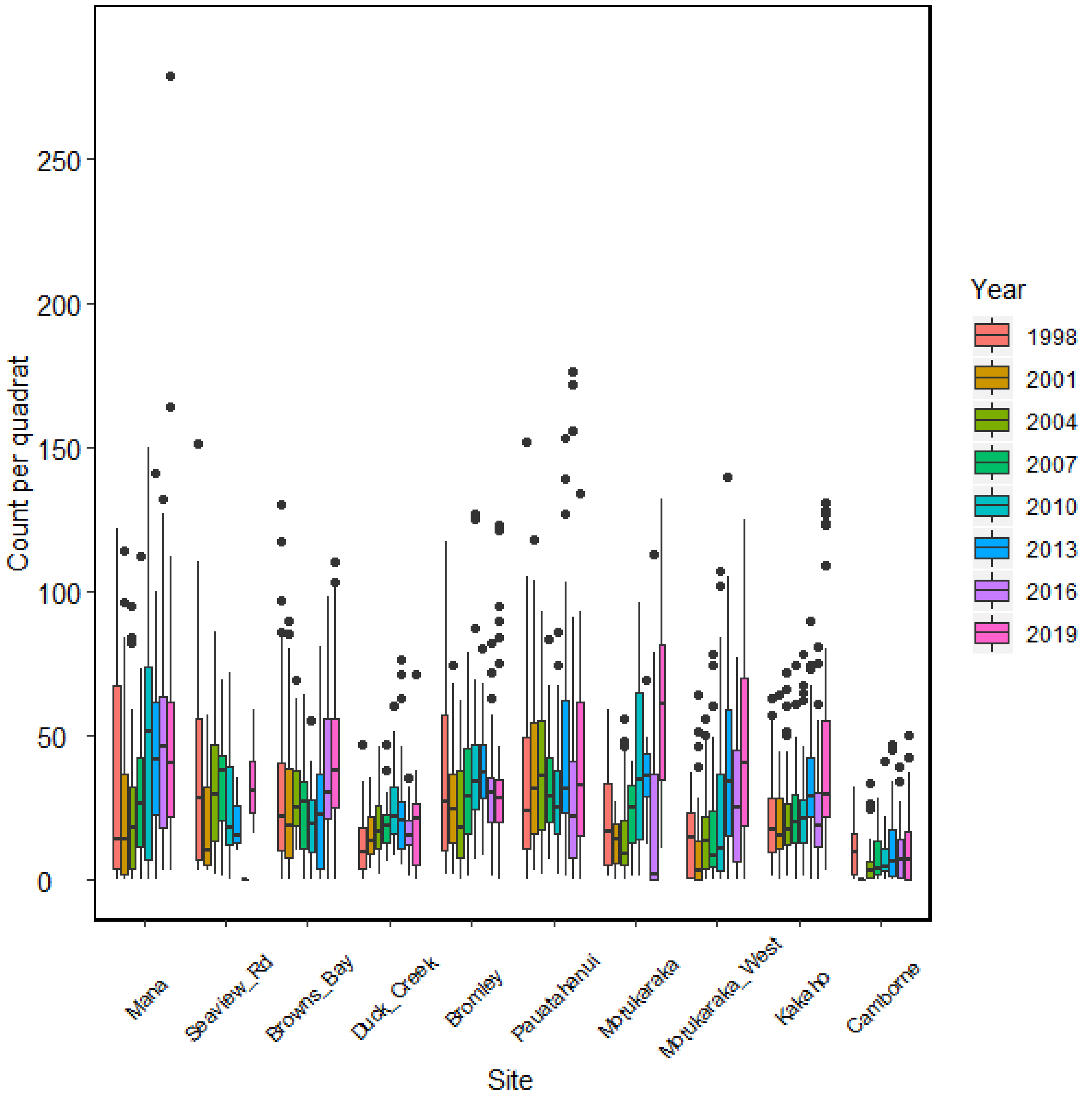

Figure 3-5: Box plots of the total numbers of cockles per quadrat (0.1 m²) by site between 1998 and 2019. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016 and transect 30 has not been sampled since 2010. Only half of Transect 13 sampled in 2019.

Figure 3–6 shows bubble plots of the distributions of cockle densities by site and by size class (juvenile and adults) since 1998. Adult cockle (greater than 10 mm in length) densities have remained relatively high at Mana, Brown's Bay, Bromley, Pāuatahanui and Kakaho since 1998. Sites that show increasing trends over time are: Mana, Motukaraka, and Motukaraka West. The sites showing stable trends include Bromley, Pāuatahanui, and Kakaho. Those sites that have been fluctuating slightly without trend include Seaview Road, Duck Creek, and Camborne.

Juvenile cockle densities show broadly similar trends to adults, with densities consistently high at Pāuatahanui, and increasing over time at Mana, Brown's Bay, Bromley, and Motukaraka West since 1998. Trends in juvenile densities have remained similar, fluctuating slightly without trend at Seaview Road, Duck Creek, Motukaraka and Camborne (Figure 3–6).

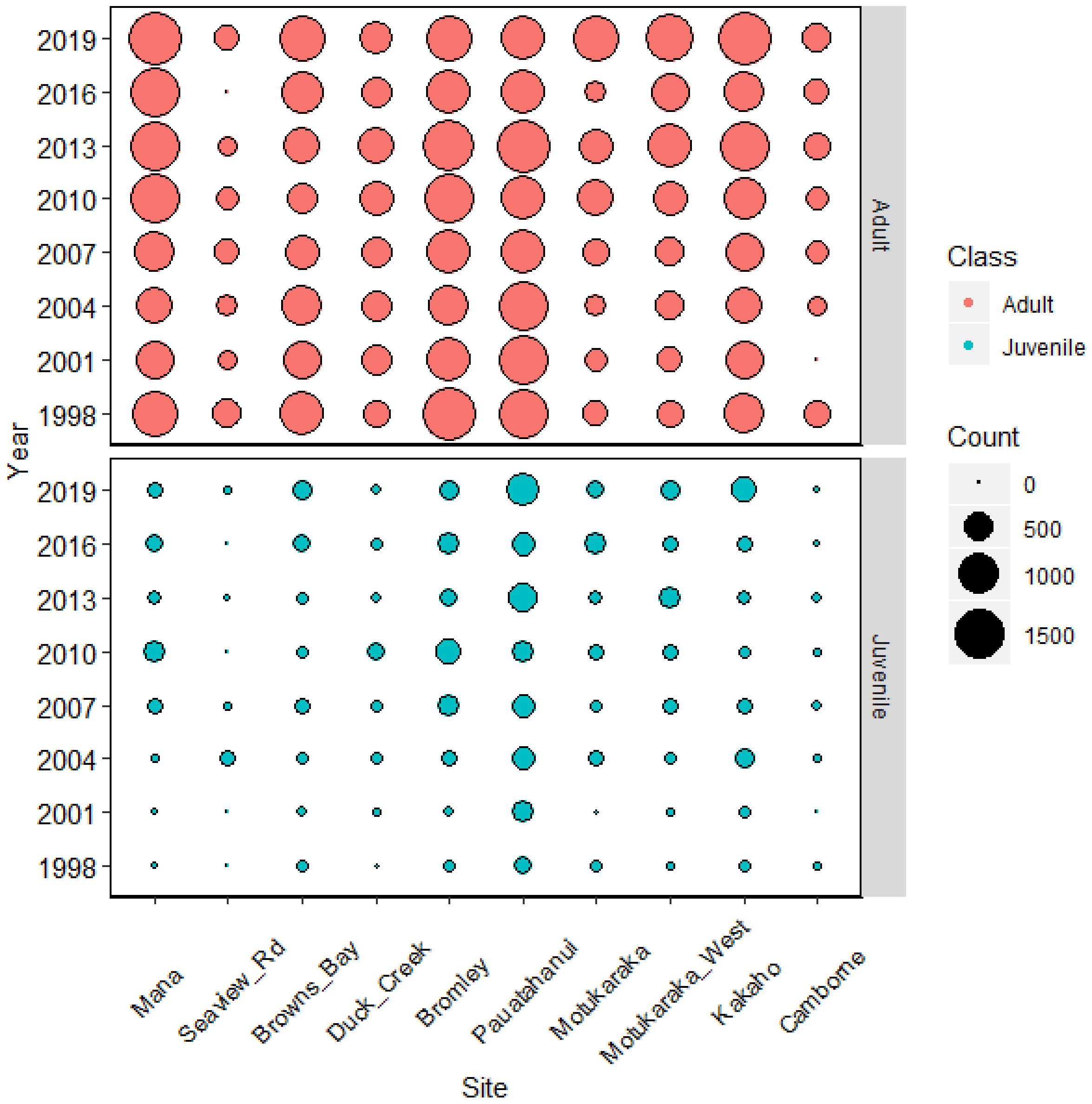

Figure 3-6: Bubble plot representing the changes in the counts of adult cockles (greater than 10 mm in length) and juveniles (10 mm and smaller in length) at each site between 1998 and 2019. The size of the bubbles scaled to total count per site. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016 and transect 30 has not been sampled since 2010. Only half of Transect 13 sampled in 2019.

3.1.4 Cockle densities by tidal height

Median cockle densities were broadly similar across all tidal heights in all three most recent surveys (2013, 2016 and 2019) (Figure 3–7). Counts were similar and lower at high tide quadrats (HT) compared with those from quadrats closer to low tide. Consistently higher counts were recorded from upper (UMT) and lower mid-tide (LMT) quadrats in 2019 compared with 2016 and 2013. In 2019, low tide (LT) quadrats recorded fewer high counts than in 2013; however, more than in 2016.

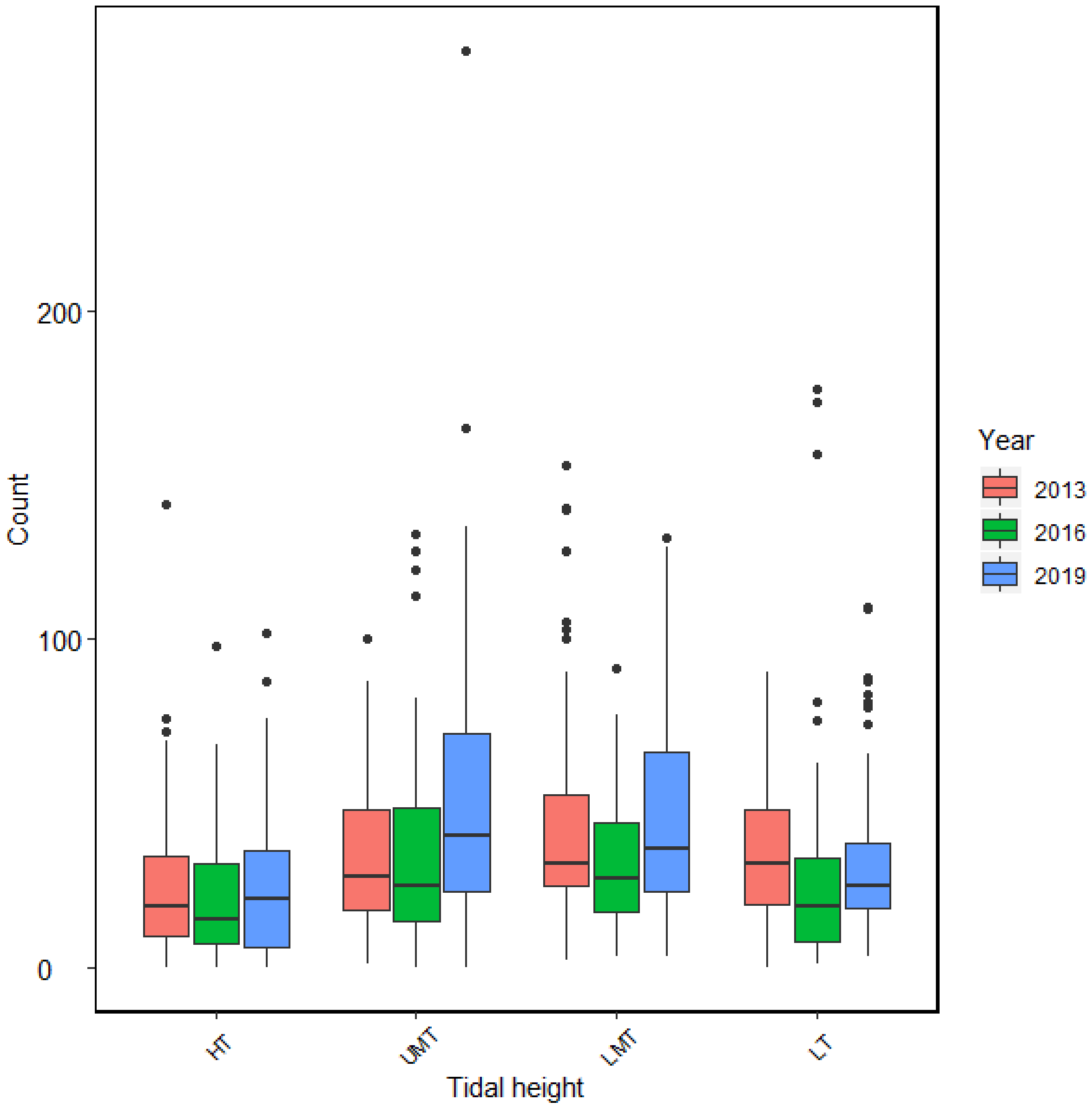

Figure 3-7: Boxplots of the numbers of cockles in 0.1 m^2 quadrats by tidal height for years 2013, 2016 and 2019. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles.

