Community survey of cockles (*Austrovenus stutchburyi*) in Pāuatahanui Inlet, Wellington, November 2022

Update of intertidal survey time series

Prepared for the Guardians of Pāuatahanui Inlet

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Prepared by:
Keith Michael

For any information regarding this report please contact:

Dr Keith Michael
Scientist
Coastal Ecology and Fisheries
+64 4 386 0586
keith.michael@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

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Executive summary

The Guardians of Pāuatahanui Inlet (GOPI) and community volunteers have carried out eleven triennial surveys of cockles (*Austrovenus stutchburyi*) in Pāuatahanui Inlet (Porirua Harbour, Wellington) since 1992. These surveys provide an important time-series of data to monitor trends in intertidal cockle densities and their size structures over space and time. 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 survey undertaken mostly on Sunday 6 November 2022; some transects were sampled afterwards. Twenty eight of the 31 original transects were fully sampled and comprised 336 of the 372 quadrats available.

This report updates the 2020 report of the 2019 survey and provides an in-depth context and discussion of the surveys. Key findings of the 2022 Pāuatahanui Inlet cockle survey are:

- The total survey counts of cockles were the highest since 1992 and increased 86.5% between 1992 and 2022. Most transects in 2022 had higher or markedly higher total counts of cockles than in previous surveys. The highest number of cockles recorded per 0.1 m^2 quadrat in 2022 was 289, higher than previous surveys. Mean cockle density over the intertidal survey area in 2022 was 44.0 per 0.1 m^2 (99% CI 39.6–48.4), higher than previous GOPI surveys since 1992.

- The two methods used to estimate cockle population size show upward trends and significant differences from 2007 to 2013, a decrease between 2013 and 2016, and marked increases between 2016 and 2022. The low coefficients of variation (CVs) of 3–6% suggest statistically significant increases. The first survey of Pāuatahanui Inlet cockles was undertaken by the New Zealand Oceanographic Institute in 1976. The 2022 mean population size using Method 1 (440 million cockles, 99% confidence interval 396–484 million) is 84.1% of the first and highest population estimate from the 1976 survey.

- 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 19.8% in 2022. The 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.

The increase in population size of cockles in the intertidal zone of Pāuatahanui Inlet in 2022 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 suggest that successful settlement of larvae and good survival of spat, or potentially some immigration of juvenile cockles from subtidal areas. This trend is not consistent with the expectation of relatively high mortality of small cockles from the high levels of mud and suspended sediment from the 2016 floods. The high percentages of cockles above spawning size (larger than 18 mm in length) should maintain larval production in the Pāuatahanui Inlet.

Deteriorating 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 as a whole; however, localised effects are evident.

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 Tangata whenua and 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 into PHT and Guardians of Pauatahanui Inlet (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 is 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 change in the components of ecosystems that can infer changes in ecological processes. 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). The first survey of Pāuatahanui Inlet cockles was undertaken by the New Zealand Oceanographic Institute in 1976. 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, Michael and Lyon 2020) have provided a living document that is a depository for information on cockles in Pāuatahanui Inlet. This present report updates the 2019 cockle survey report (Michael and Lyon 2020) with the results of the 11th GOPI cockle survey, carried out in November 2022.

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) with the assistance of community volunteers, and overseen by NIWA (Grange 1993). Most of the survey sites sampled by Richardson et al. (1979) in 1976 (Figure 1–2) were also sampled in 1992. The 1992 survey observed a decrease in the numbers of cockles in the Inlet since 1976 (see Figure 3–3), with 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 have been due factors such as heightened natural mortality and differences in the two survey designs.

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, Michael and Lyon 2020) used the same sites and methods as the 1992 and 1995 surveys (see section 2).

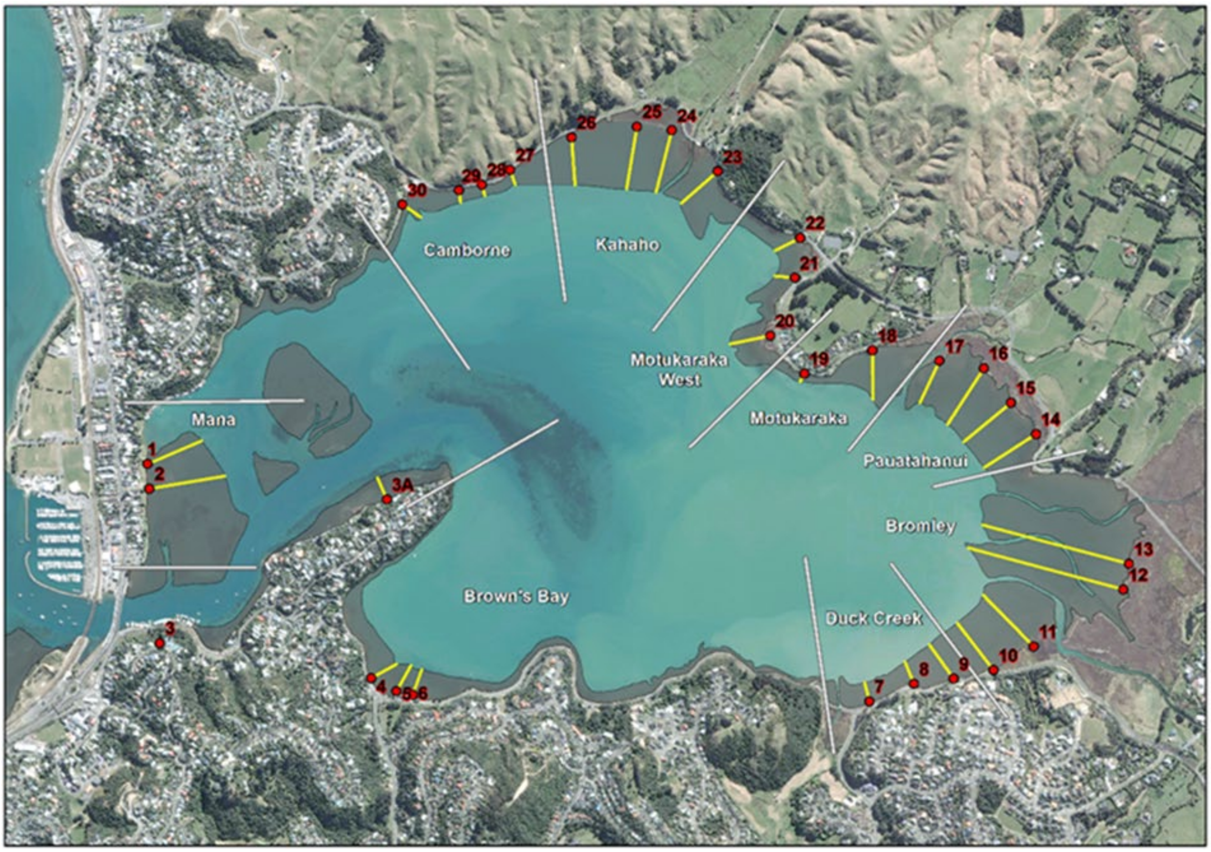

Figure 1-1: Location of all 31 transects sampled in Pāuatahanui Inlet sampled for intertidal cockle densities and population size structure by the Guardians of Pāuatahanui Inlet (GOPI), between 1992 and 2022. Since 1998, Transect 3A has been sampled instead of Transect 30.

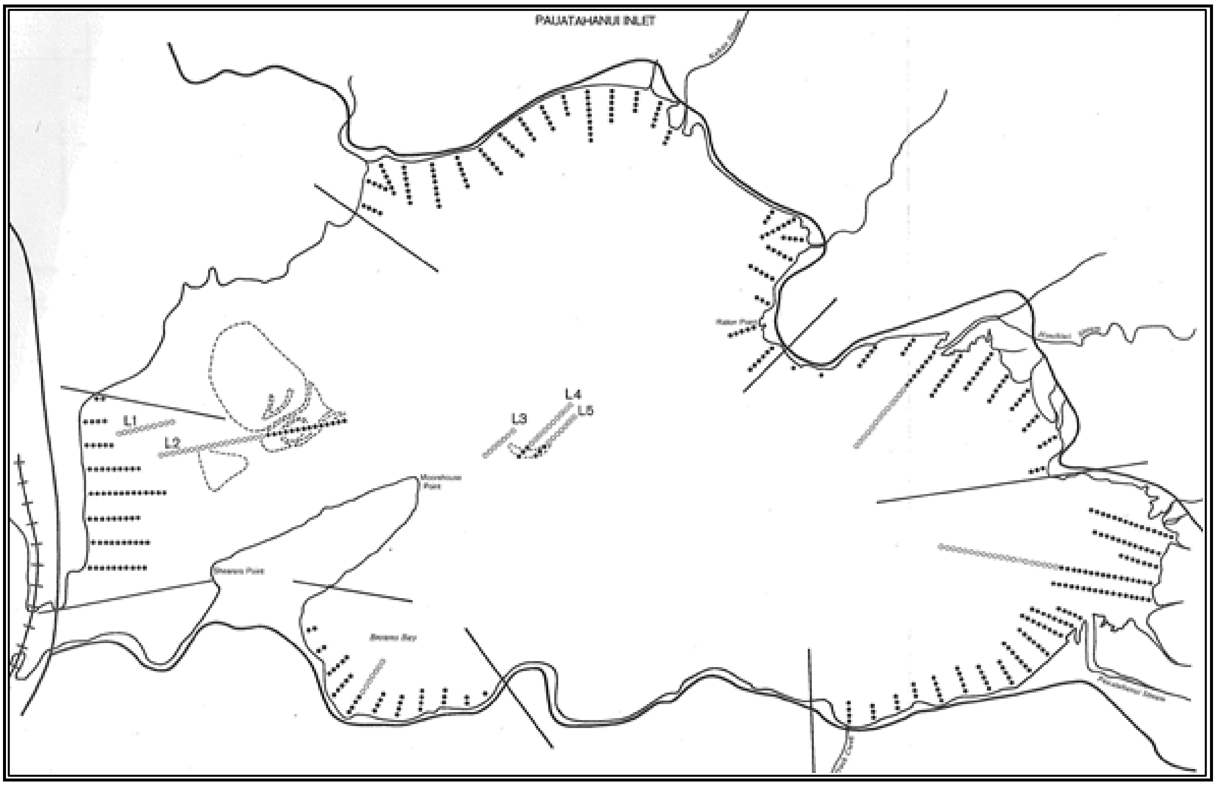

Figure 1-2: 1976 survey stratification of Pāuatahanui Environmental Programme (Healy 1980). Pāuatahanui Inlet was divided into seven sectors, and intertidal and subtidal zones were sampled in five sectors. Straight lines delineate sectors, filled circles show the location of intertidal transects, and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

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. The trend in population size between 2001 and 2013 showed a continuous increase.

The total population size of cockles increased 87% between 1995 and 2013, declined 14% between 2013 and 2016, and increased 32% between 2016 and 2019.

In 2019, cockle counts per quadrat were mostly higher than in 2016 and ranged from zero to a maximum of 279 per 0.1 m^2 , higher than in any of the previous surveys. Consequently, the total population size of cockles in the intertidal zone of Pāuatahanui Inlet was the highest since 1992; however, 73% of that estimated in 1976 (Michael & Lyon, 2020).

1.1.3 Juvenile Abundance

The population size of juvenile cockles (10 mm in length and smaller, Richardson et al. 1979) was low in 1992 and 1995, 2.3 million and 3.3 million respectively. Between 1995 and 1998, the population size of juvenile cockles increased to 16.3 million, and the percentages of juveniles in the total population from 1.8% to 6.4%. Since 1998, the population size of juvenile cockles has shown an upward trend, increasing to 59.3 million in 2019, 16% of the total population.

Assuming that recruitment to the intertidal cockle population and juvenile mortality remained near long-term mean (average) levels, and there was negligible net migration of juveniles to subtidal areas, and growth rates were typically fast, then the higher recruitment of juveniles observed in 1998 to 2019 has driven the increase in the cockle population.

2 Methods

Community volunteers have undertaken triennial intertidal surveys of the cockle population in Pāuatahanui Inlet since 1992, and most recently in 2022. These surveys sampled mostly the same transects (Figure 1–2) and used similar methods.

When using volunteers for surveys it is important to include adequate 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, who was Andre van Helderen in 2022, 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 2022 survey comprised 30 fixed transects (see Figure 1–2). Transect 30 was not sampled between 2013 and 2022, because this area is now a launching place for jet skis and the beach shows relatively high degradation caused by the vehicle traffic. Although transect counts would not be comparable to years before 2013, data between 1992 and 2013 were included in analyses to give a complete description of cockles in Pāuatahanui Inlet.

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 (these replicates were recorded as A, B, and C), at each tide height.

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

Site	Transect	Length (m)
Mana	1	213
Mana	2	277
Mana	3	320
Seaview Road	3A	86
Brown's Bay	4	105
Brown's Bay	5	105
Brown's Bay	6	96
Duck Creek	7	71
Duck Creek	8	85
Duck Creek	9	151
Bromley	10	215
Bromley	11	259
Bromley	12	580
Bromley	13	546
Pāuatahanui	14	223
Pāuatahanui	15	222
Pāuatahanui	16	241
Pāuatahanui	17	166
Motukaraka	18	177
Motukaraka	19	34
Motukaraka West	20	147
Motukaraka West	21	72
Motukaraka West	22	102
Kakaho	23	174
Kakaho	24	230
Kakaho	25	230
Kakaho	26	173
Camborne	27	57
Camborne	28	41
Camborne	29	44
Camborne	30	80

These replicate quadrats were sampled to a depth of about 7 cm and the entire sample was sieved. In 2022, the survey used kitchen colanders as for all previous surveys, with mesh sizes of 3–5 mm (Andre van Halderen, GOPI, pers. comm.). Volunteers flushed sediments and fines through the sieves using seawater.

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 densities

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 2022 survey are compared with those from the previous nine GOPI surveys (1992–2019). 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

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

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 means from all transects (up to 30 transects in total). The 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 (336–372) 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.

