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Cockle (*Austrovenus stutchburyi*) survey of Otago Harbour in 2020

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EXECUTIVE SUMMARY

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This report describes the random stratified survey of the New Zealand cockle (*Austrovenus stutchburyi*) in Otago Harbour in January-February 2020 and is the second Fisheries New Zealand survey of the five main cockle beds, with the previous survey conducted in 1999. An additional small cockle bed of customary importance to Te Rūnanga ō Ōtākou (Te Rauone Beach) was added to the survey in 2020. For each bed, current biomass and mean density of cockles for all sizes and the recruited population (30 mm and over) were estimated. Size composition and spatial distribution were also determined.

The total areas surveyed and strata of bed 1 (Harwood), bed 3 (Port Chalmers), bed 4 (Sawyers Bay), and bed 5 (St Leonards) were identical to those of the 1999 survey. Bed 2 (Aramoana) was re-stratified, but the total area was unchanged. Stratification of Te Rauone Beach was based on consultation with local representatives of the Te Rūnanga ō Ōtākou around perceptions of where cockles were the most and least abundant, and after an on-site inspection. From 58 to 93 stations (0.09-m^2 quadrats) per bed were sampled, to give a total of 453 stations for all beds combined. Phase 2 stations were sampled only for Harwood. All cockles sampled were measured for length, and for four beds all individual cockles were individually weighed. For two beds with the highest densities, cockles were randomly subsampled for weight, and a length-weight relationship was used to determine total sampled weight. The total number of cockles sampled was 6798 with a combined weight of 102.6 kg.

The total recruited biomass estimate for Otago Harbour was 20 672 t ranging from 1251 to 9295 t for each of the main beds and 69 t for Te Rauone Beach. Coefficients of variation (CV) for abundance estimates ranged from 10.9 to 19.0% for the main beds and 20.5% for Te Rauone Beach. Total recruited number was 986 million ranging from 59.7 to 451.8 million for the main beds and 2.5 million at Te Rauone Beach. CVs for numbers estimates ranged from 11.4 to 18.2% for the main beds and 20.9% for Te Rauone Beach. Total mean density by weight of recruited cockles was 2267 g m^{-2} ranging from 784 to 4163 g m^{-2} for the main beds and 1203 g m^{-2} at Te Rauone Beach. Total mean density by number of recruited cockles was 107 cockles m^{-2} ranging from 55 to 213 cockles m^{-2} for the main beds and 47 cockles m^{-2} at Te Rauone Beach.

Biomass declined for all five main beds between 1999 and 2020 and this is likely to be statistically significant for all beds except Sawyers Bay where there is considerable overlap in the confidence intervals. The decline in recruited biomass by bed since 1999 has ranged from 21% at Sawyers Bay to 62% at Harwood, and the all harbour recruited biomass has declined by 12 368 t or 37.5%. Commercial beds 3 and 4 were surveyed in 2007, 2012, and 2017 by the main commercial harvester but the stratification and areas surveyed differed slightly to those used in 1999 and 2020. For Port Chalmers the five survey time series also indicates a clear trend of declining recruited biomass, but for Sawyers Bay there is no trend. Despite this, other characteristics of the population have remained stable including higher biomass in the inner harbour beds, the spatial distribution of cockles within beds, the length frequency distribution within beds, and the presence/absence index (percent of zero catches) of recruited cockles.

The recruited components of the length distributions are characteristic for each bed and remarkably consistent between years, despite variable recruitment pulses which are consistent with high mortality of juveniles.

Seagrass was statistically positively correlated with cockle density in four of the six beds where seagrass cover was highest.

1. INTRODUCTION

This report describes the random stratified survey of the New Zealand cockle (*Austrovenus stutchburyi*) in Otago Harbour in January-February 2020. This is the second Fisheries New Zealand survey of the five main cockle beds in Otago Harbour, with the previous survey conducted in 1999 (Breen et al. 1999). An additional cockle bed of customary importance to Te Rūnanga ō Ōtākou was added to the areas surveyed in 2020. For each bed, current biomass and mean density of cockles for all sizes and recruited (30 mm and over) was estimated. Size composition and spatial distribution were also determined.