Variation in cockle counts by quadrat was higher at site level than tidal height level (Figure 3–8) for all three surveys (2013, 2016 and 2019) (Figure 3–8). In 2019, cockle counts were generally higher at all tidal heights for Seaview Road, Brown's Bay, Motukaraka, Motukaraka West, Kakaho and Camborne except for the high tide (HT) quadrats at Brown's Bay and Camborne where counts were generally lower. Cockle counts at Duck creek were similarly low at all tidal heights and for all three surveys. Cockle counts at Pāuatahanui were similar with slight variations at high tide (HT) and upper-mid tide (UMT) quadrats, and mostly lower at lower-mid tide (LMT) and low tide (LT) quadrats (Figure 3–8).

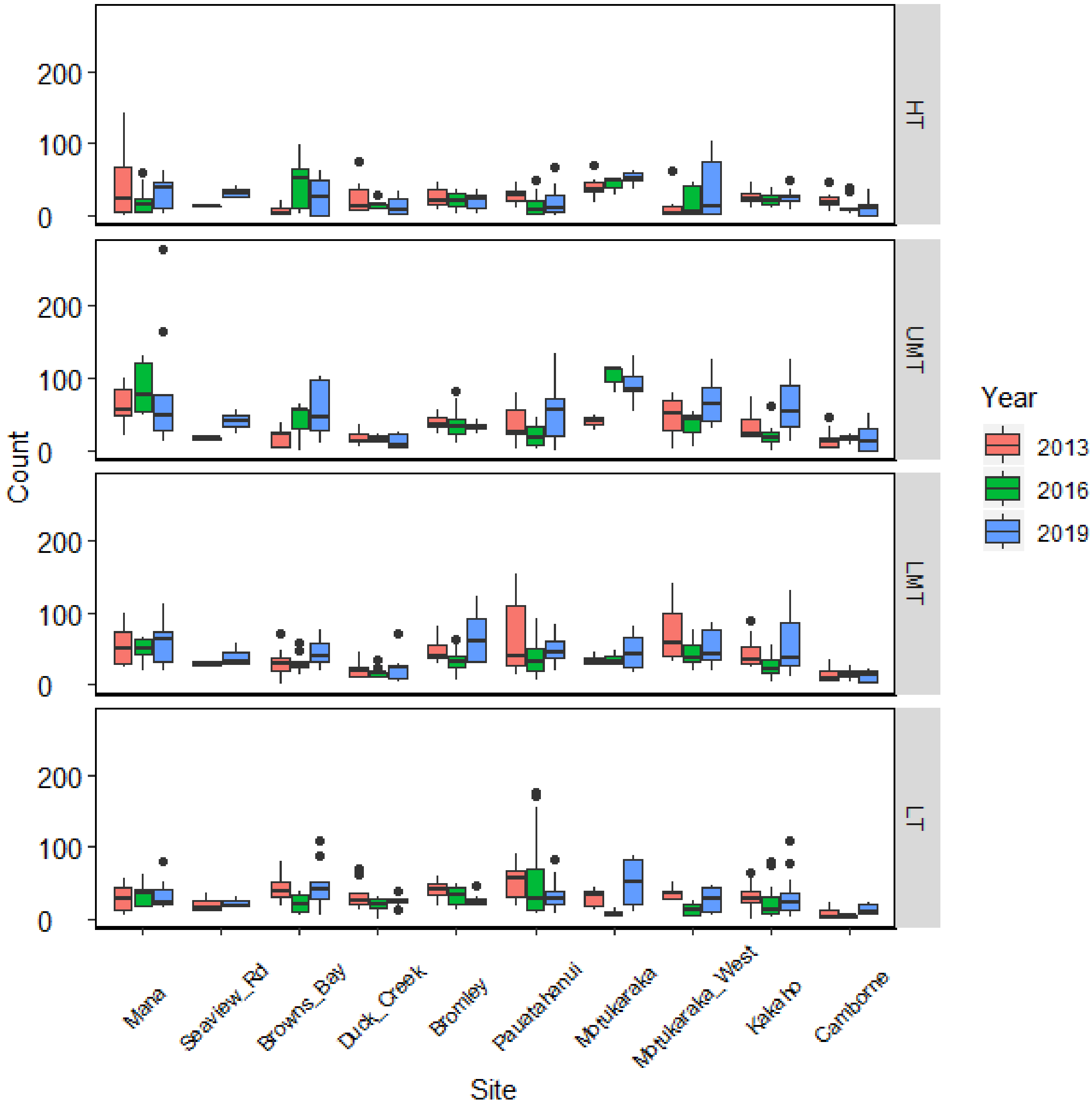

Figure 3-8: Boxplots of the numbers of cockles in 0.1 m2 quadrats by tidal height and site for years 2013 and 2016. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers are 10th and 90th percentiles, and outliers are shown as filled black circles. The spatio-temporal changes in cockle densities between 1998 and 2019, by tidal heights and sites are given in Figure 3–9. The spatial

patterns have not changed substantially through time. Cockle densities have been consistently low at all tide zones over surveys at Seaview Road, Duck Creek, and Camborne. Cockle density has generally been lower and more consistent at the high tide (HT) than the lower three tide levels. The highest counts from 1998–2019 have generally been recorded at upper and lower-mid tidal areas at all sites except for Pāuatahanui where counts have been consistently higher at lower-mid and low tides. The cockle densities show the greatest patchiness at low tide, particularly before 2007.

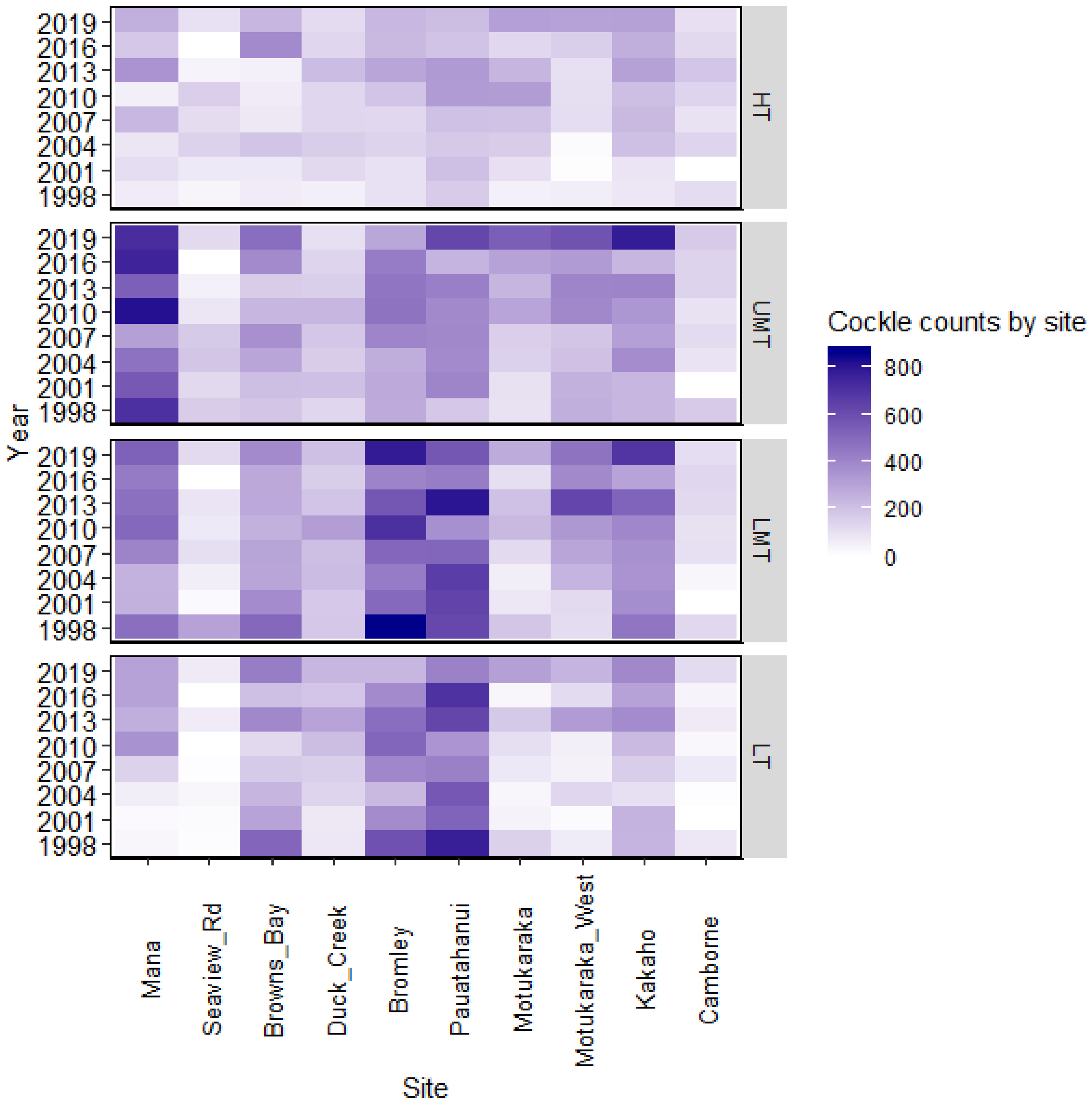

Figure 3-9: Heat map plots representing the changes in cockle counts of at each site between 1998 and 2019 by tidal height. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Cell colour intensity is scaled to total count per site. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016 and transect 30 has not been sampled since 2010. Only half of Transect 13 sampled in 2019.

3.2 Cockle size frequencies

Cockles sampled in the intertidal zone of Pāuatahanui Inlet between 2013 and 2019 generally ranged in length from 3 mm to 40 mm (Figure 3–10). In 2019, the largest cockle was 52 mm in length, the same as for 2016 and slightly smaller than in 2013 (58 mm in length). The distributions of percentage frequencies (Figure 3–10) do not show clearly separated modes or cohorts to identify the progression of different cockle settlements and age classes. Size composition i.e., the proportions of each size group, has remained broadly similar since 2013 (Figure 3–10), the combined sizes of cockles has neither got larger or smaller over time. The overall size of the population Histograms of the size (length) frequency of cockles for all sites combined since 1998 are shown in Appendix G.