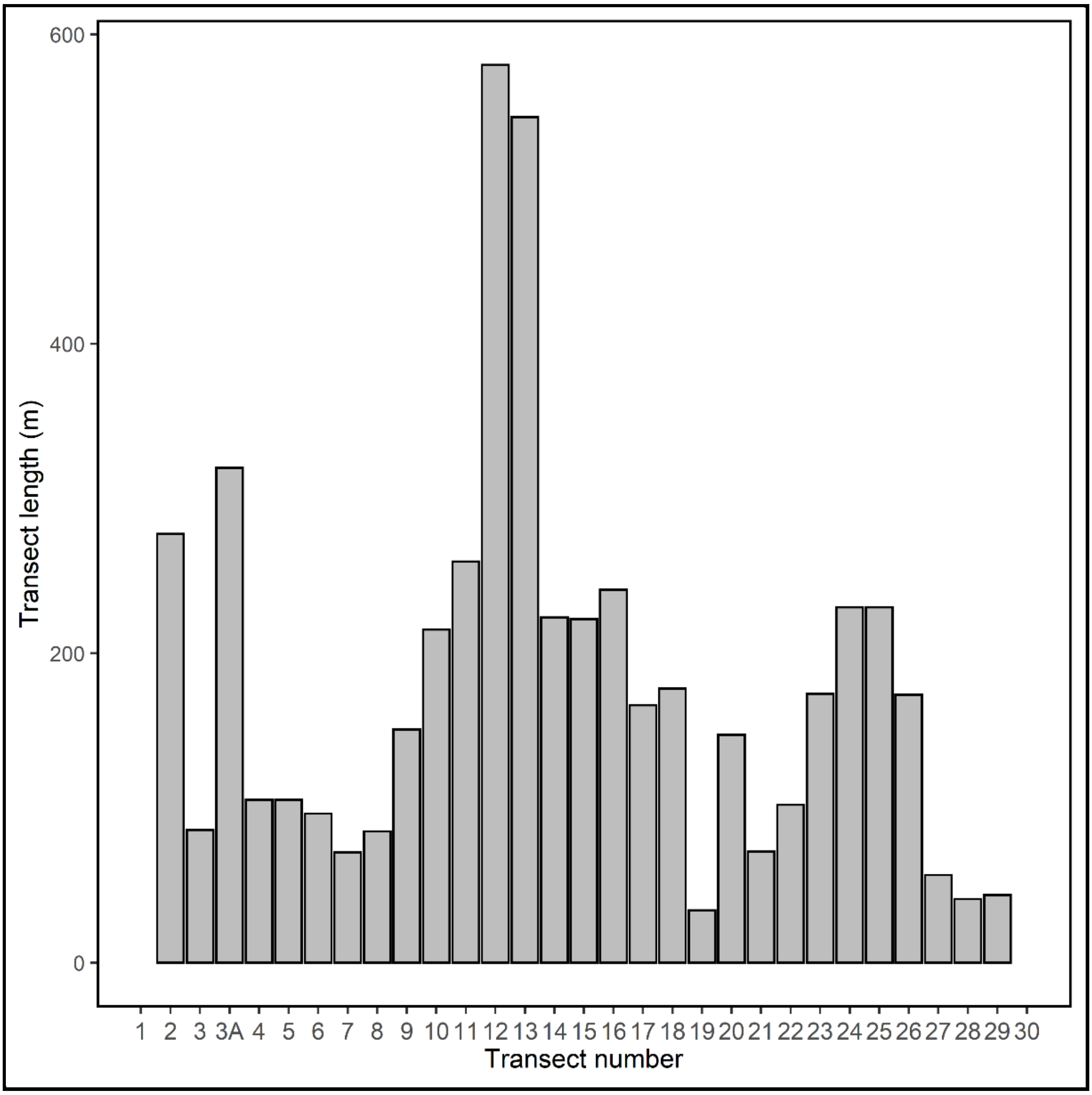

Figure 2-1: Approximate transect lengths estimated from distances between high and low water from a map of the intertidal zone.

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.

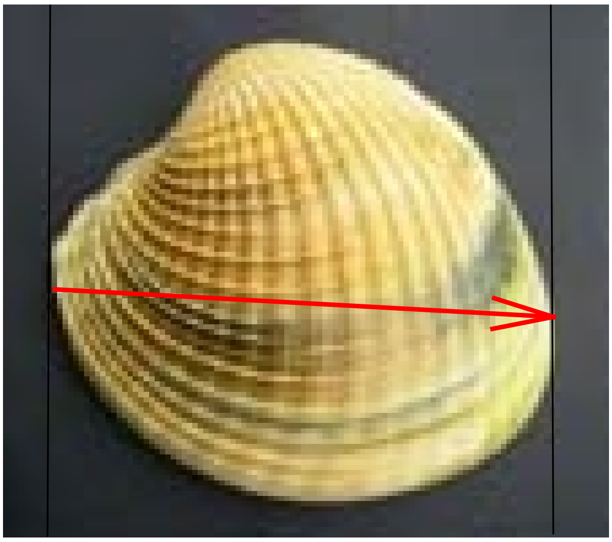

Figure 2-2: Cockle showing the length measurement along the anterior–posterior axis.

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 (individuals 11 mm or larger).

3 Results

The GOPI community survey of cockles in Pāuatahanui Inlet was undertaken mostly on Sunday 6 November 2022; some transects were sampled afterwards. Twenty nine transects were sampled, with transects 28 and 30 not sampled in 2022. Additionally, data from transect 29 were uncertain and omitted from the data summaries and population estimates.

Data from 336 quadrats were used in the analysis in 2022, fewer than in 2019 (354 quadrats and 29.5 transects). Sampling was similar to 2016 (336 quadrats and 28 transects), 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 (*Linucula 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 2022 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, increased 40.9% between 2016 and 2019, and further increased 15.5% between 2019 and 2022 (see Table 3–1).

The total numbers of cockles sampled at each transect between 2013 and 2022 generally increased at most transects during this time period (Figure 3–1).

Plots of the total numbers of cockles sampled at each transect and the means of total counts, each year between 1998 and 2022 are shown in Figure 3–2. Surveys between 1998 and 2016 showed that total counts increased over successive surveys until 2013. In 2016, total survey counts were much more variable with some transects recording high total counts while others recording near historical lows. In 2022, total counts per transect were mostly higher than the long-term average (see dark pink stars representing the 2022 counts), with the exception of three transects.

Spatial variation around Pāuatahanui Inlet is able to be interpreted from Figure 3–2 by comparing transect counts in 2022 to the long-term trend around Pāuatahanui Inlet. 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. In 2022, 18 transects recorded higher total counts than the long-term average, 8 were average and 2 transects (15 and 23) lower than the long-term average, Figure 3–2.

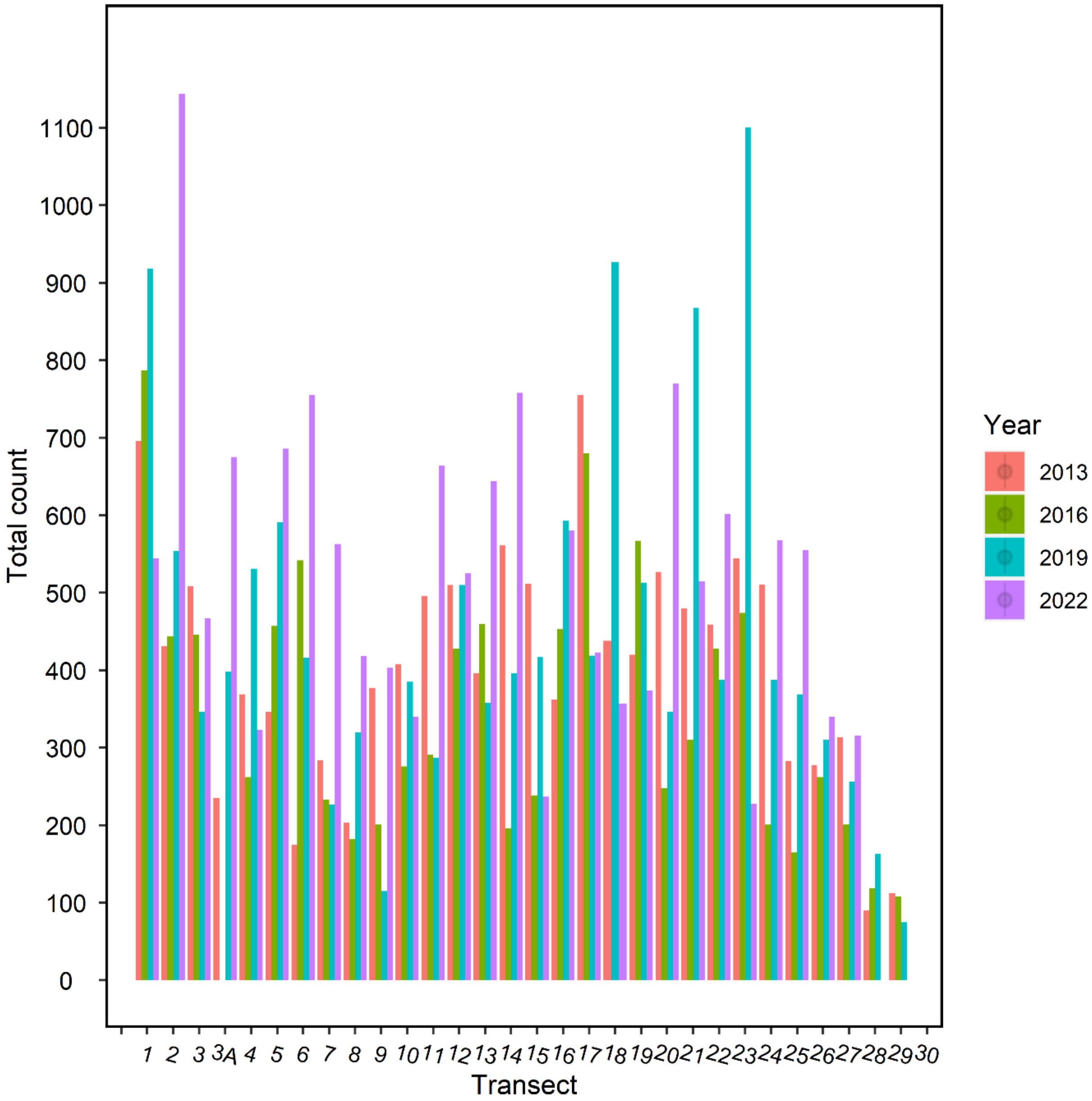

Figure 3-1: The total numbers of cockles (adults and juveniles combined) sampled from each transect in the 2013, 2016, 2019, and 2022 surveys. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, transects 28 and 29 (Camborne) were not sampled in 2022,and only half of Transect 13 sampled in 2019.

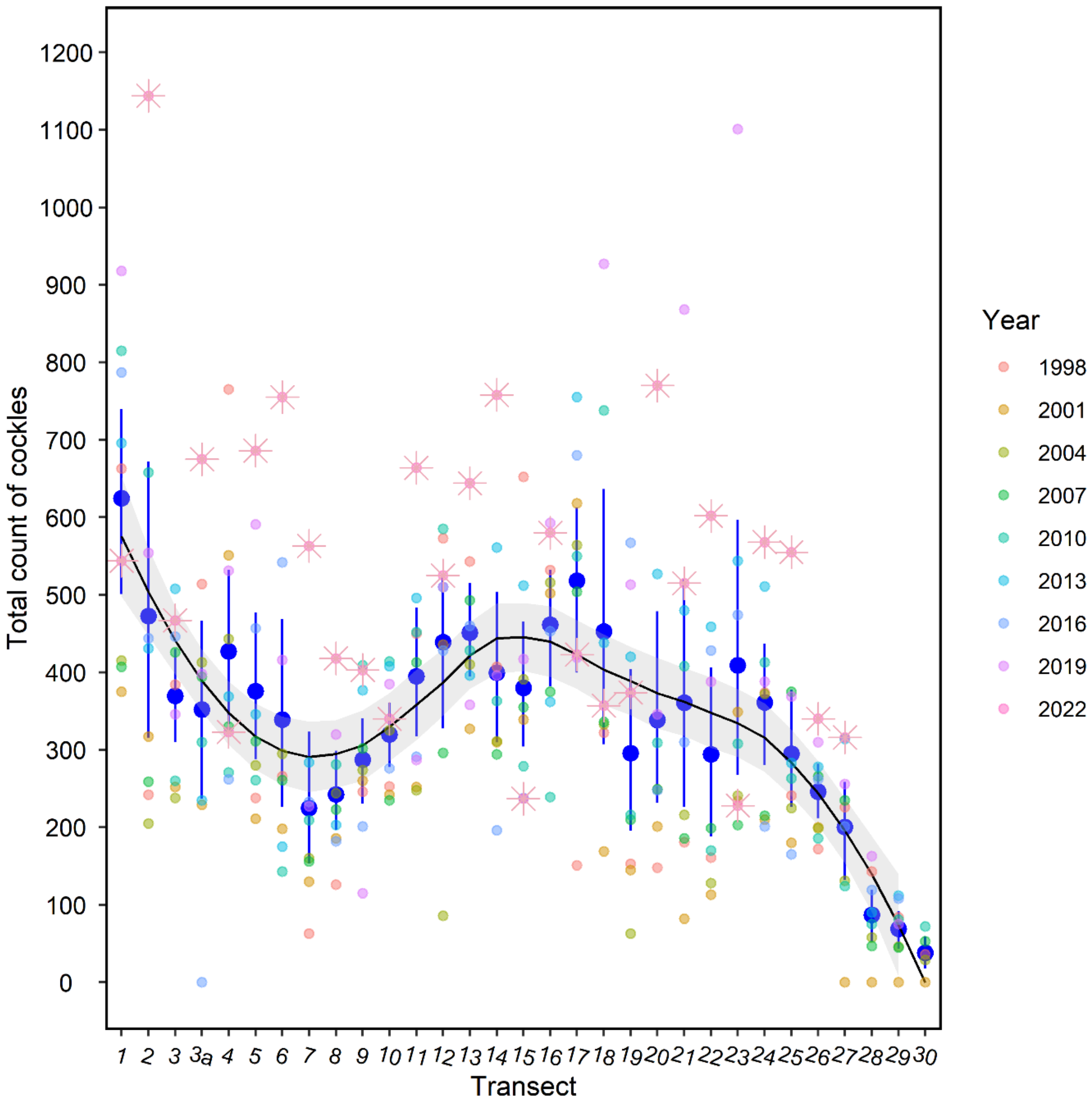

Figure 3-2: The total number of cockles (adults and juveniles combined) sampled from each transect in surveys between 1998 and 2022. Counts shown as coloured filled circles, 2022 counts shown as dark pink stars, means for all years (dark blue filled circles) and 95% confidence intervals as blue lines. 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 standard error (SE) shown in grey shading. Refer to Table 2.1 for site names for each transect. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, transects 28 and 29 (Camborne) were not sampled in 2022,and only half of Transect 13 sampled in 2019.