1.1 Background

Most often referred to as cockles, this species is marketed commercially as the Littleneck Clam and is known by South Island Māori as tuaki. The New Zealand cockle is a suspension-feeding bivalve belonging to the family Veneridae that includes over 460 species worldwide and is endemic to New Zealand. Found on harbour sandflats and estuaries in fine sand in the intertidal zone, cockles experience a period of submergence and exposure with every tidal cycle depending on height on the shore, but the optimal period of submergence is thought to be about 3.5 hours per day (Larcombe 1971). They live buried just below the surface and extend inhalent and exhalent siphons through the mantle to the surface while submerged, filtering the water column for organic material, particularly phytoplankton, and excreting waste (Beentjes 1984). Cockles exhibit a persistent endogenous circa-tidal rhythmicity in shell gaping, siphon extension, and filtration activity which is cued to the time of high water, and they only feed for a part of the time they are submerged (Beentjes & Williams 1986). An experimental study found that a single cockle, 40 mm in length, filters about 2.1 litres of sea water an hour (Beentjes 1984) and hence cockle populations can have major effect on the water quality in harbours.

Cockles are distributed throughout New Zealand in harbours and estuaries (Breen et al. 1999, Williams et al. 2009, Berkenbusch & Neubauer 2015, Berkenbusch & Neubauer 2019, Fisheries New Zealand 2019). There are major populations in and around Otago Peninsula in Papanui Inlet, Waitati Inlet, Purakanui Inlet, and within Otago Harbour in five main beds (Figure 1). Based on the 1999 survey, Otago Harbour holds the largest biomass of cockles in New Zealand with a combined (five beds) recruited biomass (30 mm and over) estimate of 33 000 t (Breen et al. 1999), conservatively comprising more than 2000 million individuals.

1.2 The Otago cockle fishery

Cockles have been commercially fished in Waitati Inlet and Papanui Inlet since 1983, and from two distinct beds within Otago Harbour (Sanitation Areas 1804 and 1805) since 2009, initially under a special permit (Fisheries New Zealand 2019). In November 2018, the regulation closing Otago Harbour to commercial shellfish harvest was amended to allow harvest from the two beds corresponding to Sanitation Areas 1804 and 1805. The total reported commercial landings from these two sanitation area beds from 2008–09, when harvesting began, to 2018–19 was 4031 t and over this time these beds have contributed 42% of the commercial COC 3 (Otago Peninsula) catch with 57% coming from Waitati Inlet (Fisheries New Zealand 2020). Recreational harvest estimates from the 2011–12 and 2017–18 National Panel Surveys are only available for the entire FMA 3 (Slope Point to Cape Campbell) and were 7.5 t and 2.6 t, so are relatively insignificant (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019). Cockles (tuaki) are of great importance to Māori as a traditional customary food source and in Otago this includes harvesting by Kāti Huirapa Rūnaka ki Puketeraki and Te Rūnanga ō Ōtākou. The total reported customary take in Otago collated from customary fishing permits issued by Tangata tiaki was 85 282 tuaki over the period 2000–01 to 2018–19 (Fisheries New Zealand 2020) which, if converted to weight based on a mean length of 35 mm, is only 1.5 t over almost 20 years. This is likely to be underestimated because cockles are often taken under amateur (recreational) regulations. The Ōtākou Mātaitai Reserve was established over the outer harbour in 2016 in recognition of the importance of this area as a traditional customary food source (Figure 1).

1.3 Biomass surveys of Otago Harbour cockles

The first survey of the cockle beds within Otago Harbour was carried out by the National Institute of Water & Atmospheric Research Ltd (NIWA) on behalf of Fisheries New Zealand (then Ministry of Fisheries) from December 1998 to January 1999 (from here on referred to as the 1999 survey) and covered the main five beds (bed 1, Harwood; bed 2, Aramoana; bed 3, Port Chalmers; bed 4, Sawyers Bay; and bed 5, St Leonards) (Breen et al. 1999) (Figure 1). The survey used a two-phase random stratified design after Francis (1984). With no previous surveys to inform the survey design each bed was arbitrarily divided into 8–10 strata with outer boundaries following low water at 0 metres chart datum and for beds with shoreline up to the high tide. From 90 to 100 randomly generated phase 1 stations were sampled in each bed with similar numbers allocated to each stratum. Harwood was the only bed to have phase 2 stations allocated and sampled. The target coefficient of variation (CV) for each bed was 20% for recruited biomass of cockles (30 mm and over). Sampling units were quadrats of 0.09 m^2 from which substrate was excavated with a spade and sieved. Length was measured for all cockles and a random selection of cockles were individually weighed from which length-weight relationships were used to estimate biomass of the different length groups.