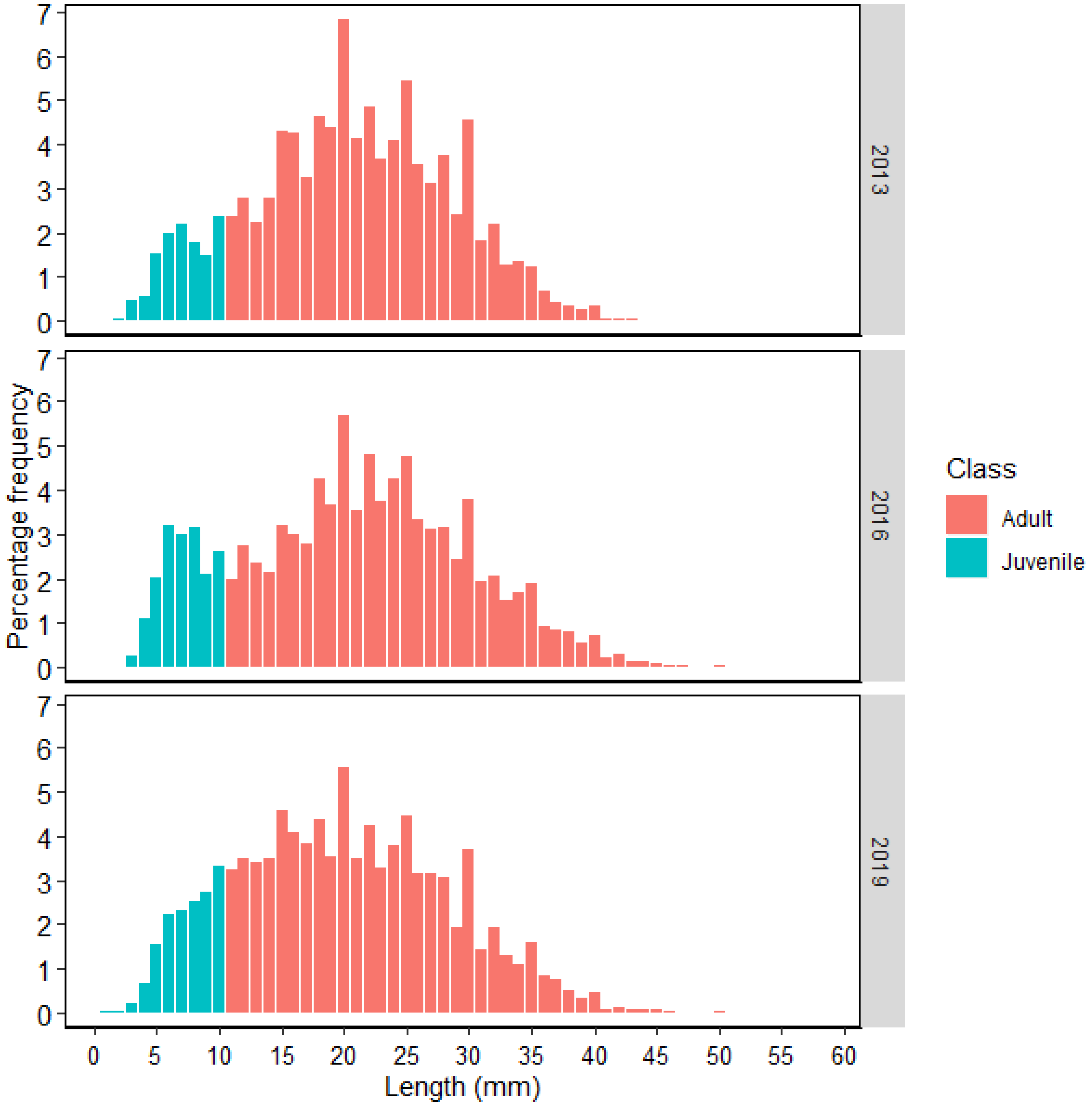

Figure 3-10: Percentage length frequencies of cockles sampled in the intertidal zone of Pāuatahanui Inlet in 2013, 2016, and 2019. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red.

The cumulative percentage length frequencies 1998–2019 show changes in the proportions in the sizes of cockles that make up the cockle population for a given year (survey). The size structures of the intertidal cockle populations in Pāuatahanui Inlet have broadly remained similar since 2004 (Figure 3–11). Cumulative percentage length frequencies in 2019 show a high percentage of cockles less than 25 mm in length, similar to 2010. Cumulative percentage length frequencies in 1998 and 2001 were characterised by lower proportions of juvenile cockles (Figure 3–11). The size range of cockles and their median size has remained similar between 2004 and 2019 (Figure 3–12).

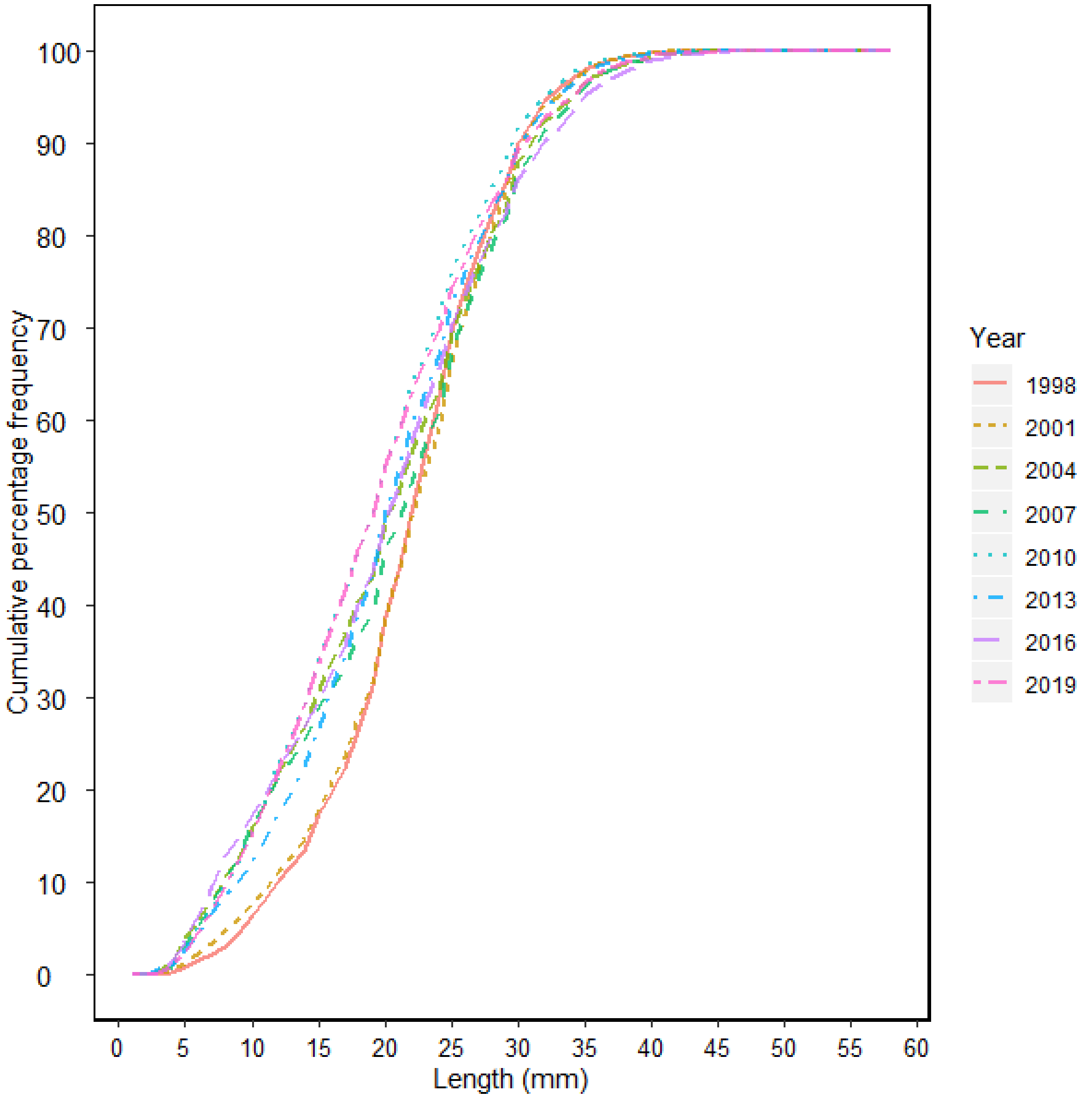

Figure 3-11: The cumulative percentage length frequencies of cockles sampled in the intertidal zone of Pāuatahanui Inlet between 1998 and 2019. 2019 shown as a dashed pink line and 2016 as a solid purple line.

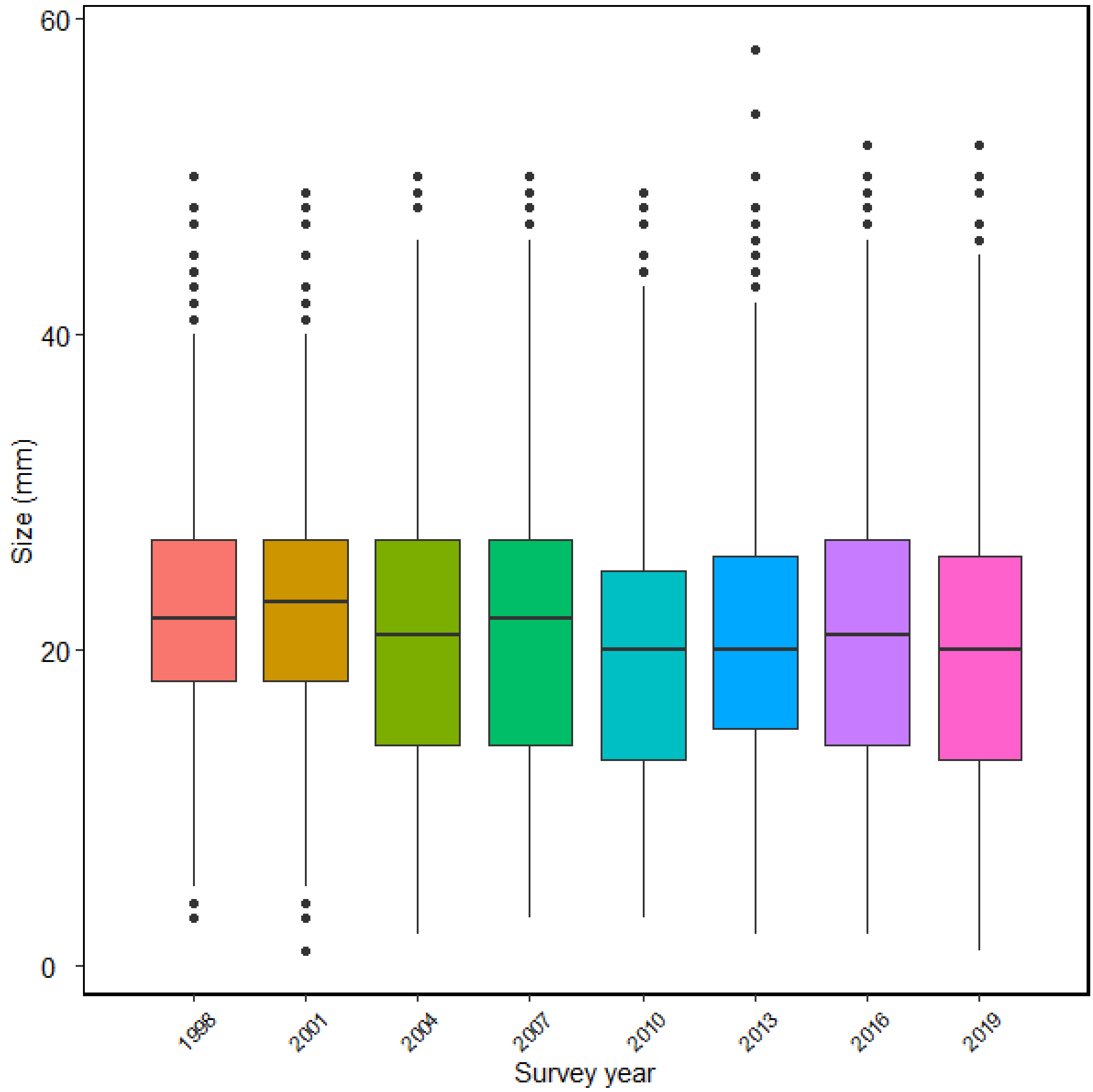

Figure 3-12: Boxplots of the sizes of cockles in Pāuatahanui by survey year 1998–2019. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles.

3.2.1 Percentages of juvenile cockles

The percentage of juvenile cockles in the Pāuatahanui Inlet population in 2019 declined slightly to 15.6% from 17.4% in 2016, and similar to the percentages in 2004–2010 (Figure 3-13). There has been a substantial increase in the percentages of juveniles since the 1990s, when the juvenile population percentage was < 10 %. There was little apparent change between the 1998 and 2001 surveys. However, between 2001 and 2010, the percentage of juvenile cockles in the total population more than doubled to 16%, then declined to 12% in 2013. The 2016 survey recorded the highest proportion of juvenile cockles (17.4%).