3.1 Cockle densities and population size

3.1.1 Cockle densities

In 2022, cockle counts per quadrat ranged from zero to 289 per 0.1 m^2 (at transect 2, lower-mid tide, Mana), similar to 2019 (279 per 0.1 m^2 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 2022, no cockles were recorded from 7% of quadrats. Mean cockle density in 2022 (40.4 per 0.1 m^2, 99% CI 39.6–48.4) was significantly higher than in 2019 (38.1 per 0.1 m^2, 99% CI 34.6–41.7), and higher than in 2013 (33.6 per 0.1 m^2, 99% CI 30.9-36.2). Mean cockle density in 2022 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.

3.1.2 Population size

Population estimates using Method 1 are consistently lower than those using Method 2 (transect counts weighted by transect length) (see Tables 3–1 & 3–2, Figure 3–3). Both methods show upward trends from 2007 to 2013, a decrease between 2013 and 2016, and marked increases between 2016 and 2022 (Table 3–1, Figure 3–3). The CVs of the survey estimates have been consistently low, 3–6% (Table 3–1).

Pairwise multiple comparisons for significant differences (Holm-Sidak method undertaken at a significance level of 0.05) among population estimates (using Method 1) between triennial surveys are given in Table 3–2 and show the same pattern. Cockle population size was significantly higher every triennial survey between 2004 and 2013, lower between 2013 and 2016, and higher each survey 2016 to 2022.

In 2022, the mean cockle population size estimated using Method 1 was 15.5% higher than in 2019 and 17.6% higher estimated using Method 2. Since 2001 the mean cockle population size has increased between 93.7% and 121.1%. 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 patchy distributions. The 2022 mean population size using Method 1 is 84.1% of the first and highest estimate in 1976.

Table 3-1: Cockle densities and population estimates for cockles in Pāuatahanui Inlet between 1976 and 2022. Estimates from Method 1 (unweighted data) and Method 2 (weighted data) given separately. The 2019 estimates given for all transects sampled; however, transect 13 was partly completed. 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	2022
Method 1												
No. transects	75	30	30	31	31	31	31	31	30	28	29	28
No. quadrats	NA	NA	NA	372	372	372	372	372	360	336	354	336
Max number per quadrat	280	168	191	273	118	95	112	150	153	176	279	289
Total numbers of cockles	15633	7976	6484	9264	7807	8124	8653	10290	12080	9569	13485	14774
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	44.0
Cockle population (millions)	523	222	180	257	199	218	233	277	336	288	381	440
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	396–484
Method 2												
Mean population (millions)	NA	NA	NA	316	240	236	270	335	369	309	409	465
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	458–471

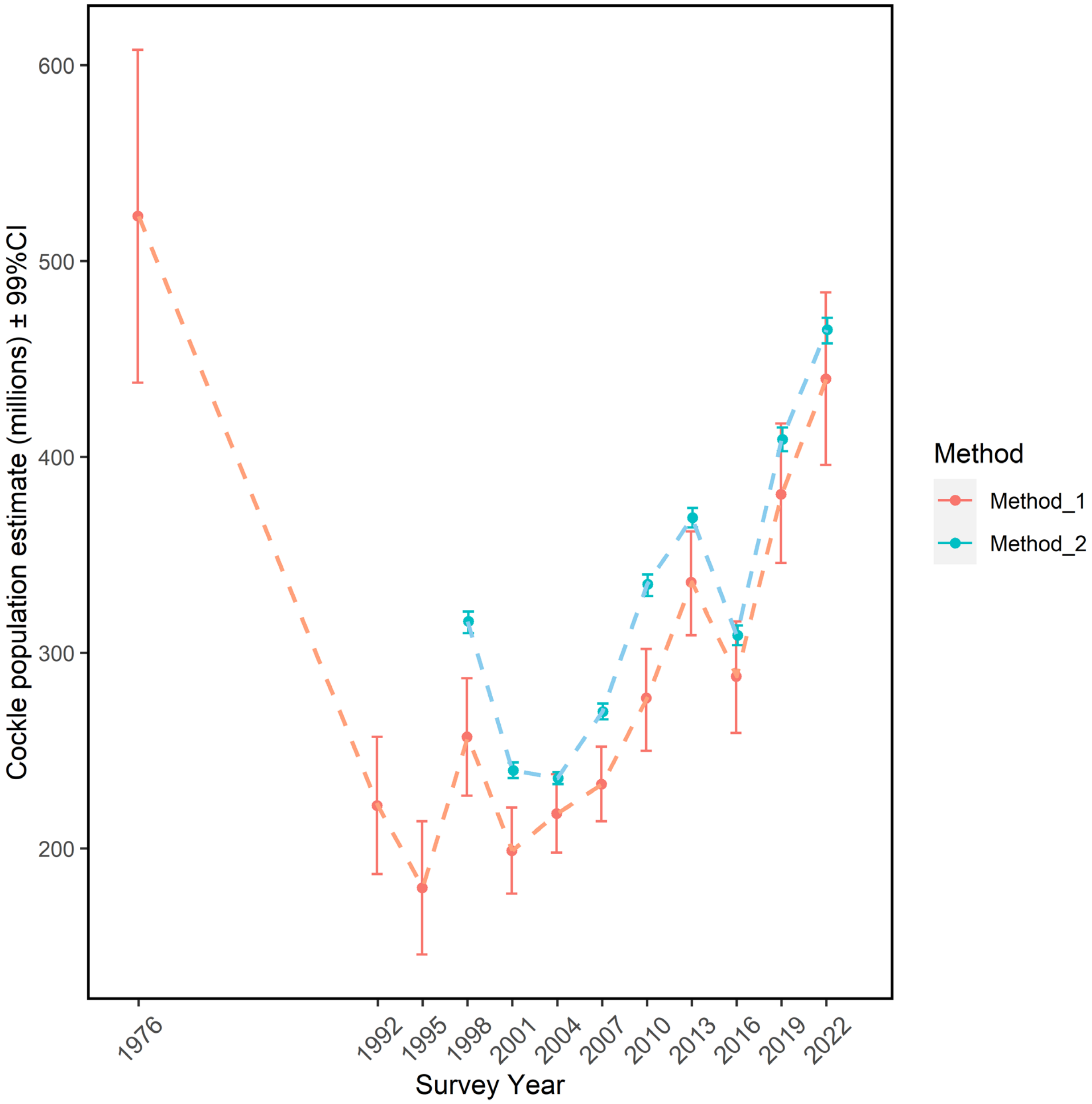

Figure 3-3: Estimates of total cockle population size and 99% confidence intervals for Pāuatahanui Inlet, 1976–2022. The initial survey in 1976 (Richardson et al. 1979) used a different survey design, surveys since 1992 (carried out by the Guardians of Pāuatahanui Inlet) have used the same survey design 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 2022 using cockle counts by quadrat (Method 1), at a significance level of 0.05. Significant differences shown with blue shading and differences between survey years that are not significantly different given as "NS" (and with orange shading).

Survey years	1998	2001	2004	2007	2010	2013	2016	2019
2001	0.059	-	-	-	-	-	-	-
2004	NS	NS	-	-	-	-	-	-
2007	NS	NS	NS	-	-	-	-	-
2010	NS	0.022	0.057	NS	-	-	-	-
2013	0.013	< 0.001	< 0.001	< 0.001	NS	-	-	-
2016	NS	0.0403	NS	NS	NS	NS		-
2019	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NS	< 0.001	-
2022	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.004	< 0.001	0.003

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, 2019, and 2022. Trends in median densities varied by site. Median densities were broadly similar across the four surveys at Mana, Pāuatahanui, and Kakaho. Trends in median densities increased at Seaview Road, Brown's Bay, Duck Creek, Bromley, Motukaraka , Motukaraka West, and for those transects sampled at Camborne (Figure 3–4).

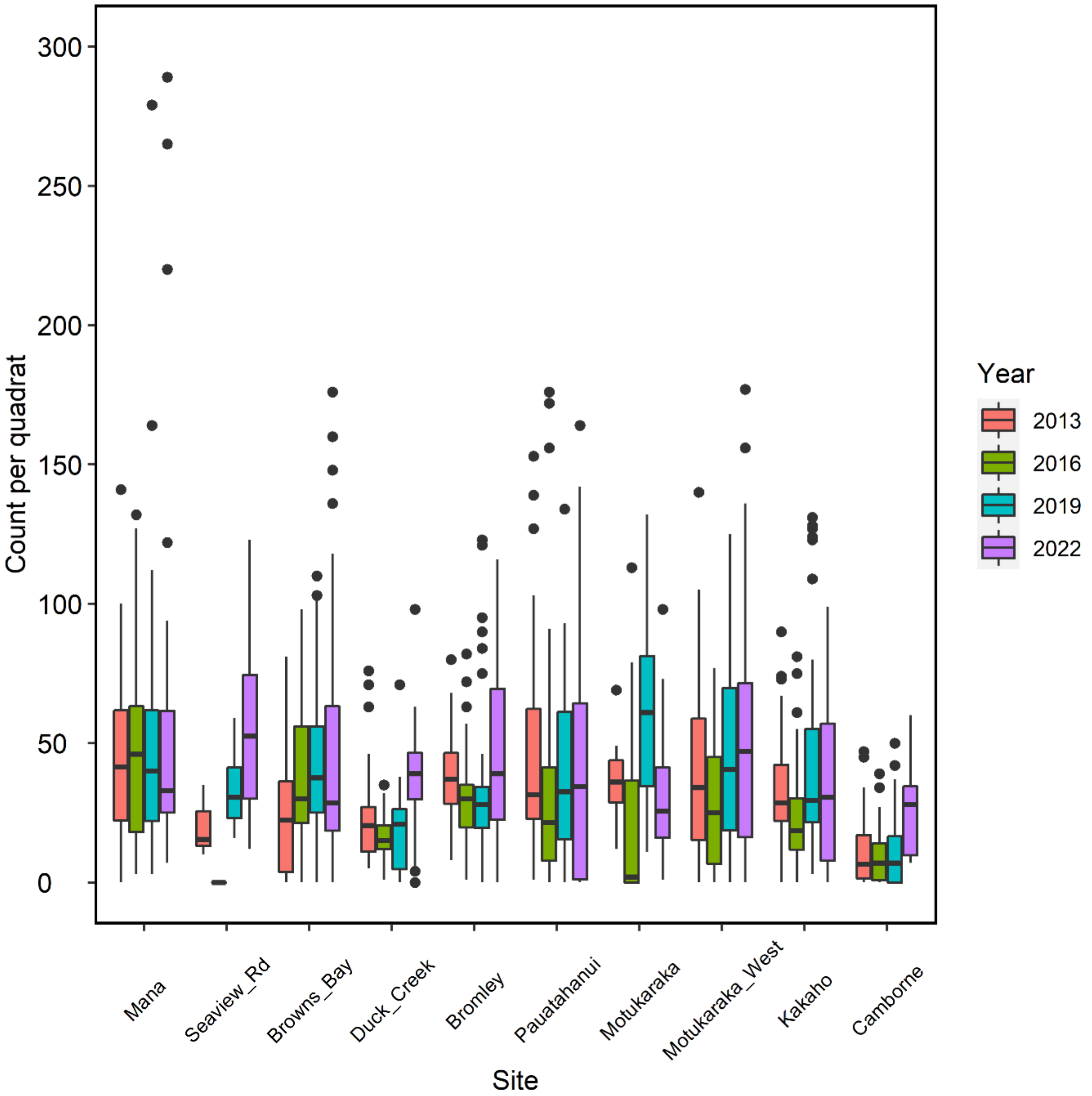

Figure 3-4: Box plots of the total numbers of cockles per quadrat (0.1 m^2) by site in 2013, 2016, 2019, and 2022. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

Boxplots of cockle numbers per quadrat by site and year show similar trends to the population estimates with medians generally increasing until 2013, declining in 2016, increasing further in 2019, and generally increasing in 2022, except for Motukaraka (Figure 3–5). The large numbers of outliers (represented by filled black circles) show high variation in quadrat densities at each transect and year reflecting high variation in the distribution of cockle densities at small-spatial scales.

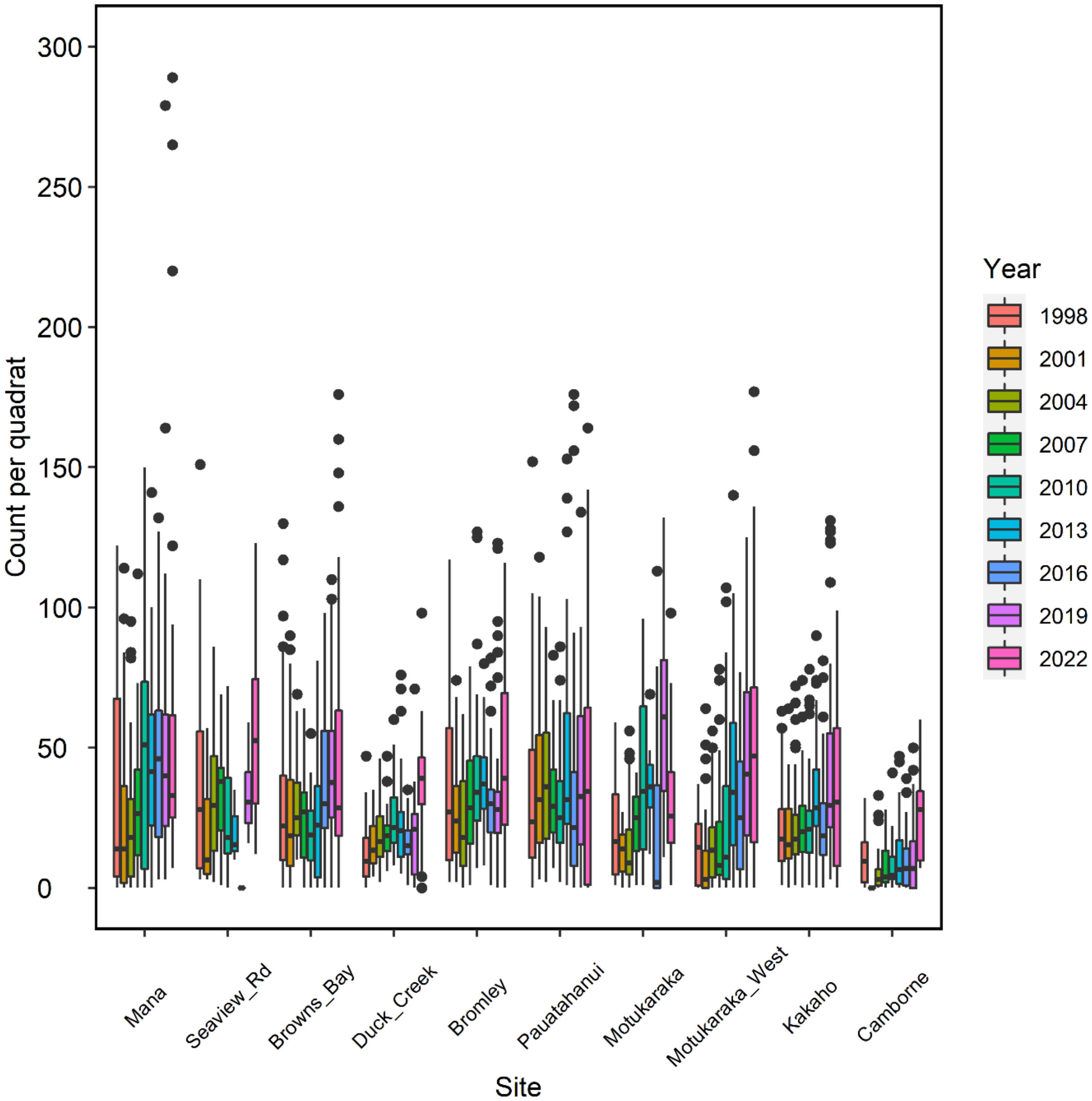

Figure 3-5: Box plots of the total numbers of cockles per quadrat (0.1 m^2) by site between 1998 and 2022. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

Figure 3–6 shows bubble plots of the distributions of cockle densities by site and by size class (juvenile and adults) since 1998. Adult cockles (greater than 10 mm in length) densities have remained high at Mana, Brown's Bay, Bromley, Pāuatahanui and Kakaho since 1998. Motukaraka West shows an increasing trend over time.