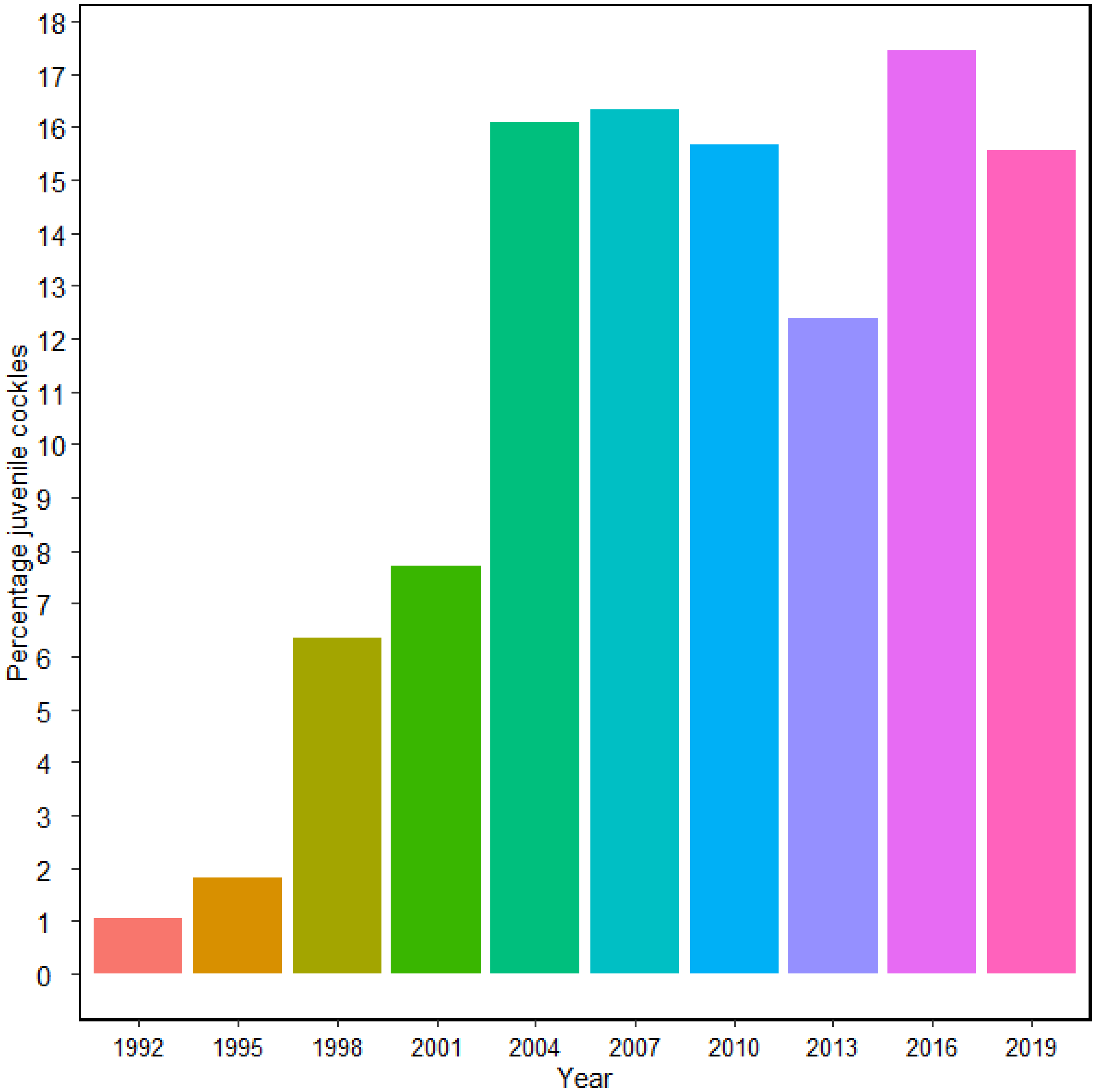

Figure 3-13: Juvenile cockles (10 mm and smaller in length) as a percentage of total cockle population, 1992–2019.

3.2.2 Cockle size frequencies by site

The size structure of cockles varied among sites around Pāuatahanui Inlet (Figures 3–14 & 15). Size distributions ranged from predominantly flat (unimodal, a single, broad size group with no definitive modal structure) as at Kakaho, to distributions with a number of distinct modes (polymodal) such as at Motukaraka (Figure 3–14). Bromley, Duck Creek, Motukaraka and Pāuatahanui in 2016 and Brown's Bay, Duck Creek and Pāuatahanui in 2019 showed strong modal structure that represents high settlement cohorts. Juvenile cockles at sites with high settlement events in 2016 survived and grew to larger numbers of small cockles in 2019 (Figure 3–14).

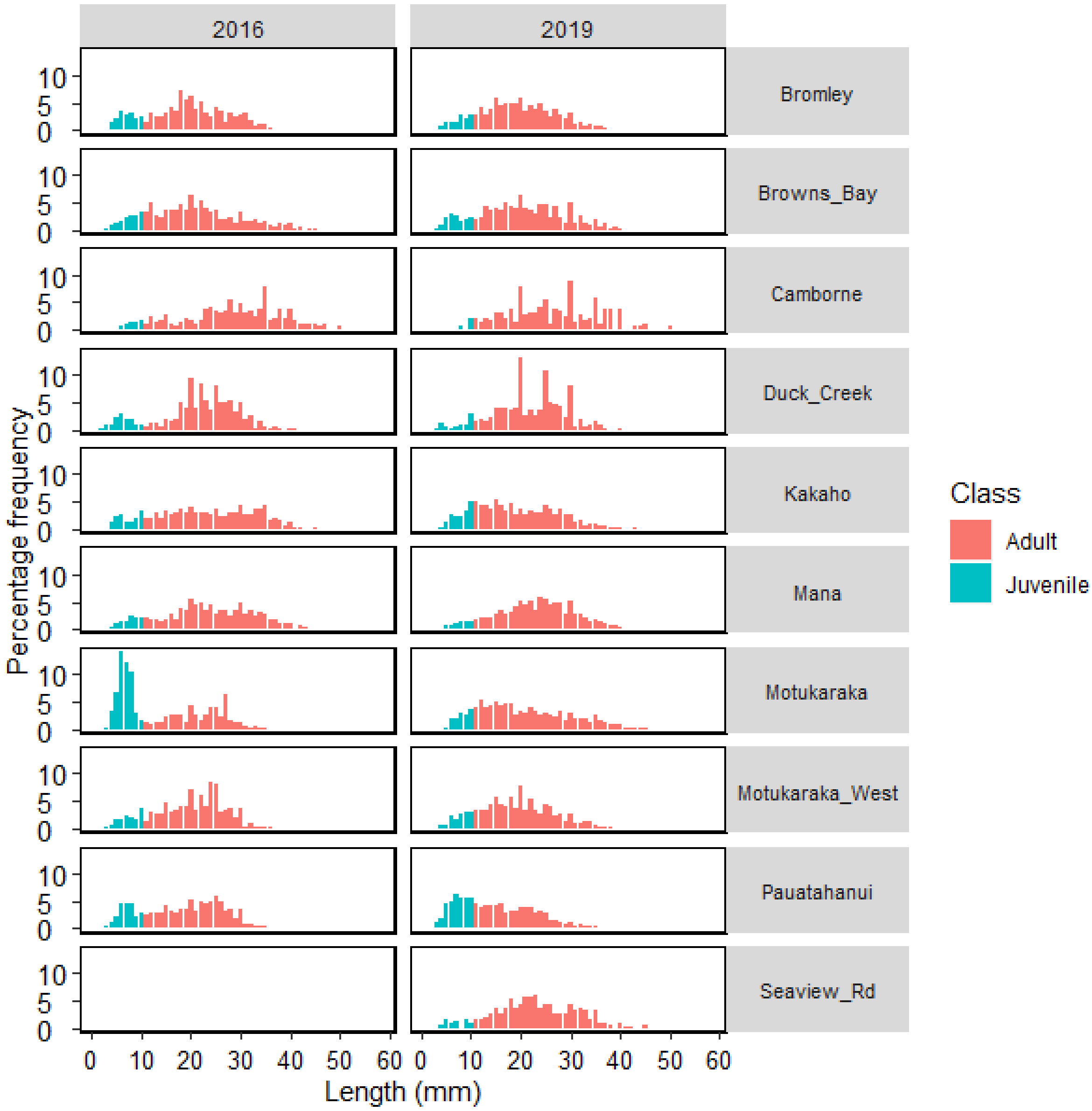

Figure 3-14: Histograms of the size (length) frequency of cockle by sites from the 2016 and 2019 surveys. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red. Seaview Road (Transect 3A) not sampled in 2016.

The cumulative percentage frequency identified differences in cockle size distributions between sites in 2019 (Figure 3–15). The proportions of different sizes were broadly similar amongst sites, except at Pāuatahanui where juveniles represented 35% of the population. Mana, Seaview Rd, Duck Creek and Camborne sites had proportionately larger cockles (i.e. fewer small cockles); and at Camborne, 50% of the cockles were greater than 26 mm in length.

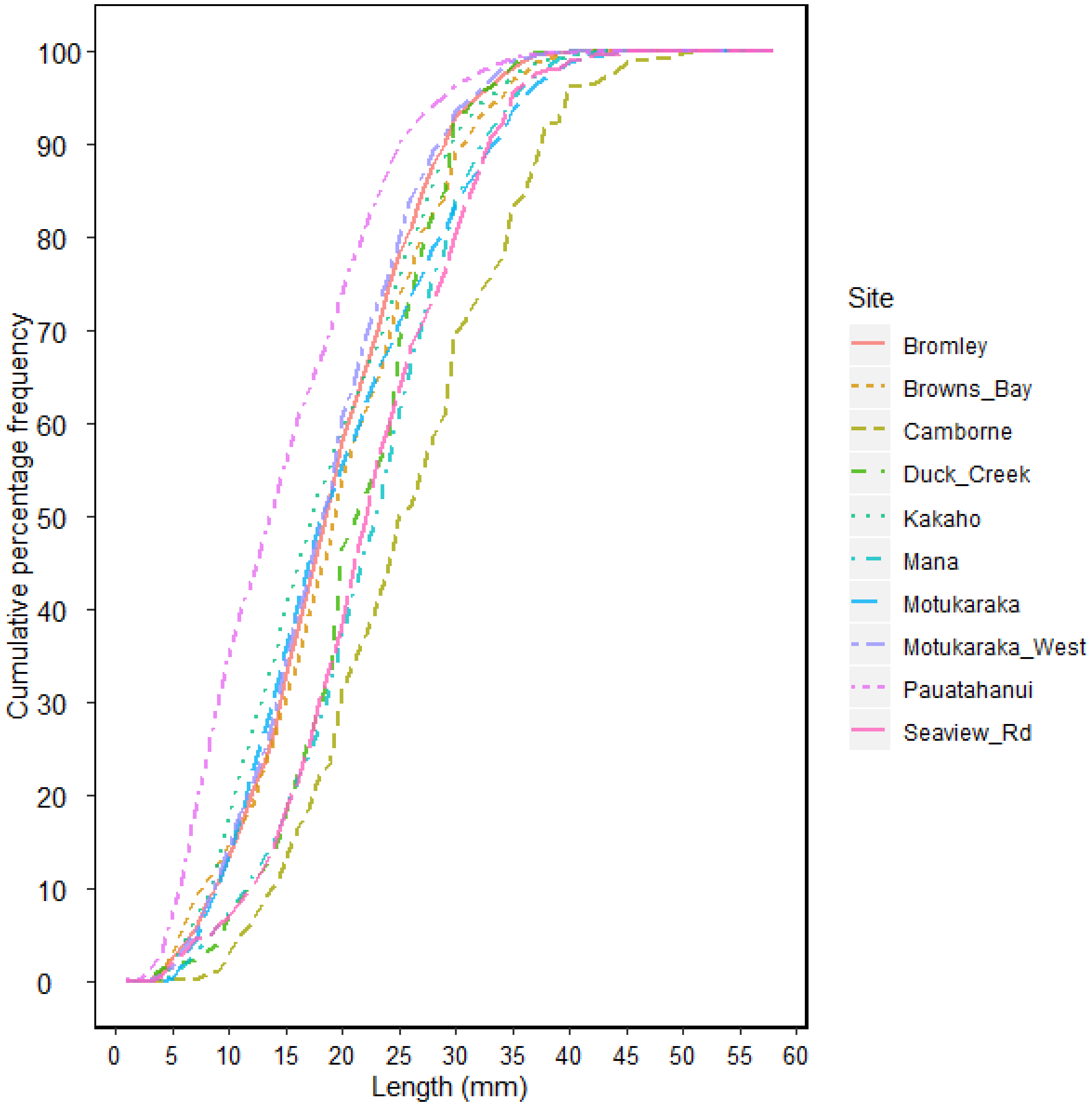

Figure 3-15: Cumulative percentage frequencies of cockle lengths by site sampled in 2019.

Cumulative percentage frequencies 1998–2019, by tidal height (Figure 3–16) show increases in the proportions of larger cockles with increasing tidal level. High tide (HT) and upper mid-tide (UMT) levels contained fewer small-sized cockles in 1998 and 2001 than in later surveys. The size structures of cockles at lower mid-tide (LMT) and low tide (LT) were broadly similar.