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, Motukaraka, Motukaraka, West, and Kakaho since 1998. Trends in juvenile densities have remained similarly low, fluctuating slightly without trend at Seaview Road, Duck Creek, and Camborne (Figure 3–6).

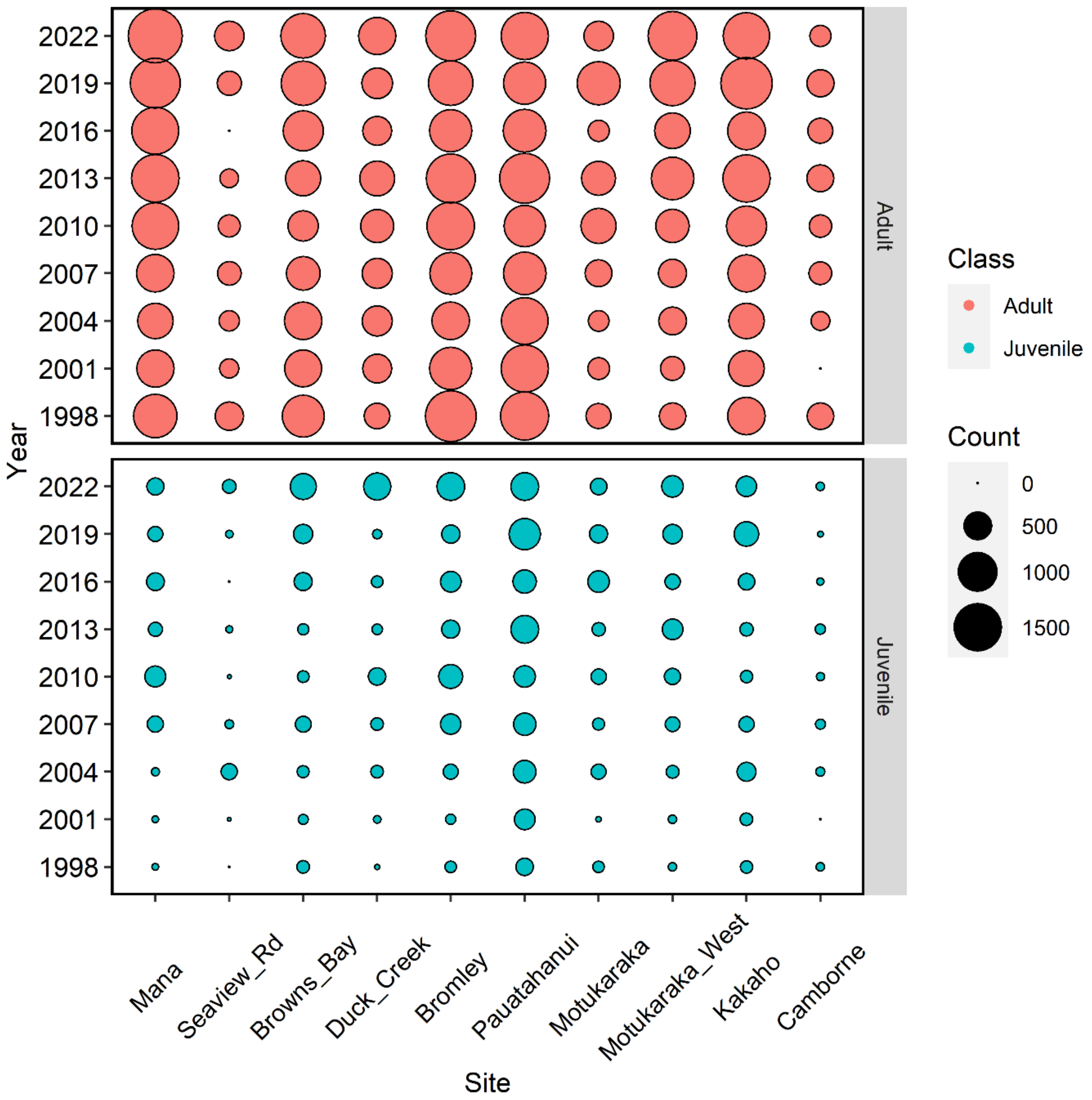

Figure 3-6: Bubble plot representing the changes in the counts of adult (greater than 10 mm in length) and juvenile cockles (10 mm and smaller in length) at each site between 1998 and 2022. The size of the bubbles scaled to total count per site. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

3.1.4 Cockle densities by tidal height

Median cockle densities were broadly similar across all tidal heights in all four of the most recent surveys (2013, 2016, 2019 and 2022) (Figure 3–7). In 2022, counts were higher at all tidal heights than in previous years. Consistently higher counts were recorded from upper (UMT) and lower mid-tide (LMT) quadrats in all years. In 2022, low tide (LT) quadrats recorded higher counts than in previous years.

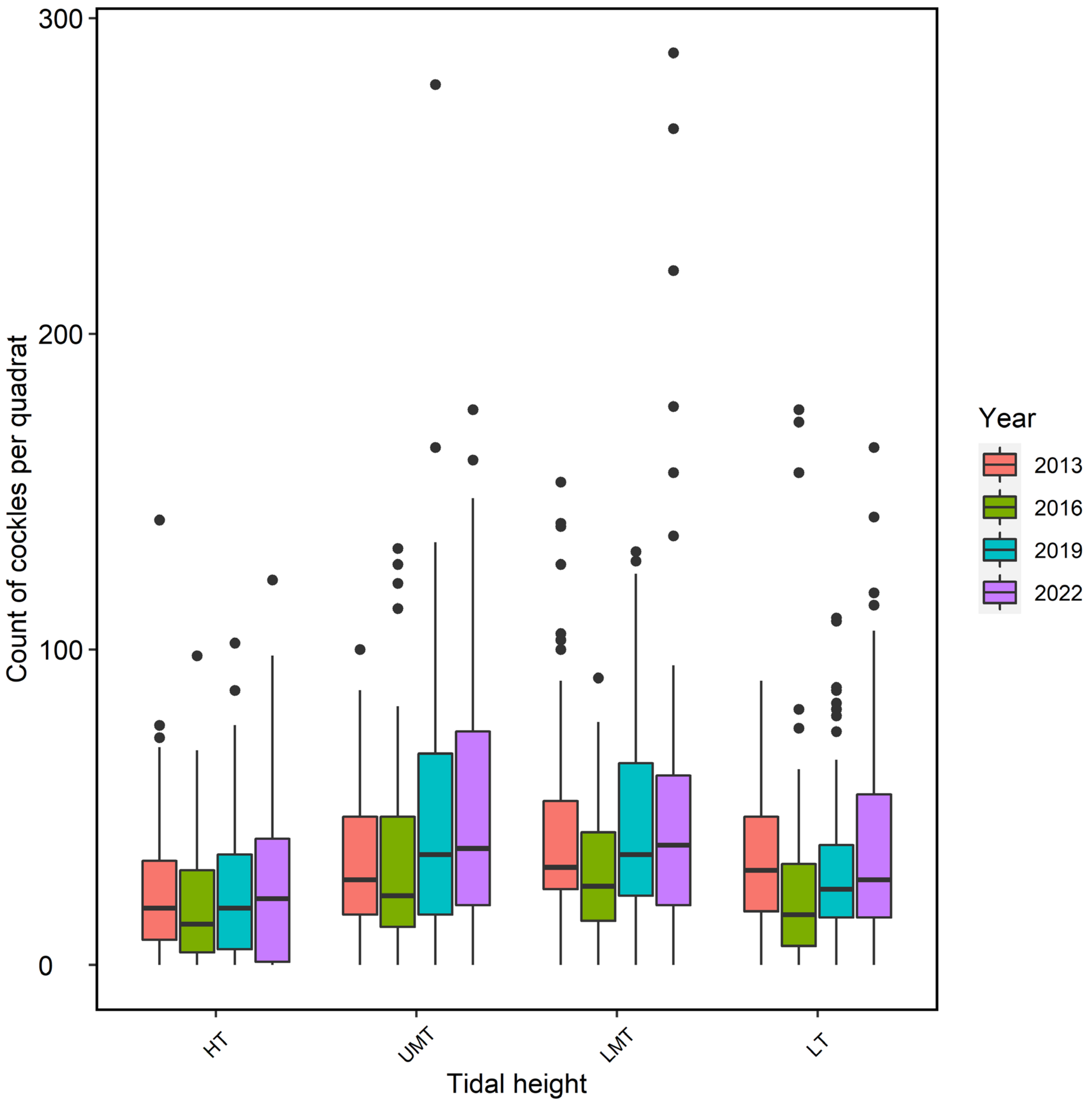

Figure 3-7: Boxplots of the numbers of cockles in 0.1 m^2 quadrats by tidal height for years 2013, 2016, 2019, and 2022. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

Variation in cockle counts by quadrat was higher at the site than tidal height level (Figure 3–8) for all four surveys (2013, 2016, 2019 and 2022) (Figure 3–8). In 2022, cockle counts were higher at all tidal heights for Seaview Road, Brown's Bay, Pāuatahanui, Kakaho and Camborne except for the low tide (LT) quadrats at Camborne where counts were generally lower. Cockle counts at Duck Creek were similarly low at all tidal heights and for all four surveys except for high tide (HT), Figure 3–8.

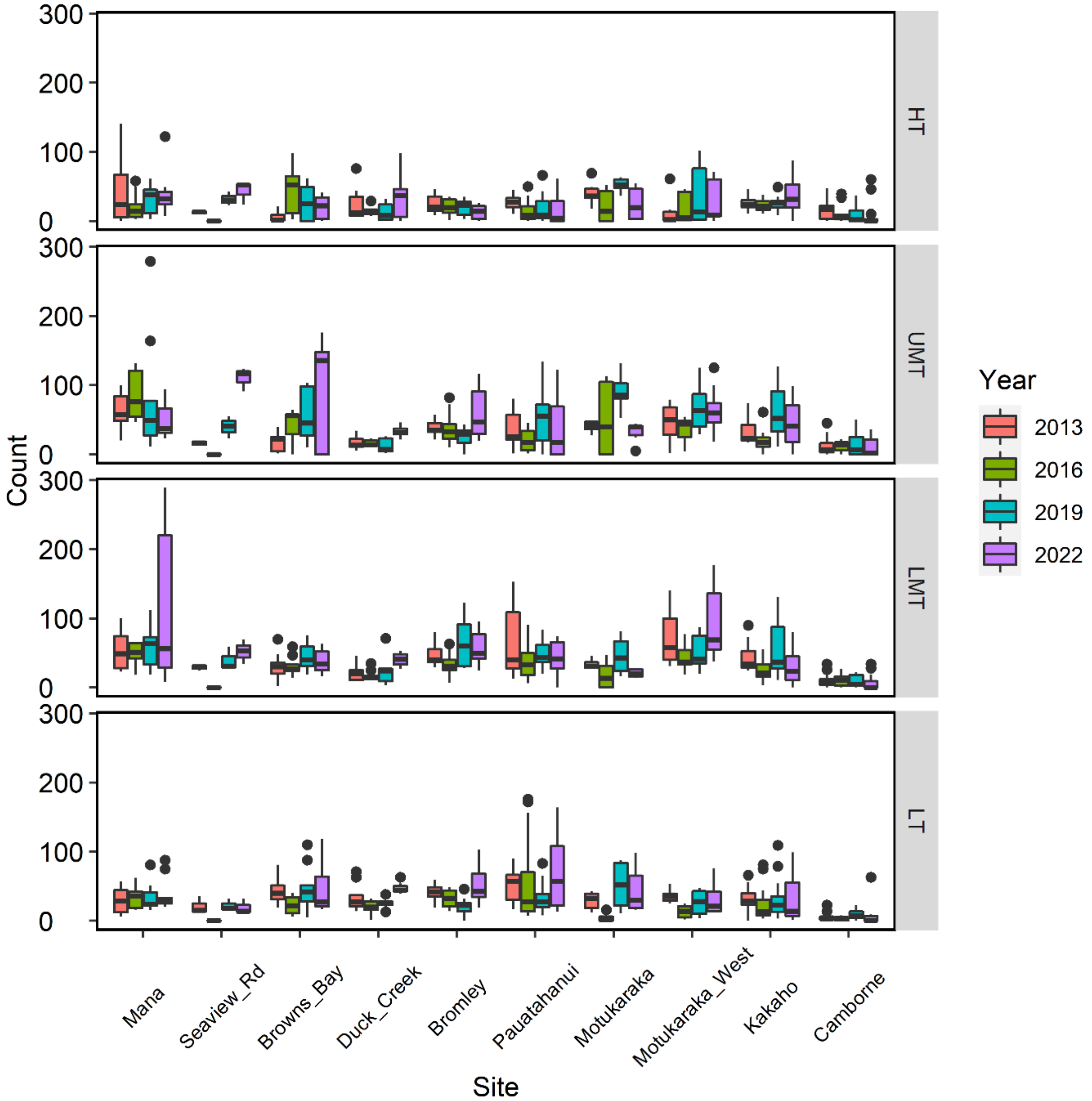

Figure 3-8: Boxplots of the numbers of cockles in 0.1 m2 quadrats by tidal height and site for years 2013, 2016, 2019, and 2022. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers are 10th and 90th percentiles, and outliers are shown as filled black circles. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

Spatio-temporal changes in cockle densities between 1998 and 2022, 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 Camborne, and high at Pāuatahanui. Cockle density has been lower and more consistent at the high tide (HT) than the lower three tide levels. The highest counts from 1998–2022 have 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. Cockle densities show the greatest patchiness at low tide, particularly before 2007.