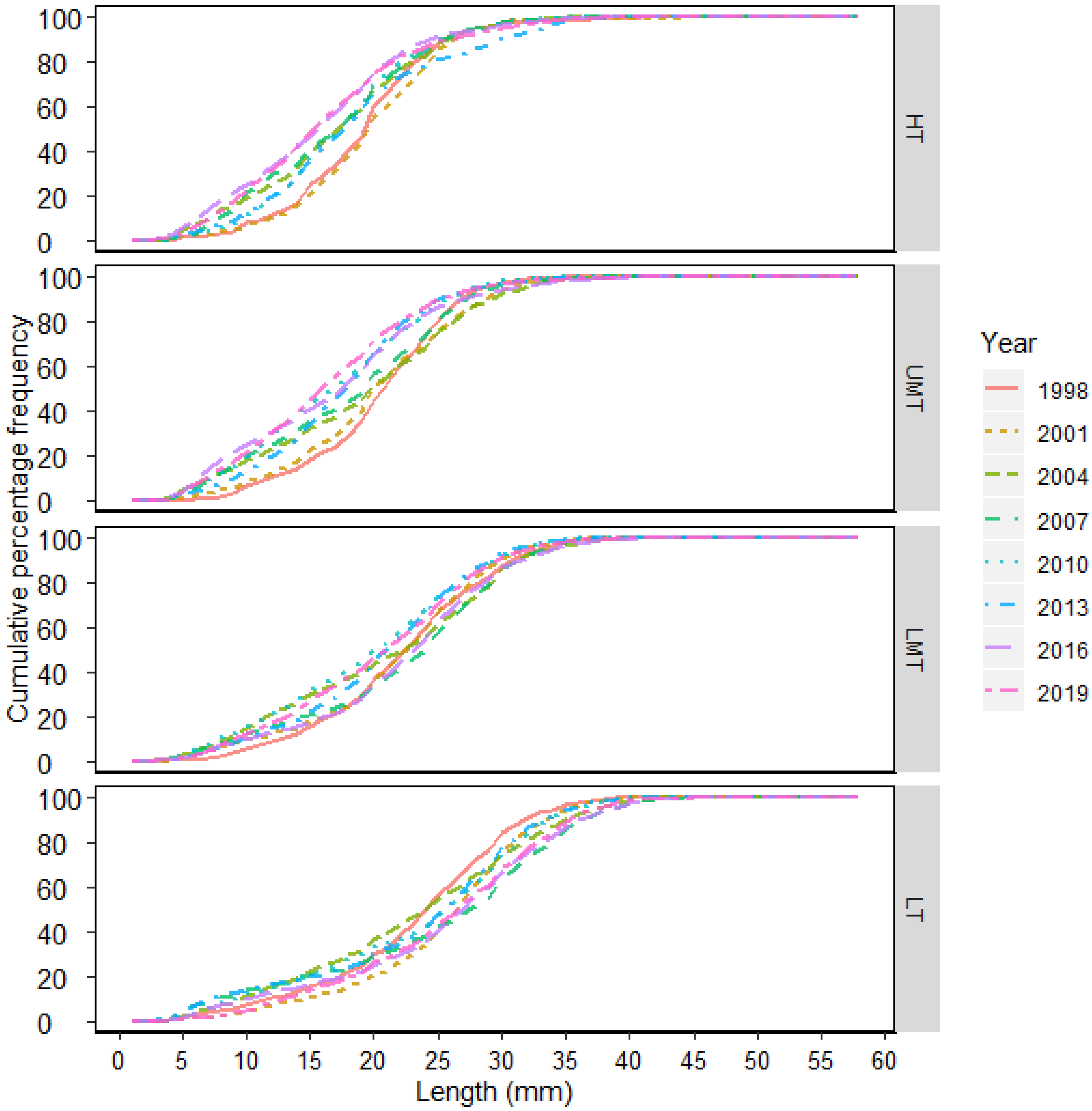

Figure 3-16: Cumulative percentage frequencies of cockle lengths by tidal height for surveys between 1998 and 2019.

4 Discussion

4.1 Survey comparability

4.1.1 Consistency of sampling and possible effects on data quality

Maintaining sampling methods and sampling intensities is important to determine reliable trends from time-series data, so that changes in the data reflect changes in the cockle population and not the variability in sampling. The 2019 survey used the same sample locations and methods including quadrats and sieves (3–5 mm mesh) as used in all other surveys since 1992.

Most of these transects were completed between the 24th of November 2019 and the 15th of January 2020. Transect 30 has not been sampled since 2010 because of the degradation of its intertidal area due to its location next to the Camborne Jet Ski Club and, because of that, a lack of comparability to previous surveys. Only half of Transect 13 was sampled in 2019. Transects 3A (Seaview Road) and 18 (Motukaraka) were not sampled in 2016. These missing data are unlikely to have had a substantial effect on density estimates and comparisons; however, the relatively high spatio-temporal variation in cockle densities does not allow any effects on estimates to be determined.

Several sampling issues in 2016 may have reduced the consistency of sampling and therefore the comparability of survey data and population estimates with previous surveys and with the 2019 survey data. GOPI postponed the original survey because of the November 2016 earthquake and floods. Fewer volunteers than expected turned up for the deferred survey, consequently 11 transects could not be completed and two were not sampled at all.

The high muddiness of substrates at some transects may have affected sampling in 2019 by preventing standard samples being excavated and effectively sorted, and small cockles reliably identified. Misidentification of small bivalve shellfish, especially two visibly similar species (cockles and nutshells) is not quantifiable. Where nutshells have been counted as cockles, these data will show higher than actual cockle densities, and vice versa.

Spikes in the length frequencies of cockles at 5 mm increments (15 mm, 20 mm, 25 mm, and 30 mm) suggest some measurement biased towards these lengths.

4.1.2 Survey analysis

In previous surveys, the cockle population size was estimated using the mean density estimated from each individual quadrat (0.1 m^2) as an independent (random) sample (as if from a single stratum) and scaled to the size of the intertidal area, assumed to be about 1 km^2 (Richardson et al. 1979) - Method 1.

Method 2 takes into account that cockle densities in the intertidal zone of Pāuatahanui Inlet can vary considerably over tidal height, with the highest cockle densities at mid- and lower- tide levels, and the intertidal area should be stratified by tidal height. Because of this, the samples taken from each transect cannot be assumed to be a truly random sample from a single area of similar cockle density. It is more appropriate to average the density for each tidal height, and then average all the tidal heights to get a transect mean. Moreover, as the width of the intertidal areas varies around the Inlet, transect length reflects the size of the intertidal area. Transect means therefore need to be adjusted (weighted) for these differences. Transect means are then averaged to get a mean cockle density for the whole inlet that is then scaled up to the estimated area of the intertidal zone. There are no direct measurements of transect length available and best estimates from maps are used. The weighting of transect mean cockle densities has made little difference to the trends in population estimates as weighting represents a constant scalar.

Whether the size of the intertidal area in Pāuatahanui Inlet has changed over the sequence of surveys, or whether transect lengths have changed is not known. Because mean cockle density is multiplied by the size of the intertidal area, any error in the estimate of the survey area will be proportionally represented in the estimate of cockle population size. All previous estimates of population size use the same estimate of the size of the intertidal area (1 km^2). This estimate differs from the size of the intertidal area of Pāuatahanui Inlet estimated from the interpolation of depth soundings from a report to the Porirua City Council (Anon 2009) and from a map of the Pāuatahanui Inlet bathymetry (Irwin 1978), which suggests that the intertidal area is about 2.13 km^2. Using a larger survey area in the calculation of population size will increase the population size of cockles for each survey, but it will not change the relative trend between surveys.

Multiple, paired comparisons for differences amongst populations sizes for surveys between 1998 and 2019 (see Table 3–2) used the Holm-Sidak test, as this test is considered to have high power to detect significant differences. The precision of survey estimates (expressed as a coefficient of variation or CV of the population estimate) since 1998 have been relatively low (see Table 3–1). These low CVs allow more reliable differences between surveys to be identified.

Errors associated with the misidentification of species and from sampling error generally, are thought to be relatively small and reasonably constant from survey to survey which is unlikely to hinder temporal comparisons. However, if the levels of misidentification actually vary between surveys, it will affect the ability to detects differences in densities, particularly for juvenile cockles

The physical low water mark will vary from survey to survey as it depends on many variables: the wind direction and strength that may hold water in the Inlet, the weather (barometric pressure), and the continual changing magnitude of the tidal flows. The higher numbers of cockles are usually sampled in the mid-tide zones (UMT and LMT). The relatively low cockle counts at low tide quadrats may reflect the difficulty in sampling this tidal zone and underestimate cockle densities there. If sampling effectiveness is the same at all tidal zones, the physical low tidal height would have more of an influence on the estimate of population size. There may be a slight underestimate in the numbers of large cockles in Pāuatahanui Inlet due to the changing physical low tide mark as larger sized cockles are generally sampled at low water levels, and a differing low water level (between surveys) might include more or less of those large cockles, depending on where that physical low water level is for a given survey.

4.2 Ongoing effects of the 2016 floods on cockle habitat

Significant floods on 13 August 2016, 16 September 2016 and the especially large flood on 15 November 2016significantly increased the fine sediment over the intertidal survey area. The heavy rain that followed the 7.8 (Mw) Kaikoura earthquake on 14 November 2016 caused several slips that further exacerbated runoff and sediment loads to the inlet.

At the time of the 2016 cockle survey, extensive subtidal deposition of terrestrial muds was evident in Pāuatahanui Inlet, with fine muds readily disturbed when wading (Stevens 2017). The widespread mud deposition was quickly remobilised from most intertidal areas and deposited primarily in the subtidal, and in some saltmarsh areas. Kakaho was the most affected site with mud blanketing the entire area. Mana and Camborne were also more affected than other sites (Stevens 2017).

Sediment deposition affected the entire intertidal area between mid-November and late-December 2016 (observations, John Wells). These muds were unconsolidated and easily remobilised by wind driven waves and tide action (Stevens 2017). Intertidal sediments were transported into the shallow subtidal areas of Pāuatahanui Inlet. By January 2017, the main area of the inlet still affected was from Camborne to Pāuatahanui. Kakaho was the only area with widespread intertidal mud deposits remaining (Stevens 2017). Mud content in the intertidal zone at Kakaho increased from 16% to 38% following the 2016 floods, consistent with a very high ecological risk rating category (Stevens 2017). Average increases in mud content over the intertidal zone of Pāuatahanui Inlet doubled between 2012 and 2017 to about 13%, consistent with a moderate ecological risk rating category (Stevens 2017). There was a large increase in the deposition of sediments in the subtidal basin of Pāuatahanui Inlet, 54 mm adjacent to Kakaho and 90 mm off Duck Creek (Stevens 2017). Monitoring in January 2019 (Stevens 2019) showed an increase in sediment deposition in the intertidal zone of Pāuatahanui Inlet from 2016-2019; however, the annual and net change was spatially and temporally variable.

Cockles are generally most abundant in sediments of below 12 % mud (Thrush et al. 2003, Anderson 2008). The deposition of terrestrial muds over estuarine macrobenthic communities such as those in the intertidal areas of Pāuatahanui has highly deleterious effects (Norkko et al. 2002). Their experiments showed that irrespective of mud thickness, the numbers of taxa declined by 93% and abundance by 97% after 10 days. Very few cockles were found alive. After 408 days, recovery was slow and incomplete; there were 80% fewer individuals than prior to disturbance and juvenile cockles were found in low numbers (Norkko et al. 2002).The increased muddiness of estuaries has significant negative effects on the cockle populations: increased physiological stress; decreased reproductive status; and decreased juvenile growth rates (Nicholls et al. 2003, Gibbs & Hewitt 2004, Norkko et al. 2006). Suspended and deposited sediments affect cockle fitness and survival, with terrestrial sediments having greater effects than marine sediments (Gibbs & Hewitt 2004). Sediment deposition has also been shown to negatively affect cockle densities and thereby population sizes (Lohrer et al. 2004). Leigh Stevens (Wriggle Coastal Management, pers. comm.) did not detect mass die offs of shellfish in January 2017.

Differences in the relative densities of cockles at different tidal height may be driven by the effects of wave action in mobilizing sediments. Higher tidal zones (HT, UMT, and LMT) may be more exposed to wave action than lower tide levels and have lower percentages of terrestrial sediments.

GOPI volunteers reported the presence of black, anaerobic mud at several transects during the 2019 survey, particularly the Mana and Brown's Bay sites (transects 1–6). The anoxic surface sediments or shallow redox potential discontinuity layer may render the habitats at these sites unsuitable for cockle and explain the relatively low cockle densities at these sites.

There do not appear to be any lasting negative effects of the 2016 floods on the population size of intertidal cockles in Pāuatahanui Inlet. Cockle densities at many sites around Pāuatahanui Inlet have increased markedly and the population size has increased 32.2% between 2016 and 2019. Most notable is the increase in cockle counts for both juveniles and adult sizes at Kakaho between 2016 and 2019, a site with increasing mud content and a very high ecological risk rating category. It cannot be determined if some of the increase there is driven by migration from unsuitable subtidal habitat in adjacent areas to the intertidal zone.