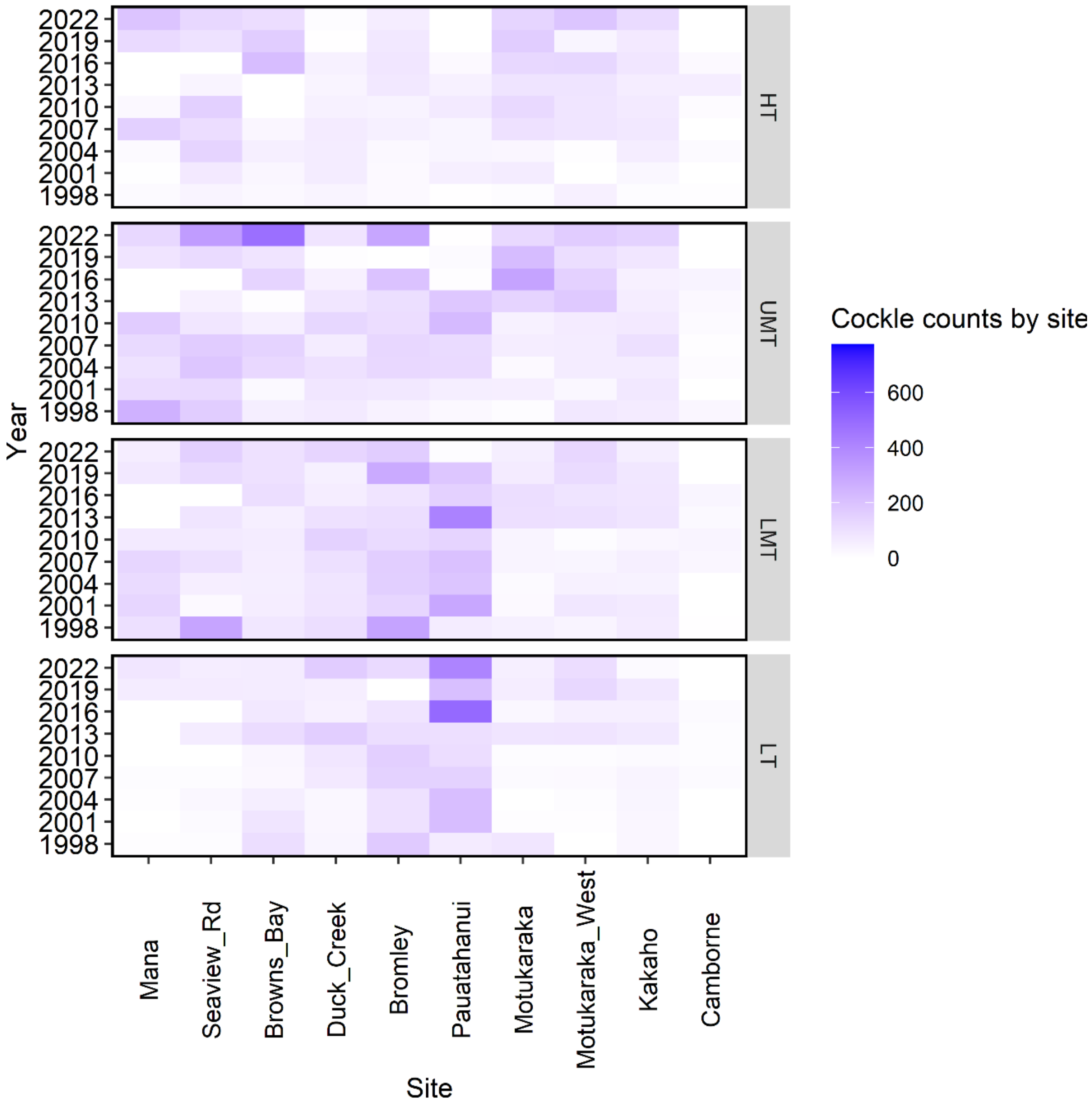

Figure 3-9: Heat map plots representing the changes in cockle counts at each site between 1998 and 2022 by tidal height. High tide (HT), upper-mid tide (UMT), lower-mid tide (LMT), and low tide (LT). Cell colour intensity is scaled to total count per site. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

3.2 Cockle size frequencies

Cockles sampled in the intertidal zone of Pāuatahanui Inlet between 2013 and 2022 ranged in length from 3 mm to 52 mm (Figure 3–10). In 2022, the largest cockle was 52 mm in length, the same as for 2016 and 2019, 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, was broadly similar between 2013 and 2019; however, the 2022 percentage size frequency shows fewer large cockle over 20 mm in length relative to between 2013 and 2019 (Figure 3–10). Histograms of size (length) frequencies of cockles for all sites combined for each of the triennial survey between 1998 and 2022 are shown in Appendix G.

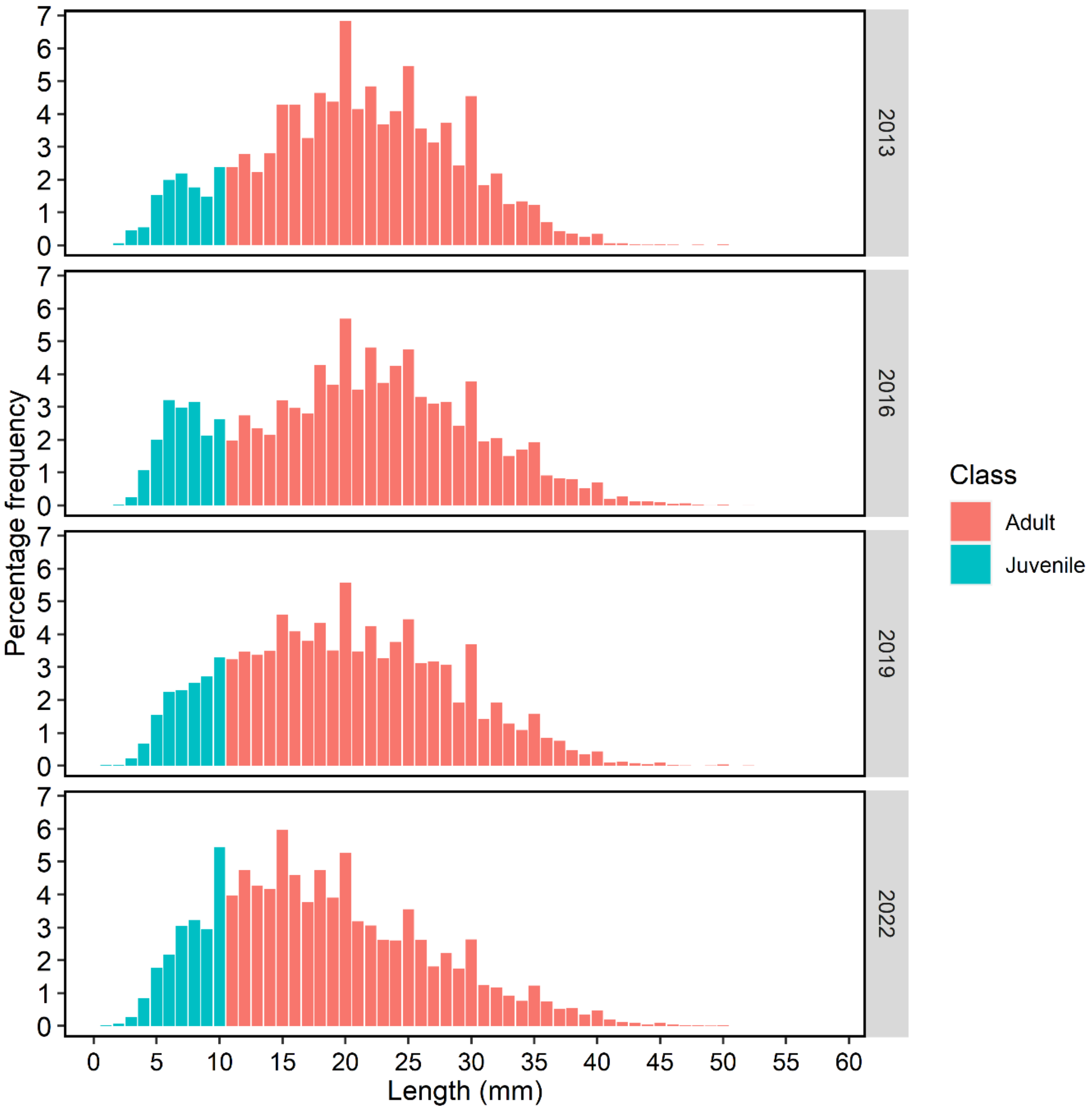

Figure 3-10: Percentage length frequencies of cockles sampled in the intertidal zone of Pāuatahanui Inlet in 2013, 2016, 2019, and 2022. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

The cumulative percentage length frequencies 1998–2022 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 show proportionately large cockles in 1998 and 2001, and broadly similar and smaller cockles between 2004 and 2019 (Figure 3–11). In 2022, there were proportionately more smaller cockles in the population, the cumulative percentage length frequency in 2022 shows that 80% of cockles were 25 mm in length or smaller (Figure 3–11). Although the size range of cockles was similar between 1998 and 2022, in 2022, the median size was smaller (Figure 3–12).

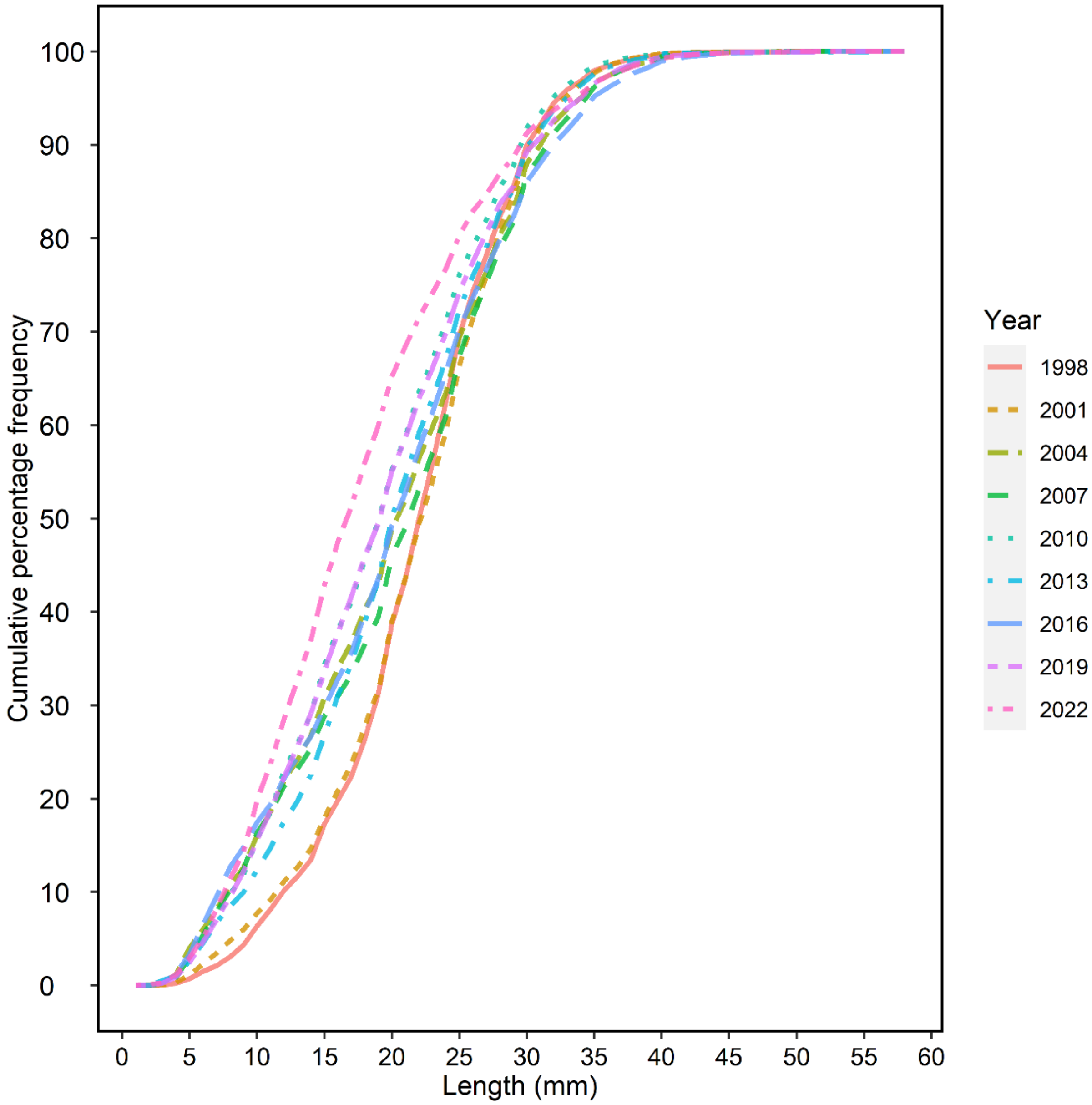

Figure 3-11: The cumulative percentage length frequencies of cockles sampled in the intertidal zone of Pāuatahanui Inlet between 1998 and 2022. 2022 is shown as a dot-dash pink line.