4.3 Trends in population estimates

4.3.1 Cockle recruitment

Growth in cockles varies spatially, interannually, and is strongly seasonal, with the highest growth in mid-summer (January) and lowest or no growth in mid-winter (July) (Tuck & Williams 2012). There is high spatial and interannual variability in cockle recruitment (the settlement of larvae and survival of spat, Fisheries New Zealand 2019). Larval settlement may be conspecific (Fisheries New Zealand 2019) i.e., there is greater settlement of cockle larvae in areas with higher densities of adults that are not directly related to the densities of spawning individuals (larvae can disperse some distance during the three-week planktonic phase). Sites with high adult densities in 2019 had high densities of juvenile cockles (see Figure 3–6). Juvenile cockles (10 mm in length and smaller) in November 2019 are likely to be spat that have settled and survived during the spring and early summer of 2019 (0+ age class).

The high percentages of juvenile cockles in 2016 and 2019 is inconsistent with the expectation of relative high mortality of small cockles (compared to the adult cockle population) from the mud deposition and suspended sediment from the 2016 floods. The increasing trend in cockle densities and population size since 2001 suggest consistently significant cockle recruitment and survival of small cockles. One possible explanation for the high numbers of juvenile cockles in 2016 and 2019 is that favourable climatic conditions may have produced large recruitment events (cockle spat settlement) and regardless of the potential for heightened juvenile cockle mortality, a relatively large number of these settlers have survived, maintaining relatively high numbers of Juvenile cockles. There is a low possibility that cannot be discounted that these increases may be an artefact of large numbers of nutshells being counted as cockles (e.g., as suspected for transect 19 in 2016 where 51% of the cockles were juveniles).

The proportion of juvenile cockles in the population has ranged from 12.0% to 17.4% between 2004 and 2019. The relatively high percentage of juveniles since 2004, as the population has increased over this time, suggests regular recruitment and good survival of newly settled spat over their first winter. Generally, this increasing trend is unlikely to be due to high levels of misidentification in recent surveys nor in an improvement in the detection of juvenile cockles. There are many factors that may drive the recruitment strength of cockles in Pāuatahanui Inlet; some that may be associated with the health of the Inlet such as levels of fine suspended silt, some that are likely to be driven by climate, and others associated with the ecology of Pāuatahanui Inlet such as predation pressure. There are also several other unknowns:

1. The proportion of the total Inlet-wide population that occurs subtidally, and the contribution the subtidal population makes to the recruitment of juveniles in the intertidal zone.

2. Extensive movements of juvenile cockles have been documented, but individuals over 25 mm length remain largely sessile, moving only in response to disturbance (Fisheries New Zealand 2019). Whether there is any movement of juvenile cockles from the intertidal to the subtidal areas, and vice versa is unknown. Hooker (1995) found evidence of movement in pipi (*Paphies australis*) in the Whangateau Harbour, suggesting that pipis (both juveniles and adults) can move long distances from unsuitable habitats using mucus parachutes. Cummings & Thrush (2004) also considered juvenile pipis and wedge shells (*Macomona liliana*) to be mobile and found that both species were less likely to establish themselves in areas that had elevated levels of terrestrial (land derived) sediments.

3. Whether cockles still occur on the intertidal areas of the large offshore sand banks in the western half of the Inlet. The sand banks were partially sampled in 1976, but not in the GOPI surveys (for safety reasons with volunteers). The area of these sand banks has increased significantly in the last decade or so.

Cockles attain sexual maturity at a size of about 18 mm length, in their second year (Larcombe 1971). In 2019, more than half of the intertidal population was sexually mature (54–61% between 2014 and 2019) that should maintain larval production as a prerequisite for good recruitment.

4.3.2 Trend in cockle population size

Cockles are often a dominant species in New Zealand estuaries, where cockle densities can be as high as 4 500 per m^2 (Fisheries New Zealand 2019). Mean cockle density in Pāuatahanui Inlet in 2019 was the highest since 1976 at 381 per m^2 (99% CI 346–417).

Both Methods 1 and 2 used to estimate population size in Pāuatahanui Inlet both show an increase of 32.2% between 2016 and 2019, and both show a decline in the cockle population between 2013 and 2016. Mean population estimates are higher than for any other survey, except for 1976, which may not be directly comparable.

The coefficients of variation (CVs) are low for these surveys: 0.04 to 0.06 for Model 1, and 0.03 to 0.04 for Model 2. These low CVs are likely to reflect the large numbers of quadrats sampled (up to 372). CVs are all well below the target of 20% set for other shellfish surveys by Fisheries New Zealand (Ministry for Primary Industries). The low CVs suggest that the increasing trend in population size is likely to be real.

The decline in population size between 2013 and 2016 is attributed to the 2016 floods. Whether the muddiness of sites reduced sampling efficiency, whether cockles moved away from unfavourable habitats or whether there was heighted mortality (or any combination of the three factors) cannot be determined.

4.4 Status of the cockle population in Pāuatahanui Inlet

The increase in overall population size, and recovery from the decline between 2013 and 2016 show the population of cockles in the intertidal zone of Pāuatahanui Inlet is in an improving state. The consistently high percentages of juvenile cockles since 2004 (12.4–17.4% of the total populations) suggest successful settlement of larvae and good survival of spat, or the immigration of juvenile cockles from subtidal areas. High percentages of cockles (more than 50%) are above spawning size (larger the 18 mm in length, see Figure 3–12) that should maintain larval production in the inlet.

Changes in the environmental conditions in Pāuatahanui Inlet, particularly the increase in terrestrial sediments considered deleterious to cockles, do not appear to have affected the intertidal cockle population.

5 Recommendations for future research

The surveys or new research should reflect the specific biological or ecological questions being asked of the data. There is high value in continuing the current time-series of surveys, depending on the questions being asked. There may be value in considering additional sampling to provide additional data if required.

The current survey design allows spatial and temporal changes in cockle densities and cockle sizes to be determined, and how they might differ at different intertidal locations around the inlet. The time-series of survey data already suggests the deleterious effects of terrestrial sediment inputs at some locations within Pāuatahanui Inlet, and thereby the time-series of data are of high value in determining future changes.

5.1 Options

1. The easiest way to improve the intertidal survey and to provide the greatest value to the data time-series is to ensure that all sampling of survey sites is standardised as much as possible:
   a. Use the same quadrats with depth gauges, sieves, and measuring boards or rulers for every survey.
   b. Accurate location of sample site, GPS positions of each tide levels on each transect would be helpful.
   c. Excavate the substrate accurately without "infilling" or "outfilling" and to a standard depth.
   d. Accurate sorting of taxa and identification of small cockles from nut shells.
   e. Accurate measurement of cockle size.

This will ensure changes in the numbers and sizes of cockles reflect what is happening in the inlet and not variance in the sampling; and:

2. To estimate mortality from the shells of recently dead cockles and their size.
3. To estimate the diversity of taxa in samples. Count but don't necessarily measure all other taxa (bivalves and snails (gastropods)).
4. To undertake tagging studies for growth, mortality and movement.
5. If sufficient data are available, to investigate what effects changing sediment compositions and rates if sedimentation in the intertidal zone have on changes in cockle densities.

6 Acknowledgements

This is the first Cockle Population Survey conducted since Professor John Wells passed away in late 2018. John organised the triennial Cockle Population Surveys (known to the Inlet community as cockle counts) from 2004 until 2016. With help and support from his wife Marjery, John managed the planning, organisation, training and logistics, the post count follow-up analysis with NIWA, and dissemination of the findings. John's scientific skills and the careful, rigorous methodology he applied to the cockle counts meant that the surveys were accepted by the scientific and local authority communities as a reliable and valuable indicator of the health of the Inlet. Thanks to John's work in successfully managing the process over 12 years, the Inlet cockle counts have become the longest running community science project in New Zealand.

Thanks to the Conservation Volunteers, GOPI members and community members who sampled Pāuatahanui Inlet in 2019, ensuring the value of this time-series of data. Thanks to Greater Wellington Regional Council (led by Jo Fagan) for all their help and logistic support. Also, thanks to the GOPI committee members and partners (Andre and Caroline van Halderen, Janet and Ray Ryan, John McKoy, Lindsay Gow, and Michael Waldron) who helped with the logistics and prepared the inlet to be sampled; thanks to the GOPI committee members and GOPI members who mopped up all the remaining sites in the weeks after the count; thanks to Nigel Clarke (PCC) who arranged for the data to be punched, and to Megan Oliver (Greater Wellington Regional Council (GWRC)) for information on the changes in sediments and mud deposition in 2019. Thanks to Ian Tuck (NIWA) who reviewed this report, and to Ken Grange and Peter Horn (NIWA) whose reports provided the foundation for this report series.

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Appendix A 2019 Sampling instructions hand-out

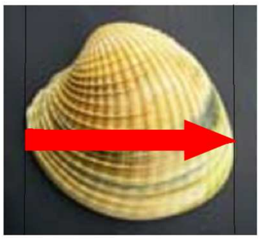
Sampling instructions

Cockle **First recognise your cockle!** **Nut Shell**

Cockle shells have a distinctive pattern of ridges and a prominent recurved 'beak'

Nut Shells are much smaller than adult cockles but can be confused with juvenile cockles

INSTRUCTIONS FOR DIGGING, MEASURING, TALLYING



Length (anterior-posterior axis)

- Assign one person as recorder. Recorder must try to keep hands dry and clean.
- The transect is sampled by 3 quadrats at 4 tidal levels (see your transect sheet)
- Your first task is to mark the High Tide sample site with a stake.
- **Begin sampling at the Low Tide site, if it is exposed, and work up the beach to High tide site. If LT site is not exposed begin sampling at the Lower Mid Tide site, and sample the LT site if and when you can.**
- At each site quadrat B should be on the transect line and A and C be about 5 paces to the right and left of the line.
- For each quadrat:
  - Drop the quadrat frame randomly (don't choose good places).
  - Dig out the mud and animals inside the frame to a depth of about 7 cm and place in your sieve. Take care not to excavate an area larger or smaller than the quadrat.
  - The best way to sieve is to lower it into water and jig it up and down.
  - Pick out stones and empty shells to make it easier to find live cockles.
  - Take out each live cockle and put it into an ice cream carton.
  - **Be careful not to count nut shells as small cockles — see photos above.**
  - Measure length (see illustration above) of each cockle to the nearest mm. and call the measurement to the recorder.
  - Recorder puts a single tally dash (/) for each cockle beside the correct mm size. Tallies are marked in groups of 5 like this: "### //" = 7

PLEASE COLLECT ALL GEAR AND RETURN TO STOUT COTTAGE

Thank you, your help is much appreciated

Appendix B 2019 Transect data sheet

Transect number 1

Mana beach; access by lane beside 34 Mana Esplanade.	Turn left and walk to a large taupata bush, a clump of Agapanthus and a blue rubbish bin about 65 paces north of access lane (pink spot on taupata).
Aim transect towards → **(see photo on back of this sheet)**	Kakaho Stream mouth.
Number of **ADULT** paces from —	
location marker to **high tide** site	**20**
high tide site to **upper mid tide** site	**70**
upper mid tide site to **lower mid tide** site	**70**
lower mid tide site to **low tide** site	**80-90**
Estimated time of low tide	**3:40 pm**

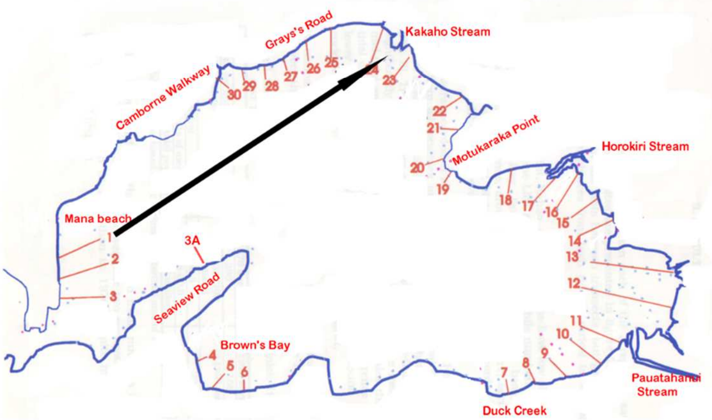
RECORD OF COMPLETED QUADRATS

	Date	Tick	Tick	Tick
High tide quadrats		A	B	C
Upper mid tide quadrats		A	B	C
Lower mid tide quadrats		A	B	C
Low tide quadrats		A	B	C

INSTRUCTIONS

- Use pink topped stakes to mark position of each sampling site.
- **Begin sampling at the Low Tide site, if it is exposed, and work up beach to High Tide site. If LT site is not exposed begin sampling at the Lower Mid Tide site, and sample the LT site if and when you can.**
- Do not attempt to sample if standing water at the site is deeper than about 3 cm.
- If sampling area is covered by stones or large green seaweed, lift off gently before digging.
- Follow instructions for sieving out, measuring and recording cockles.
- **Take care not to confuse nutshells and cockles (see photos).**
- Write any comments about this transect at the bottom of the tally sheet.
- When finished check you have all your gear – especially the quadrat.
- Return all equipment and this Transect-booklet to Stout Cottage.