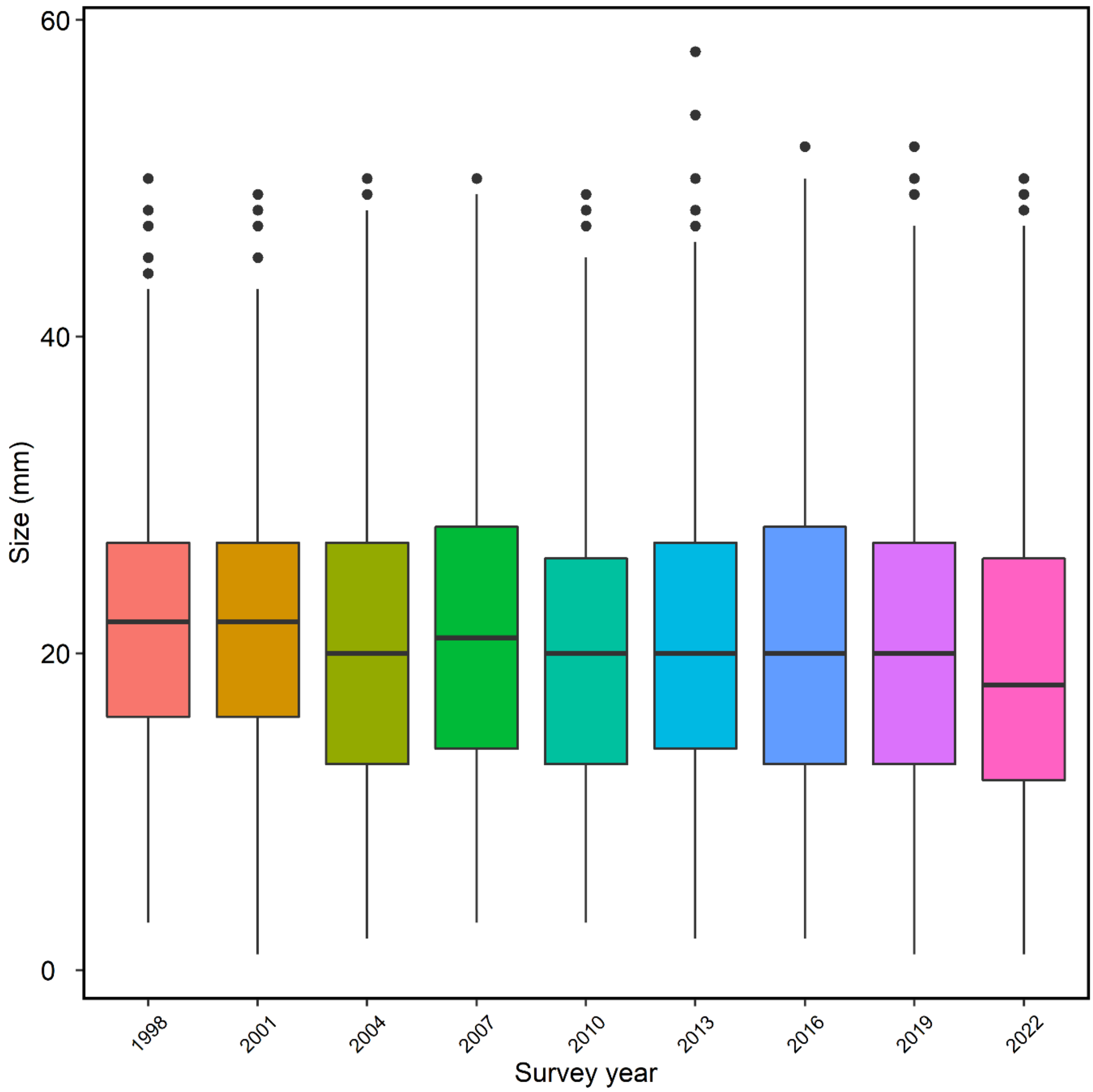

Figure 3-12: Boxplots of the sizes of cockles in Pāuatahanui by survey year 1998–2022. Boxplots show medians (solid horizontal black lines), filled boxes represent 25th to 75th percentiles, whiskers the 10th and 90th percentiles, and outliers are shown as filled black circles.

3.2.1 Percentages of juvenile cockles

The percentage of juvenile cockles in the Pāuatahanui Inlet population increased from 15.6% in 2019 to 19.8% in 2022, the highest level since 1992. Juvenile cockles represented 17.4% in 2016, 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 (Figure 3-13).

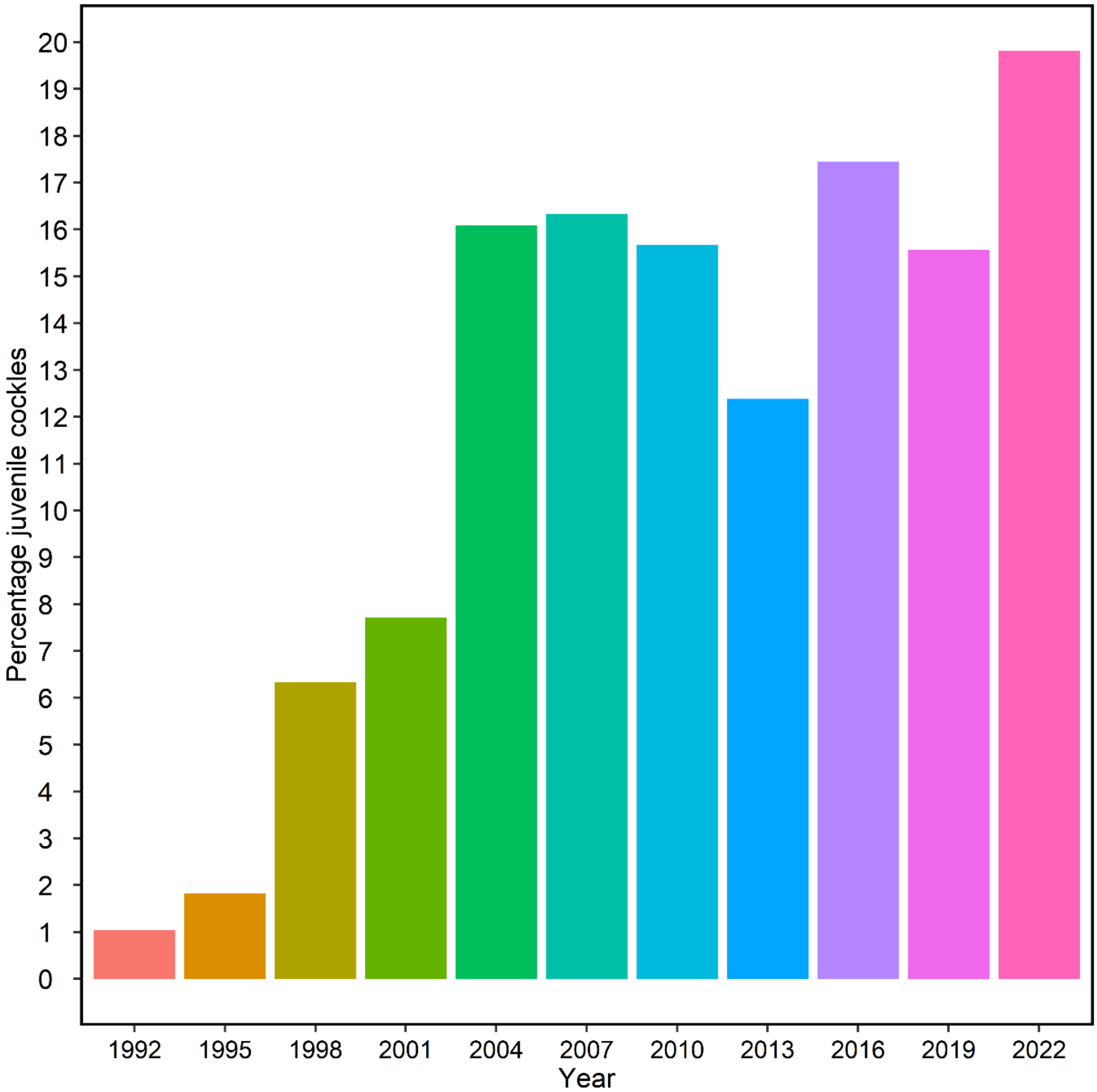

Figure 3-13: Juvenile cockles (10 mm and smaller in length) as a percentage of total cockle population, 1992–2022.

3.2.2 Cockle size frequencies by site

The size structure of cockles varied among sites around Pāuatahanui Inlet in 2022 (Figures 3–14 & 15). Size distributions ranged from 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).

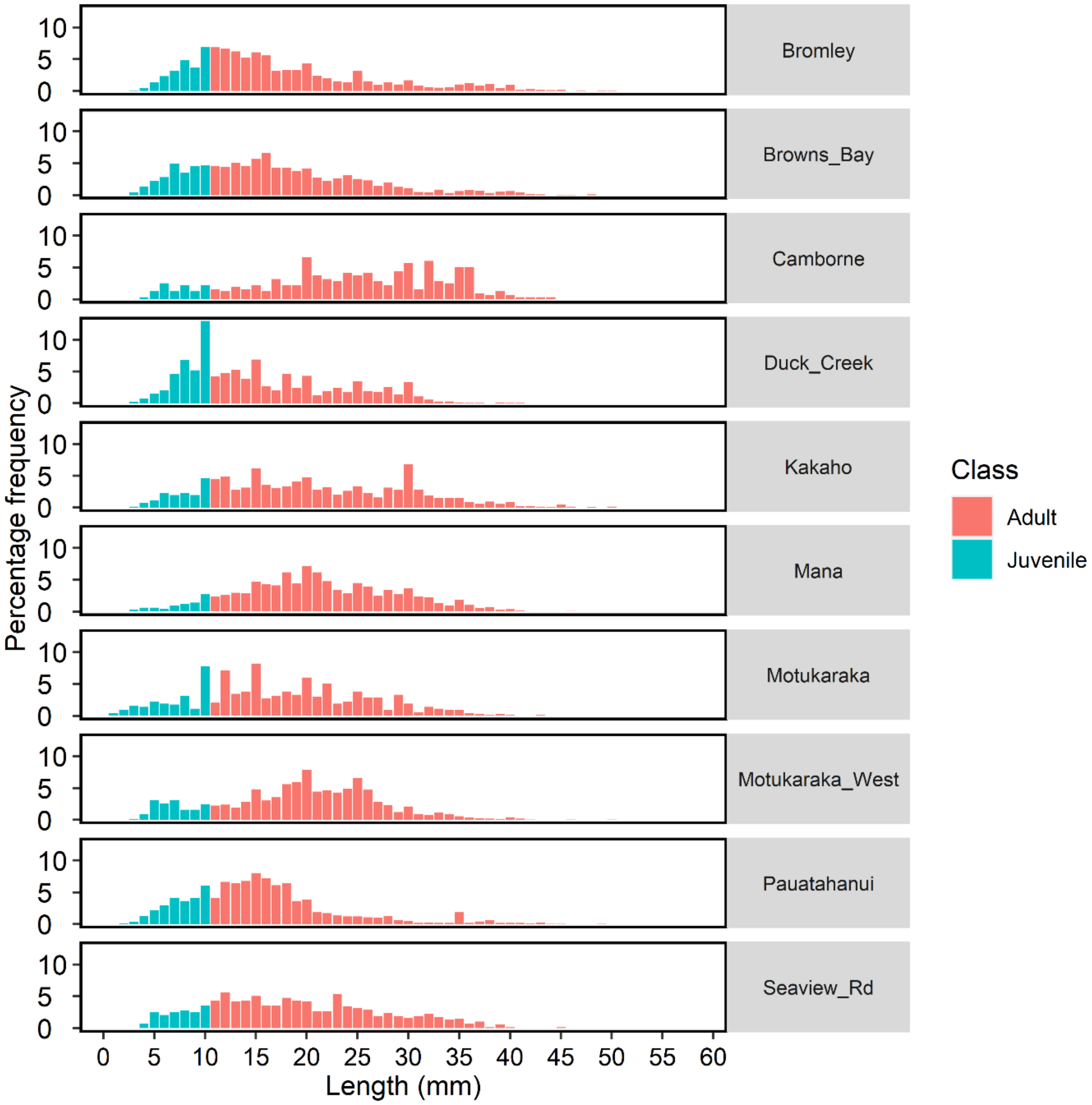

Figure 3-14: Histograms of the size (length) frequency of cockle by sites from the 2022 survey. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

Bromley, Camborne, Duck Creek, Kakaho, Motukaraka and Pāuatahanui all show some level of modal structure between 2016 and 2022 (Figure 3–15). In 2016 Motukaraka, Bromley, and Pāuatahanui show high percentages of juveniles, and Camborne and Mana show higher percentages of large cockles. In 2019, Pāuatahanui shows a high percentage of juveniles, and Camborne and Mana show higher percentages of large cockles. In 2022, Duck Creek, Kakaho, Motukaraka and Pāuatahanui show high percentages of juveniles, and Camborne, Kakaho, Mana, Motukaraka, and Seaview Road show higher percentages of large cockles (Figure 3–15).

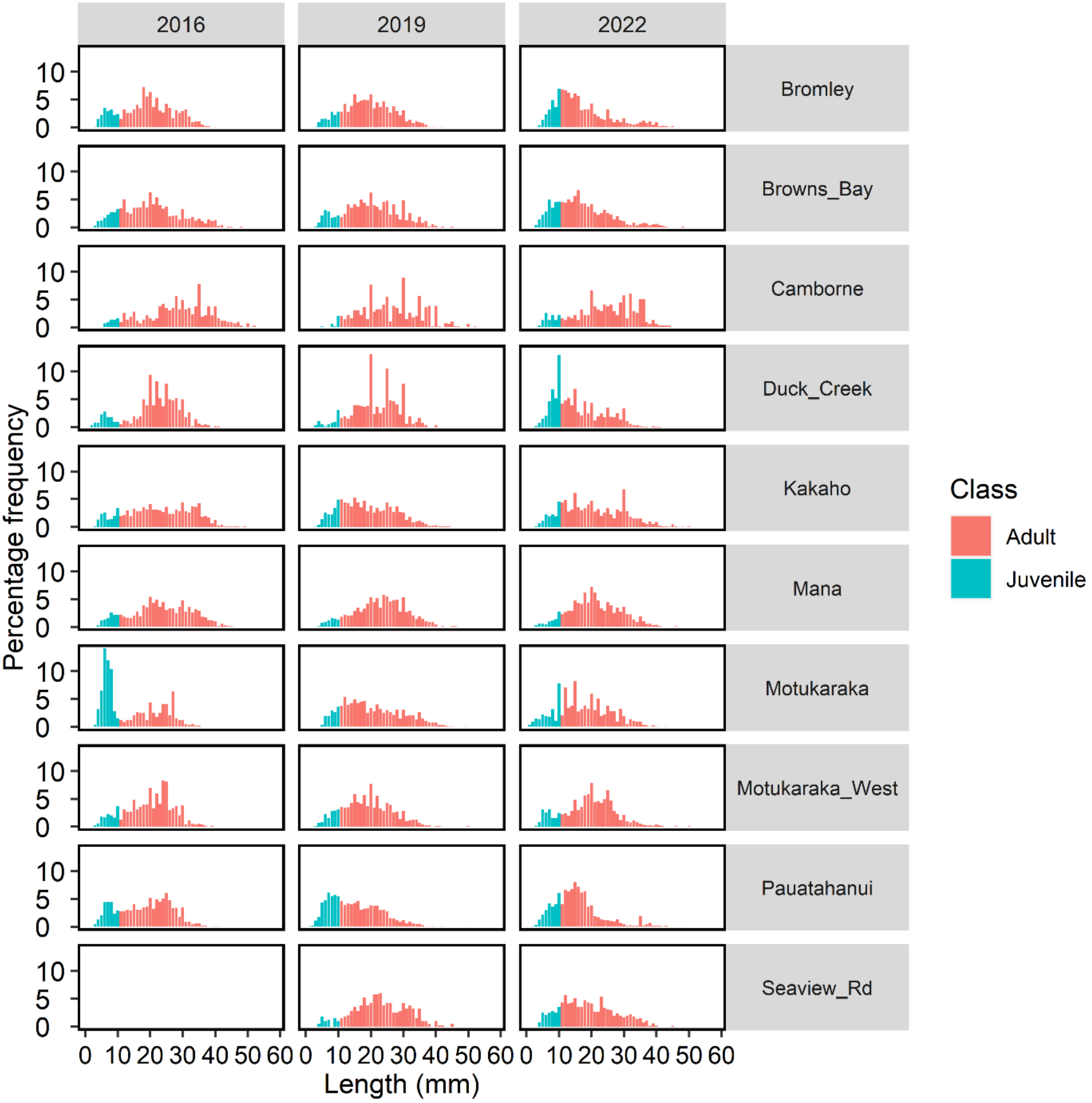

Figure 3-15: Histograms of the size (length) frequency of cockle by sites from the 2016, 2019, and 2022 surveys. Juvenile cockles classified as those 10 mm in length and smaller shown in blue and adults greater than 10 mm in length shown in red. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019, and transects 28 and 29 (Camborne) were not sampled in 2022.

The cumulative percentage frequency identified differences in cockle size distributions between sites in 2022 (Figure 3–16). The percentages of cockles 30 mm in length and less ranged from 77.7% at Camborne to 97.2% at Duck Creek. The juvenile cockles (10 mm in length and smaller) at Pāuatahanui represented 24.7%, while those cockles 25 mm in length and smaller 90.9%. At Duck Creek, juvenile cockles represented 34.0% while those cockles 25 mm in length and smaller 86.2% (Figure 3–16).

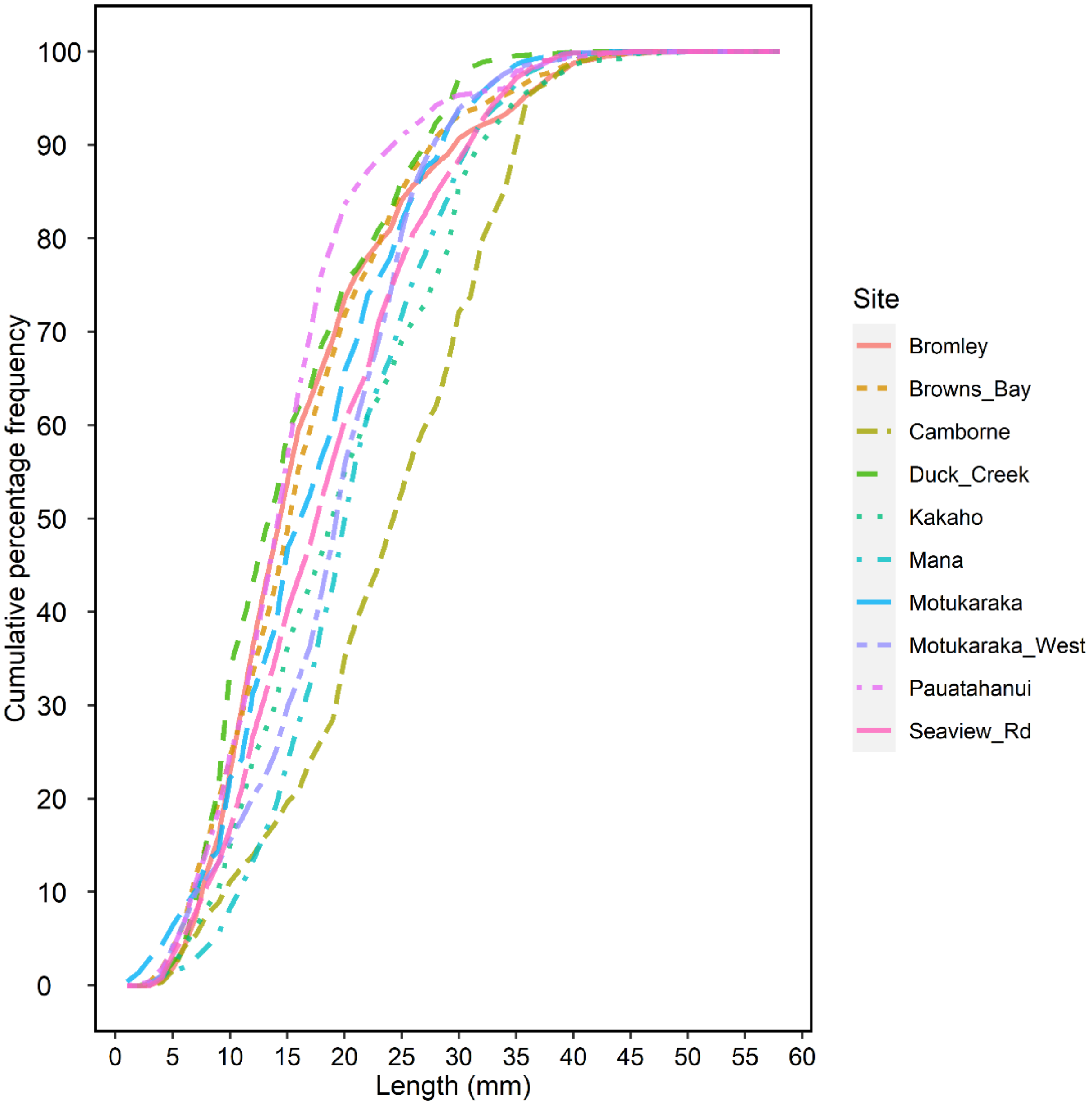

Figure 3-16: Cumulative percentage frequencies of cockle lengths by site sampled in 2022. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019**, and** transects 28 and 29 (Camborne) were not sampled in 2022.

Cumulative percentage frequencies 1998–2022, by tidal height (Figure 3–17) show increases in the proportions of larger cockles with lower tidal levels. High tide (HT) and upper mid-tide (UMT) levels contained fewer small-sized cockles in 1998 and 2001 than in later surveys and more small-sized cockles from 2016 to 2022. The size structures of cockles at lower mid-tide (LMT) were broadly similar across years, except for more small-sized cockles at low tide (LT) in 2022 (Figure 3–17).

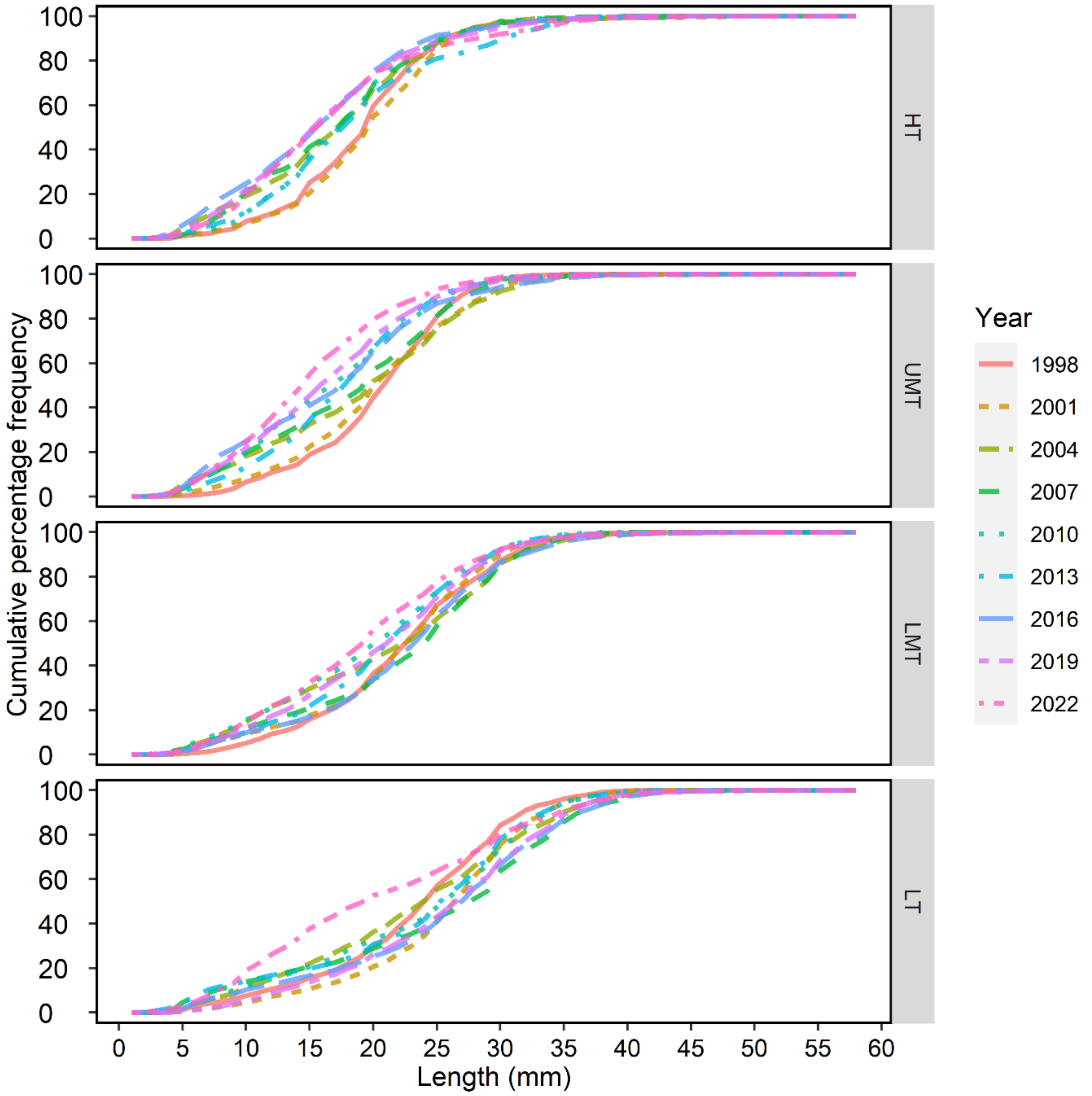

Figure 3-17: Cumulative percentage frequencies of cockle lengths by tidal height for surveys between 1998 and 2022. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019**, and** transects 28 and 29 (Camborne) were not sampled in 2022.

4 Discussion

4.1 Survey comparability

4.1.1 Consistency of sampling and 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 differences in sampling methods and numbers of samples. The 2022 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 the sampling for the 2022 survey was undertaken on Sunday 6th of November 2022. Outstanding sampling was completed after the survey. Twenty nine transects were sampled, transects 28 and 30 were not sampled in 2022. Additionally, data from transect 29 were uncertain and omitted from the data summaries and population estimates. These data comprised 336 of the 372 quadrats available. The effect of the missing data on estimates of population size is not known, however, unlikely to influence long term trends.

Transect 30 was not sampled between 2013 and 2019 because of the degradation of its intertidal area due to its location next to the Camborne Jet Ski Club and, because of that, a perceived lack of comparability to the early surveys of the 1990s. 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 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 were not completed on the day and two were not sampled at all.

The high muddiness of substrates at some transects may have affected sampling 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 juvenile cockle densities.

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 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. Both Method 1 and Method 2 show similar trends (see Figure 3–3). The population estimates in 2022 using Method 2 was 5.7% higher than that from Method 1.

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 population sizes for surveys between 1998 and 2022 (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 CV of the population estimate) since 1998 have been low (see Table 3–1). These low CVs allow more reliable detection of differences in population size between surveys to be identified. The population estimate in 2022 using Method 1 is significantly higher than for all previous estimates from 1998, except for the decline in 2016 after the floods and earthquake (see Table 3–2).

Errors associated with the misidentification of species and from sampling error, are thought to be 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. Cockles can occur at high densities below low water. 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 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 2016 significantly increased the fine sediment over the intertidal survey area. The heavy rain that followed the 7.8 (Mw) Kaikoura earthquake on 14 November 2016 also 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 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). The experiments of (Norkko et al. 2002) 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.

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 cockles and explain the relatively low cockle densities at these sites.

Sediment plate monitoring of Pāuatahanui Inlet in 2022 found the 10-year mean annual sedimentation rate shows high deposition in the Pāuatahanui Inlet subtidal zones, and moderate increases in the intertidal zones (Stevens et al. 2022). Sediment conditions since the 2016 floods remain severely degraded and may cause adverse ecological effects, especially in the subtidal zone. Changes in the intertidal sediments are spatially variable. Fine sediment (mud) deposition has increased at the Pāuatahanui site (Transects 14–17), possibly as a result of fine sediments being transported from the subtidal zone (see results from sites P8 & P9 in Stevens et al. 2022). There has been some recovery from the widespread intertidal deposition of muds recorded in 2020 at Kakaho (Transects 24 & 25) and at Duck Creek (Transects 7–9) (Stevens et al. 2022).

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 muds.