When you walk out the Transect, aim at the Kakaho stream mouth



Aim toward Kakaho stream when you are walking your Transect

Appendix C 2019 team leader check list

GOPI cockle survey 2019–Transect 1

Checklist for Team Leaders

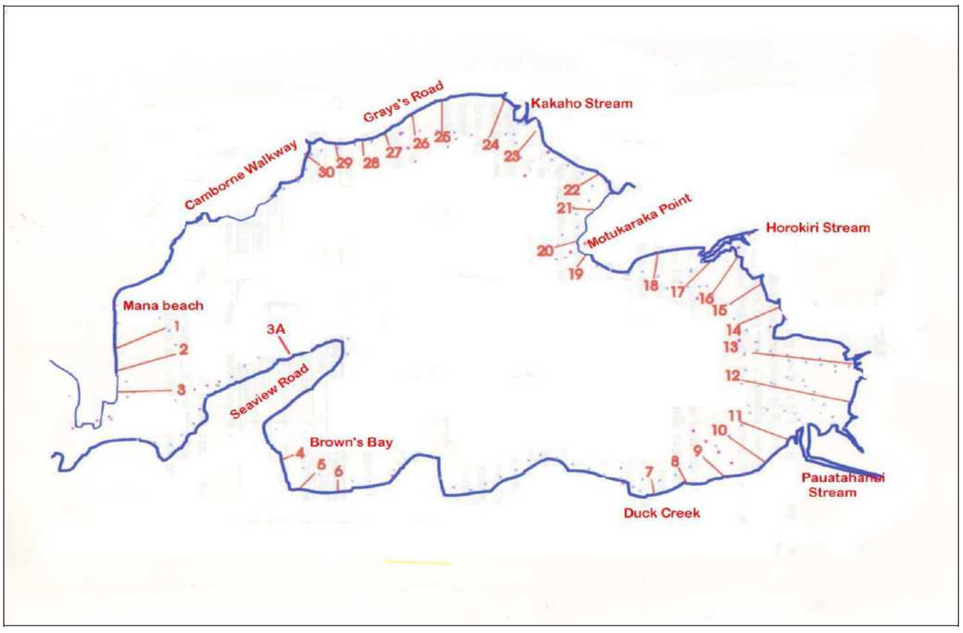
Before you meet and brief your team --

1. **Read and understand the Sampling Instructions sheet–especially the order in which to do the sampling stations.**
2. **Read and understand the Health & Safety guidelines on safety issues.**
3. **Check that you have the correct gear for your allotted transect.**
4. **Check that you have a spade or other suitable digging tool.**
5. **Check that you have your transect book.**
6. **Check that you are fully familiar with the transect location and direction.**
7. **Check that you are fully familiar with any instructions on car parking and access to the shore–this is a health and safety issue.**

Before you head off with your team --

Check that your team know where to park and how to get there safely (instructions are on transect sheet). If possible, use one vehicle only as parking space may be limited.

Make sure that your team understands the Health & Safety guidelines.



Appendix D 2019 survey tally sheet

		Transect No.		Name	
2019	Pauatahanui inlet cockle tally sheet	Tide location (circle one)	Low-tide	Lower mid-tide	Upper mid-tide	High-tide
Use Tally marks (### //)		Contact			

Size (mm)	Quadrat A	Size (mm)	Quadrat B	Size (mm)	Quadrat C
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
10		10		10	
11		11		11	
12		12		12	
13		13		13	
14		14		14	
15		15		15	
16		16		16	
17		17		17	
18		18		18	
19		19		19	
20		20		20	
21		21		21	
22		22		22	
23		23		23	
24		24		24	
25		25		25	
26		26		26	
27		27		27	
28		28		28	
29		29		29	
30		30		30	
31		31		31	
32		32		32	
33		33		33	
34		34		34	
35		35		35	
36		36		36	
37		37		37	
38		38		38	
39		39		39	
40		40		40	
41		41		41	
42		42		42	
43		43		43	
44		44		44	
45		45		45	
46		46		46	
47		47		47	
48		48		48	
49		49		49	
50		50		50	

Notes

Appendix E 2019 Pāuatahanui Inlet cockle count transect location details

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
1	Mana	**Mana beach; access by lane beside 34 Mana Esplanade.** Large taupata bush and a clump of Agapanthus about 65 paces north of access lane.	S:41 05 911 E:174 52 252	E2667 131 N6010 344	Kakaho Stream mouth	20	65	65	70-90
2	Mana	**Mana beach; access by lane beside 34 Mana Esplanade.** Pin '2' on rock by long line of bushes just south of access lane. Below two pohutakawa trees.	S:41 05 955 E:174 52 258	E2667 135 N6010 250	Southern edge of Motukaraka Point	30	65	65	65-80
3	Mana	**Mana beach car park just over Paremata Bridge.** Walk north from toilet block to end of sloping wooden retaining wall in front of very large macrocarpa tree.	S:41 06 258 E:174 52 295	E2667 151 N6010 090	2 storey house with 2 green roofs on Golden Gate at beach level	30	110	110	90-110
3A	Mana (Golden Gate) (Seaview Road)	**Park at Ivey Bay car park. CROSS ROAD VIA UNDERPASS TO KINDERGARTEN.** Front left corner of boatshed with ramp by house number 37A.			Most easterly boatshed on Camborne walkway at Camborne	0	25	25	30-50
4	Browns Bay	Seawall opposite large brown house at foot of Postgate Drive. A half buried pole about 25 paces west of large storm drain	S:41 06 320 E:174 52841	E2667 847 N6009 562	Houses at Motukaraka Point	10	40	4o	40-50
5	Browns Bay	Foot of western steps from car park to beach.	S:41 06 344 E:174 52 910	E2668 038 N6009 515	Kakaho Stream mouth	22	38	38	35-40
6	Browns Bay	Foot of eastern steps from car park to beach.	S:41 06 347 E:174 52 947	E2668 099 N6009 502	Moorhouse Point (end of Golden Gate peninsula)	30	27	27	27-30

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
7	Duck Creek	**Park in space by waterside traffic lane of SH 58, about 100 metres east of James Cook Drive** **Approach via Joseph Banks Drive route (see map).** Walk westward along beach **(do not walk alongside road)** to pink '7' on concrete sea wall 50 metres east of junction of James Cook Drive and SH58 identifies location.	S:41 06340 E:174 54 123	E2669 738 N6009 474	Large white house at right block of trees on Motukaraka Point	15	25	25	30-40
8	Duck Creek	**Park in space by waterside traffic lane of SH 58, about 100 metres east of James Cook Drive** **Approach via Joseph Banks Drive route (see map).** Walk westward along beach **(do not walk alongside road)** to rip rap rock wall about 30 metres west of twin palm trees. Pink '8' on rocks identifies location.	S:41 06 304 E:174 54 240	E2669 908 N6009 535	Long group of pine trees behind houses at Motukaraka Point	25	33	33	30-40
9	Duck Creek	**Park in space by waterside traffic lane of SH 58, about 100 metres east of James Cook Drive** **Approach via Joseph Banks Drive route (see map).** Walk westward along beach **(do not walk alongside road)** to 2 water culverts in rip rap rock sea wall below house entrance with 2 red brisk pillars.	S: 41 06 294 E: 174 54 341	E2670 045 N6009 571	Large white house at Motukaraka Point	20	55	55	50-70

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
10	Bromley	**Park in space by waterside traffic lane of SH 58, about 100 metres east of James Cook Drive** **Approach via Joseph Banks Drive route (see map).** Walk eastward along beach **(do not walk alongside road)** to Wildlife Reserve sign on SH58.	S:41 06 274 E:174 54 442	E2670 193 N6009 602	Gap between two groups of pine trees on Motukaraka Point	48	58	58	50-70
11	Bromley	**Park in space by waterside traffic lane of SH 58, about 100 metres east of James Cook Drive** **Approach via Joseph Banks Drive route (see map).** Walk eastward along beach **(do not walk alongside road)** to Wildlife Reserve sign on SH58 and on about 160 paces to pink '11' on plant stump.	S:41 06 227 E:174 54 543	E2670 322 N6009 702	Waterski Club at east end of Camborne Walkway	20	57	57	50-70
12	Pāuatahanui Wildlife Reserve	Orange ribbon on stake about 85 paces south of transect 13 stake.	S: E:	E2670 654 N6009884	Moorhouse Point	20	150	150	140-160
13	Pāuatahanui Wildlife Reserve	Pink painted stake immediately to left of entry point to beach.	S: E:	E2670 674 N6009 976	Camborne	20	130	130	100-150
14	Pāuatahanui (Ration Point)	**Park either side of Horokiri bridge (sign "Horokiri Estuary Restoration Project") and walk back to Ration Point.** Enter shore at this point Turn right and go to pink stake numbered 14 (about 70 paces).	S:41 05 814 E:174 54 539	E2670 339 N6010 440	Long red roofed house just to right of apex of hill above Bradey's Point	10	30	30	30-50

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
15	Pāuatahanui (Ration Point)	**Park either side of Horokiri bridge (sign "Horokiri Estuary Restoration Project") and walk back to Ration Point.** Enter shore at this point and go west to pink topped stake numbered 15 (about 200 paces from beach entry point). **Keep to edge of shell banks where you can to avoid mud patches. Take care crossing the drainage channel just past pink stake 14.**	S:41 05 755 E:174 54 475	E2670 251 N6010 555	Yellow cliffs at mouth of Duck Creek. Right of large white house on the cliff.	10	23	23	20-30
16	Pāuatahanui (Horikiri Stream)	**Park either side of Horokiri bridge (sign "Horokiri Estuary Restoration Project") and walk back to Ration Point.** Enter shore at this point. Turn right and go past location markers for stations 14 and 15 to pink topped stake numbered 16 (about 400 paces from beach entry point). **Keep to edge of shell banks where you can to avoid mud patches. Take care crossing the drainage channel just past pink stake 14.**	S:41 05 690 E:174 54 400	E2670 166 N6010 673	Bradey's Point	20	33	33	30-50
17	Motukaraka (Horikiri Stream)	**Park either side of Horokiri bridge (sign "Horokiri Estuary Restoration Project") and walk back to Ration.** Enter shore at this point. Turn right and walk along the shell banks on the upper shore–**DO NOT WALK LANDWARD OF SHELL BANK AS THE MUD IS DEEP**–until you reach the Horokiri stream by some large flax bushes (see photo). Location marker is a pink topped stake numbered 17. **Take care crossing the drainage channel just past pink stake 14.**	S:41 05 673 E:174 54 287	E2669 993 N6010 712	Yellow cliffs at mouth of Duck Creek	15	35	35	30-50

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
18	Motukaraka Point	Rush clumps below blue seat under a very large tree at vehicle turnaround area at east Motukaraka Point.	S:41 05 655 E:174 54 113	E2669 745 N6010 742	2 red roofed houses behind mouth of Duck Creek	30	28	28	25-40
19	Motukaraka Point	Park cars by blue seat next to a tarmac path to beach at east Motukaraka Point. Walk west along beach about 50 metres to a pink spot on remnants of a brick fireplace.	S:41 05 705 E:174 53 941	E2669 505 N6010 669	Brandon subdivision (prominent yellowish house).	10	20	20	15-25
20	Motukaraka Point	At seaward edge of grass bank opposite entrance to house number 7 a pink stake marks a path to beach. Location marker a pink spot on shell bank at end of path.	S:41 05 631 E:174 53 850	E2669 389 N6010 805	Moorhouse Point (tip of Golden Gate peninsula–house with several ball-topped turrets)	20	25	25	25-30
21	Motukaraka Point	**Park at car park by public toilets.** Find culvert outlet from grass bank in front of toilet block.	S:41 05 519 E:174 53 911	E2669 479 N6011 003	Waterski Club at eastern end of Camborne walkway	15	33	33	30-40
22	Motukaraka Point	**Park at car park by public toilets.** Walk westwards across mud flats to a large bush on shell bank on beach opposite garage at entrance to "Barrowside" 325 Grays Road and the yellow/black 55 chevron sign. **TAKE CARE TO AVOID WALKING ON SALT MARSH PLANTS.**	S:41 05 442 E:174 53 922	E2669 493 N6011 145	Moorhouse Point (tip of Golden Gate peninsula–house with several ball-topped turrets)	1525	35	25	20-30
23	Kakahao	**Park at Kakaho Bridge.** Walk eastward along path through grass alongside stream to beach. Turn left and go round to sea wall. Location marker is a pink spot on rock wall opposite 283 Grays Road (about 30 metres east of car park).	S:41 05 315 E:174 53 705	E266 9207 N6011 392	Paremata Bridge; Paremata Boating Club buildings; mouth of Inlet. **Note**: this transect crosses the Kakaho stream outfall. Find a shallow place to cross it. **Adjust sample sites to miss it.**	15	30	30	30

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
24	Kakahao	**Park at Kakaho bridge and cross bridge WITH GREAT CARE. Leave road about 20 metres from bridge and walk through mud flat to shell bank below salt marsh. DO NOT WALK ON SALT MARSH PLANTS.** Walk west along shore to pink topped stake numbered 24 on the shell bank.	S: 41 05 240 E: 174 53 586	E2669 027 N6009 540	Browns Bay	20	50	50	50-60
25	Kakaho	**Park at Kakaho bridge and cross bridge WITH GREAT CARE.** Leave road at 2nd black on yellow **>** road sign and walk through mud flat to shell bank below salt marsh. **DO NOT WALK ON SALT MARSH PLANTS.** Walk west to pink topped stake number 25 on the shell bank; about 100 paces beyond stake number 24, in line with blue house.	S: 41 05 233 E: 174 53 493	E2668 896 N6011 565	Prominent hill (Mercury Hill) in foreground just east of Browns Bay	20	65	65	65-75
26	Kakaho (Camborne)	**Park at Wellington Jet Sport Club at east end of Camborne walkway.** Walk east along beach to drain opposite wooden gate; about 25 metres before you get to a 'wiggly road' sign; dab of pink paint on wall by drain.	S: 41 05 254 E: 174 53 327	E2668 664 N6011 535	Bradey Bay (bush filled gully to right of prominent yellowish house).	25	60	60	50-65
27	Camborne	**Park at Wellington Jet Sport Club at east end of Camborne walkway.** Walk east along beach to a memorial cross by a drain just west of fallen large macrocarpa trees.	S: 41 05 324 E: 174 53 172	E 2668 450 N 6011 397	Bradey Bay (bush filled gully to right of prominent yellowish house).	20	25	25	25-30
28	Camborne	**Park at Wellington Jet Sport Club at east end of Camborne walkway.** Walk east along beach to set of steps to beach from Grays Road (about 100 paces east of black/white striped poles).	S: 41 05 349 E: 174 53 097	E 2668 342 N 6011 345	Prominent hill (Mercury Hill) in foreground just east of Browns Bay.	15	10	10	10-15

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Paces to high tide site	Paces from high tide to upper midtide site	Paces from upper to lower midtide site	Paces from lower midtide to low tide site
29	Camborne	**Park at Wellington Jet Sport Club at east end of Camborne walkway.** Walk east along beach to black/white striped pole on beach below similar pole on roadside.	S: 41 05 361 E: 174 53 037	E2668 255 N6011 331	Prominent hill (Mercury Hill) in foreground just east of Browns Bay.	15	7	7	5-10

Appendix F The number of cockles sampled from each of the three quadrants (A-C)

The numbers of cockles sampled from each of the three quadrats (A–C), tidal heights (HT, high tide; UMT, upper mid-tide; LMT, lower mid-tide; and LT, low tide) by Class (juveniles 10 mm in length or smaller and adults larger than 10mm in length) during the 2019 GOPI intertidal survey of Pāuatahanui Inlet.

Transect	Site	Class	HTA	HTB	HTC	HT	UMTA	UMTB	UMTC	UMT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	Total
1	Mana	Juvenile	1	2	0	**3**	25	49	5	**79**	3	2	0	**5**	0	0	0	**0**	**87**
1	Mana	Adult	10	2	3	**15**	139	230	72	**441**	82	56	64	**202**	51	41	81	**173**	**831**
2	Mana	Juvenile	0	0	3	**3**	0	0	3	**3**	2	4	4	**10**	0	0	0	**0**	**16**
2	Mana	Adult	61	11	46	**118**	51	11	46	**108**	71	62	108	**241**	25	22	24	**71**	**538**
3	Mana	Juvenile	4	7	11	**22**	2	4	0	**6**	0	0	1	**1**	1	0	0	**1**	**30**
3	Mana	Adult	41	31	28	**100**	44	12	27	**83**	19	33	21	**73**	23	15	22	**60**	**316**
3A	Seaview Rd	Juvenile	2	1	2	**5**	4	9	1	**14**	0	5	4	**9**	0	0	0	**0**	**28**
3A	Seaview Rd	Adult	28	22	40	**90**	19	32	54	**105**	31	23	55	**109**	32	18	16	**66**	**370**
4	Browns Bay	Juvenile	0	1	0	**1**	1	7	1	**9**	5	8	5	**18**	1	8	4	**13**	**41**
4	Browns Bay	Adult	25	13	28	**66**	26	38	23	**87**	26	54	30	**110**	87	34	106	**227**	**490**
5	Browns Bay	Juvenile	0	0	0	**0**	34	48	42	**124**	1	2	1	**4**	0	2	0	**2**	**130**
5	Browns Bay	Adult	0	0	0	**0**	69	54	56	**179**	24	57	74	**155**	34	49	44	**127**	**461**
6	Browns Bay	Juvenile	5	15	19	**39**	0	8	6	**14**	0	1	1	**2**	0	0	0	**0**	**55**
6	Browns Bay	Adult	44	40	43	**127**	10	42	23	**75**	40	40	18	**98**	28	5	28	**61**	**361**
7	Duck Creek	Juvenile	1	0	0	**1**	1	2	3	**6**	7	0	0	**7**	2	3	2	**7**	**21**
7	Duck Creek	Adult	13	8	5	**26**	6	2	8	**16**	64	3	3	**70**	36	35	23	**94**	**206**
8	Duck Creek	Juvenile	4	3	4	**11**	2	2	6	**10**	1	0	2	**3**	0	0	0	**0**	**24**
8	Duck Creek	Adult	28	27	20	**75**	24	21	17	**62**	28	24	25	**77**	28	28	26	**82**	**296**
9	Duck Creek	Juvenile	0	0	0	**0**	0	0	0	**0**	0	1	1	**2**	0	0	0	**0**	**2**
9	Duck Creek	Adult	0	0	2	**2**	2	2	4	**8**	9	14	25	**48**	23	19	13	**55**	**113**

Transect	Site	Class	HTA	HTB	HTC	HT	UMTA	UMTB	UMTC	UMT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	Total
10	Bromley	Juvenile	5	11	9	**25**	7	9	2	**18**	1	1	6	**8**	1	1	4	**6**	**57**
10	Bromley	Adult	24	20	26	**70**	28	25	28	**81**	27	45	24	**96**	22	17	42	**81**	**328**
11	Bromley	Juvenile	0	2	0	**2**	4	6	3	**13**	0	0	0	**0**	0	0	0	**0**	**15**
11	Bromley	Adult	8	8	7	**23**	27	34	26	**87**	31	28	33	**92**	25	22	23	**70**	**272**
12	Bromley	Juvenile	4	11	0	**15**	7	4	8	**19**	16	11	21	**48**	0	0	0	**0**	**82**
12	Bromley	Adult	5	12	3	**20**	17	18	35	**70**	79	79	100	**258**	32	20	28	**80**	**428**
13	Bromley	Juvenile	3	9	8	**20**	0	0	0	**0**	8	2	23	**33**	0	0	0	**0**	**53**
13	Bromley	Adult	25	17	14	**56**	NA	NA	NA	**0**	67	82	100	**249**	NA	NA	NA	**0**	**305**
14	Pāuatahanui	Juvenile	4	1	0	**5**	31	27	12	**70**	7	9	2	**18**	1	4	7	**12**	**105**
14	Pāuatahanui	Adult	22	5	5	**32**	31	33	23	**87**	31	37	31	**99**	26	26	21	**73**	**291**
15	Pāuatahanui	Juvenile	3	9	0	**12**	10	58	42	**110**	5	2	7	**14**	0	0	0	**0**	**136**
15	Pāuatahanui	Adult	7	5	8	**20**	12	76	51	**139**	27	18	33	**78**	16	20	8	**44**	**281**
16	Pāuatahanui	Juvenile	43	32	22	**97**	44	63	30	**137**	25	22	21	**68**	0	0	0	**0**	**302**
16	Pāuatahanui	Adult	23	11	14	**48**	23	23	21	**67**	36	41	26	**103**	26	28	19	**73**	**291**
17	Pāuatahanui	Juvenile	0	0	0	**0**	0	2	0	**2**	15	24	12	**51**	6	13	24	**43**	**96**
17	Pāuatahanui	Adult	0	0	0	**0**	13	1	0	**14**	27	40	72	**139**	77	52	41	**170**	**323**
18	Motukaraka	Juvenile	12	22	25	**59**	8	6	14	**28**	7	2	7	**16**	1	3	1	**5**	**108**
18	Motukaraka	Adult	24	27	37	**88**	74	101	118	**293**	53	79	62	**194**	73	85	86	**244**	**819**
19	Motukaraka	Juvenile	7	8	7	**22**	9	9	23	**41**	5	5	8	**18**	1	2	4	**7**	**88**
19	Motukaraka	Adult	41	55	48	**144**	80	71	30	**181**	21	18	8	**47**	29	9	15	**53**	**425**
20	Motukaraka West	Juvenile	0	0	0	**0**	6	6	0	**12**	2	10	5	**17**	1	2	1	**4**	**33**
20	Motukaraka West	Adult	2	0	4	**6**	82	61	48	**191**	18	58	20	**96**	3	8	9	**20**	**313**
21	Motukaraka West	Juvenile	7	13	15	**35**	17	38	13	**68**	7	13	15	**35**	2	2	0	**4**	**142**
21	Motukaraka West	Adult	80	63	87	**230**	70	87	50	**207**	80	63	60	**203**	17	41	28	**86**	**726**

Transect	Site	Class	HTA	HTB	HTC	HT	UMTA	UMTB	UMTC	UMT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	Total
22	Motukaraka West	Juvenile	1	1	2	**4**	8	8	2	**18**	4	5	4	**13**	11	4	5	**20**	**55**
22	Motukaraka West	Adult	17	12	0	**29**	21	32	37	**90**	31	36	37	**104**	36	34	40	**110**	**333**
23	Kakaho	Juvenile	12	6	17	**35**	18	16	35	**69**	18	16	35	**69**	1	1	1	**3**	**176**
23	Kakaho	Adult	15	20	32	**67**	105	111	89	**305**	106	112	96	**314**	78	108	53	**239**	**925**
24	Kakaho	Juvenile	8	1	18	**27**	4	11	11	**26**	2	2	8	**12**	0	0	0	**0**	**65**
24	Kakaho	Adult	6	7	4	**17**	41	47	19	**107**	35	42	67	**144**	18	13	24	**55**	**323**
25	Kakaho	Juvenile	12	5	12	**29**	27	11	18	**56**	2	0	1	**3**	0	0	0	**0**	**88**
25	Kakaho	Adult	23	15	21	**59**	53	23	57	**133**	27	11	31	**69**	3	13	4	**20**	**281**
26	Kakaho	Juvenile	2	4	2	**8**	6	7	0	**13**	5	4	4	**13**	3	2	9	**14**	**48**
26	Kakaho	Adult	25	13	26	**64**	20	39	11	**70**	18	33	16	**67**	20	21	20	**61**	**262**
27	Camborne	Juvenile	0	2	0	**2**	0	5	2	**7**	0	0	0	**0**	0	0	0	**0**	**9**
27	Camborne	Adult	37	14	16	**67**	13	37	48	**98**	18	18	22	**58**	6	11	7	**24**	**247**
28	Camborne	Adult	4	15	10	**29**	13	23	31	**67**	7	13	21	**41**	8	11	7	**26**	**163**
29	Camborne	Juvenile	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	3	2	1	**6**	**6**
29	Camborne	Adult	0	0	0	**0**	0	0	0	**0**	3	3	3	**9**	20	20	20	**60**	**69**

Appendix G Histograms of the size (length) frequency of cockles for all sites combined since 1998. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red