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 2022, as in previous surveys, had high densities of juvenile cockles (see Figure 3–6). Juvenile cockles (10 mm in length and smaller) in November 2022 are likely to be spat that have settled and survived during the spring and early summer of 2022 (0+ age class).

The percentages of juvenile cockles since 2016 is similar or higher than those recorded from surveys before the 2016 floods, and this trend is not consistent with the expectation of relatively high mortality of small cockles (compared to the adult cockle population) from the mud deposition and suspended sediment from the floods. The increasing trend in cockle densities and population size since 2001 suggest consistently significant cockle recruitment and survival of small cockles. One explanation for the high numbers of juvenile cockles in 2016, 2019, and 2022 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. The relatively small decline in the percentages of juvenile cockles in 2019 is likely to be caused by the increase in fine sediments from the 2016 floods; and the increase between 2016 and 2022 may be in part due to overall recovery of habitat as muds are winnowed away and redistributed within the inlet. 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 19.8% 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. 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:

- The proportion of the total Inlet-wide population that occurs subtidally and the contribution that these subtidal cockles make to recruitment of juveniles cockles in the intertidal zone.

- Extensive movements of juvenile cockles have been documented, but individuals over 25 mm length move 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.
- 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 2022, less than half of the intertidal population (48.7%) was sexually mature (compare with 54–61% between 2014 and 2019). These percentages 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 4500 per m^2 (Fisheries New Zealand 2019). Mean cockle density in Pāuatahanui Inlet in 2022 was 440 per m^2 (99% CI 396–484), higher than in 2019 (381 per m^2, 99% CI 346–417), and the highest since 1992.

Population estimates 1998-2022 using Method 1 and Method 2 have shown similar trends, albeit estimates from Method 1 are consistently lower than from those using Method 2 (transect counts weighted by transect length), see Figure 3–3. With the effects of the floods and earthquake in 2016 considered, both methods show upward trends from 2004 (Table 3–1, Figure 3–3). 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 heightened mortality (or any combination of the three factors) cannot be determined. The higher cockle densities and population sizes in 2022 are supported by the increases in cockle densities recorded at intertidal sites in Pāuatahanui Inlet during fine scale monitoring of macrofauna in 2022 (Forrest et al. 2022). The 2022 mean population size using Method 1 is 84.1% of the first and highest population estimate from the 1976 survey.

Changes in the distribution of cockle densities amongst transects between 2019 and 2022 may affect estimates of population size. These changes may be driven by changes in the accretion or erosion of muds deposited by the 2016 floods. There was an increase in muds at the Pāuatahanui site (Stevens et al. 2022) where cockle densities had decreased in 2022. There has been some recovery in 2022 from the widespread intertidal deposition of muds recorded in 2020 at Kakaho where densities changed markedly between HT, UMT, LMT, and LT tidal zones, and at Duck Creek where there was a decrease in muds and increase in cockle densities at all but the LT zone (Figures 3–8 and 3–9).

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 patchy distributions. The 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.

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 (12.4–19.8% of the populations) suggest successful settlement of larvae and good survival of spat, and or the immigration of juvenile cockles from subtidal areas. High percentages of cockles are above spawning size 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. However, any interaction between intertidal and subtidal cockle populations is not known. Therefore, the increase in muds in the subtidal zone and any effects on cockles there, and flow-on effects to the intertidal population cannot be evaluated.

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 for determining future changes.

5.1 Options

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 sites, Global Positioning System positions (GPS) of each tide level on each transect would be helpful for sampling, and especially for mapping.

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. Additional recommendations include:

- To estimate recent mortality of cockles by counting the numbers of cockle shells and measuring their sizes. Clear shell descriptors would need to be developed to enable accurate identification of the shells of cockle that had died within the last year.
- To undertake tagging studies for growth, mortality, and movement.
- If sufficient data are available, to investigate what effects changing sediment composition and rates of sedimentation in the intertidal zone have on changes in cockle density.
- A previous suggestion "To estimate the diversity of taxa in samples" is in part covered by the fine scale monitoring programme (Forrest et al. 2022) and could be extended to give better coverage.

6 Acknowledgements

We acknowledge the contribution Professor John Wells made to these surveys before he 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 GOPI members, Conservation Volunteers, and community members who sampled Pāuatahanui Inlet in 2022, ensuring the value of this time-series of data. Thanks to the 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, Jessica Bignell and Michael Waldron) who helped with the logistics and survey preparations; thanks to Nigel Clarke and Baillie Graham (PCC) who arranged for the data to be punched. Thanks to Darren Parsons (NIWA) who reviewed this report, and to Ken Grange and Peter Horn (NIWA) whose previous reports provided the foundation for this report series.

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Appendix A 2022 Sampling instructions hand-out

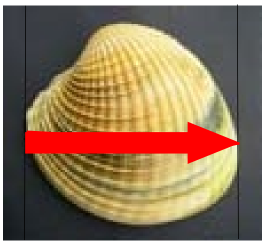
Sampling instructions

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

<u>Cockle shells have a distinctive pattern of ridges and a prominent recurved 'beak'</u>

<u>Nut Shells are much smaller than adult cockles but can be confused with juvenile cockles</u>

INSTRUCTIONS FOR DIGGING, MEASURING, TALLYING



Length (anterior-posterior axis)

- Assign one person as <u>recorder</u>. 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 <u>choose</u> 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 2022 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**

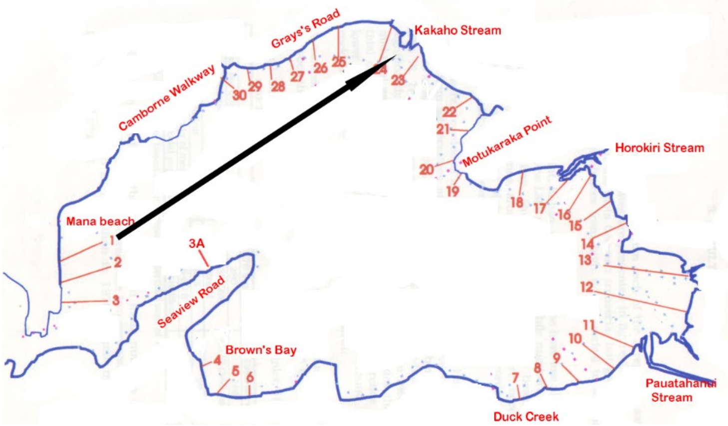
RECORD OF COMPLETED QUADRATS

	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 2022 team leader check list

GOPI cockle survey 2022–Transect 1

<u>Checklist for Team Leaders</u>

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 2022 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			
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49				49				49			
50				50				50			
Notes											

Appendix E 2022 Pāuatahanui Inlet cockle count transect location details

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide 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	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide 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
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

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide to low tide site
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
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

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide to low tide site
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
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

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide to low tide site
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	Kakaho	**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
24	Kakaho	**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

No.	Locality	Start marker description	Start Lat/long	Start NZ-map grid	Aim towards	Transect length (m)	Paces to high tide site	Paces from high tide to upper mid tide site	Paces from upper to lower mid tide site	Paces from lower mid tide to low tide site
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
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. “-“ denotes not sampled in 2022.

Transect	Site	Class	HTA	HTB	HTC	HT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	UMTA	UMTB	UMTC	UMT	Total
1	Mana	Adult	24	25	21	70	44	55	49	148	21	26	17	64	35	57	68	160	442
1	Mana	Juvenile	0	0	1	1	5	5	7	17	12	3	8	23	8	27	26	61	102
2	Mana	Adult	39	2	49	90	273	216	254	743	74	84	18	176	23	27	36	86	1095
2	Mana	Juvenile	1	5	0	6	16	4	11	31	1	4	5	10	0	1	1	2	49
3	Mana	Adult	31	41	118	190	24	22	8	54	17	29	29	75	59	31	31	121	440
3	Mana	Juvenile	1	1	4	6	5	1	0	6	3	0	3	6	7	2	0	9	27
3A	Seaview Rd	Adult	21	40	48	109	34	64	51	149	11	32	14	57	62	88	97	247	562
3A	Seaview Rd	Juvenile	3	12	6	21	0	5	2	7	1	0	0	1	29	29	26	84	113
4	Browns Bay	Adult	0	2	3	5	21	27	14	62	64	67	100	231	0	0	0	0	298
4	Browns Bay	Juvenile	0	0	0	0	4	1	2	7	0	0	18	18	0	0	0	0	25
5	Browns Bay	Adult	10	18	26	54	49	40	31	120	17	22	26	65	71	65	92	228	467
5	Browns Bay	Juvenile	0	4	3	7	14	17	21	52	0	5	1	6	27	71	56	154	219
6	Browns Bay	Adult	29	17	32	78	25	28	17	70	21	16	21	58	133	115	114	362	568
6	Browns Bay	Juvenile	7	17	9	33	9	13	7	29	0	3	0	3	43	33	46	122	187
7	Duck Creek	Adult	39	47	72	158	31	27	31	89	24	27	26	77	17	12	26	55	379
7	Duck Creek	Juvenile	7	8	26	41	8	25	22	55	15	12	17	44	14	18	12	44	184
8	Duck Creek	Adult	33	19	24	76	17	19	24	60	18	14	17	49	14	30	22	66	251
8	Duck Creek	Juvenile	5	4	13	22	10	14	3	27	25	31	27	83	12	16	7	35	167
9	Duck Creek	Adult	0	4	5	9	29	32	28	89	34	38	38	110	23	32	20	75	283
9	Duck Creek	Juvenile	0	0	1	1	19	9	20	48	29	16	12	57	8	5	1	14	120
10	Bromley	Adult	13	8	14	35	19	22	25	66	23	16	20	59	14	36	15	65	225
10	Bromley	Juvenile	8	1	12	21	5	6	13	24	2	3	6	11	26	18	15	59	115

Transect	Site	Class	HTA	HTB	HTC	HT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	UMTA	UMTB	UMTC	UMT	Total
11	Bromley	Adult	1	8	10	19	56	65	74	195	45	31	51	127	73	30	62	165	506
11	Bromley	Juvenile	3	6	8	17	22	22	21	65	3	8	9	20	18	9	29	56	158
12	Bromley	Adult	0	0	0	0	36	46	58	140	78	68	72	218	17	18	27	62	420
12	Bromley	Juvenile	0	0	0	0	9	8	9	26	25	24	26	75	2	1	1	4	105
13	Bromley	Adult	21	12	21	54	32	54	40	126	37	36	45	118	59	90	79	228	526
13	Bromley	Juvenile	2	2	2	6	11	23	6	40	3	1	0	4	19	26	23	68	118
14	Pauatahanui	Adult	44	44	29	117	52	59	39	150	52	77	50	179	31	37	29	97	543
14	Pauatahanui	Juvenile	2	17	9	28	22	13	26	61	33	37	14	84	3	11	28	42	215
15	Pauatahanui	Adult	0	0	0	0	56	31	46	133	21	8	20	49	0	0	0	0	182
15	Pauatahanui	Juvenile	0	0	0	0	7	13	21	41	5	7	2	14	0	0	0	0	55
16	Pauatahanui	Adult	11	7	25	43	28	33	25	86	46	12	16	74	68	58	89	215	418
16	Pauatahanui	Juvenile	1	1	1	3	7	6	10	23	4	1	6	11	54	47	24	125	162
17	Pauatahanui	Adult	0	0	0	0	6	0	2	8	88	143	121	352	0	1	0	1	361
17	Pauatahanui	Juvenile	0	0	0	0	0	0	1	1	18	21	21	60	1	0	0	1	62
18	Motukaraka	Adult	0	0	0	0	12	23	14	49	31	55	30	116	9	30	5	44	209
18	Motukaraka	Juvenile	3	1	3	7	15	5	0	20	67	18	12	97	15	9	0	24	148
19	Motukaraka	Adult	33	52	46	131	15	24	16	55	18	15	18	51	42	41	40	123	360
19	Motukaraka	Juvenile	3	2	4	9	1	0	0	1	0	1	0	1	2	0	1	3	14
20	Motukaraka West	Adult	7	0	0	7	141	173	122	436	13	10	16	39	62	17	100	179	661
20	Motukaraka West	Juvenile	0	0	0	0	15	4	14	33	0	4	8	12	38	1	25	64	109
21	Motukaraka West	Adult	6	7	8	21	56	66	84	206	71	9	16	96	67	30	53	150	473
21	Motukaraka West	Juvenile	2	2	1	5	1	3	2	6	5	3	1	9	7	8	7	22	42
22	Motukaraka West	Adult	43	49	55	147	37	31	44	112	19	32	33	84	48	30	38	116	459
22	Motukaraka West	Juvenile	17	11	16	44	2	7	11	20	2	16	9	27	25	16	11	52	143
23	Kakaho	Adult	23	44	26	93	0	5	2	7	1	15	53	69	0	20	0	20	189
23	Kakaho	Juvenile	9	4	4	17	0	1	4	5	0	1	1	2	0	15	0	15	39

Transect	Site	Class	HTA	HTB	HTC	HT	LMTA	LMTB	LMTC	LMT	LTA	LTB	LTC	LT	UMTA	UMTB	UMTC	UMT	Total
24	Kakaho	Adult	19	10	7	36	66	71	79	216	60	78	99	237	3	38	17	58	547
24	Kakaho	Juvenile	3	1	0	4	0	1	1	2	0	0	0	0	1	9	5	15	21
25	Kakaho	Adult	25	33	24	82	28	27	11	66	12	8	13	33	95	66	71	232	413
25	Kakaho	Juvenile	27	23	49	99	10	7	8	25	1	0	2	3	3	5	7	15	142
26	Kakaho	Adult	58	0	27	85	11	27	15	53	3	7	7	17	26	63	45	134	289
26	Kakaho	Juvenile	29	0	4	33	1	1	1	3	0	0	0	0	5	8	2	15	51
27	Camborne	Adult	37	5	54	96	25	33	17	75	7	8	7	22	25	34	29	88	281
27	Camborne	Juvenile	9	5	6	20	3	1	2	6	0	1	0	1	3	2	3	8	35
28	Camborne	Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	Camborne	Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	Camborne	Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	Camborne	Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	Camborne	Adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	Camborne	Juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix G Histograms of the size (length) frequency of cockles for all sites combined for triennial surveys 1998–2022.

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. Transects 3A (Seaview Road) 18 (Motukaraka) were not sampled in 2016, transect 30 (Camborne) was not sampled between 2013 and 2022, only half of Transect 13 sampled in 2019**,** and transects 28 and 29 (Camborne) were not sampled in 2022.