The commercially fished beds within Otago Harbour referred to by Fisheries New Zealand as Sanitation Areas 1804 and 1805 are essentially the same as bed 3 (Port Chalmers) and bed 4 (Sawyers Bay), respectively, surveyed in 1999 (Breen et al. 1999). These beds were surveyed in 2007, 2012, and 2017 by Ryder Consulting on behalf of Southern Clams Ltd (SCL) to assess the impact of harvesting on the cockle population (Stewart 2008, 2013, 2017). The strata for these SCL surveys differed to those used in 1999 and in both sanitation beds the total area surveyed was slightly less than in the 1999 survey. These surveys employed a similar two-phase random stratified survey design and sampled quadrats of 0.1 m^2 using a venturi suction device to transfer the substrate into the sieve. Relatively small numbers of cockles were sub-sampled for length composition analyses. Although the method is not explicit in the 2017 survey report (Stewart 2017), it is interpreted that the biomass was estimated from weights of cockles from all sampled quadrats, separated into specific size groups.

1.4 Consultation with tangata whenua

On 23 October 2019 the author attended a hui at Te Rūnanga ō Ōtākou and presented the proposed 2020 cockle survey design to members of Ōtākou Mātaitai Management Komiti. The komiti fully endorsed the survey, including sampling within the mātaitai, but requested that the survey be expanded to include Te Rauone Beach (Otakou), an area that yields significant customary harvest (Figure 1). A variation to include Te Rauone Beach was subsequently requested by NIWA and approved by Fisheries New Zealand.

1.5 Objectives

Overall objective

To evaluate the status of the cockles in the Otago harbour.

Specific objectives

1. Conduct a biomass survey that will provide estimates of current relative and absolute abundance (numbers and biomass in tonnes), length frequency profile, density and distribution of recruited and pre-recruit cockles in the Otago harbour.

2. Compare the estimates from objective 1 with other relevant data from previous surveys.

2. METHODS

2.1 Survey timing and area

A biomass survey of the five main cockle beds (1–5) within Otago Harbour was carried out by NIWA from 10 to 20 January 2020, with the much smaller customary bed (Te Rauone Beach) surveyed on 11 February 2020. The survey dates were selected to coincide with spring tides and are consistent with dates of the 1999 survey.

The total area surveyed and strata of beds 1, 3, 4, and 5 were identical to those of the 1999 survey (Figure 2). Aramoana was re-stratified following recommendations from the Shellfish Working Group (25 November 2019) but the total area was unchanged (Figure 2). Te Rauone Beach was not surveyed in 1999 and there were no existing strata. Seven strata were drawn for Te Rauone Beach after consulting with local representatives of the Te Rūnanga ō Ōtākou around perceptions of where cockles were the most and least abundant, and after an on-site inspection on 13th December 2019 by the author where bed densities were qualitatively assessed to inform the number, size, and boundaries of strata. The seaward boundary of the entire survey area was determined by following the low water tide mark and marking waypoints and the upper beach was similarly defined by the line of wet sand (Figure 2).

2.2 Survey design

2.2.1 Allocation of stations

Simulations to determine the optimal allocation of random stations among the strata in each of the five main beds were carried out using catch data from the 1999 survey and NIWA Optimal Station Allocation Program (*allocate*). Simulations were constrained to have a minimum of three sites per stratum and an overall target CV of no greater than 20%. Allowing for a maximum of 90 stations per bed, some beds required this full number to achieve the 20% CV, but for most beds fewer stations were required — for these beds the allocation was rerun for lower target CVs without going below about 60 stations per bed. In this way the lowest achievable CV was sought given the resources available. The number of stations planned for each bed was as follows: Harwood, 93; Aramoana, 80; Port Chalmers, 61; Sawyers Bay, 86; St Leonards, 92. For Te Rauone Beach a total of 66 stations were planned, *a priori*, and these were allocated in each stratum based on the size of the stratum and the perceived density.

The 2020 survey used a one-phase stratified random station design (Francis 1984) for beds 2–6, consistent with the 1999 survey. For Harwood, a two-phase design was used with 85% of stations (79) allocated to phase 1 and 15% to phase 2 (14), consistent with the proportion of phase 2 sites used in the 1999 survey (Table 1). Allocation of phase 2 stations was based on the mean catch rate (g quadrat^{-1}) of recruited cockles (30 mm and over) per stratum and optimised using the “area mean squared” method of Francis (1984). In this way, stations were assigned iteratively to the stratum in which the expected gain is greatest, where expected gain is given by:

$$expected\ gain_i = A_i^{\,2}\ mean_i^{\,2} / (n_i(n_i+1))$$

where for the *i*th stratum, $mean_i$ is the mean biomass density of cockles (grams per quadrat), A_i is the stratum area in quadrats (m^2 divided by 0.09), and n_i is the number of phase 1 stations in stratum$_i$.

Sufficient stations to cover both first and second phase stations (Harwood only) were generated for each stratum using the NIWA Random Station Generator Program (*Rand_stn* v1.00-2014-07-21) with the constraint that stations were at least 10 m apart. From this list, the allocated number of random stations per stratum to be surveyed was selected in the order they were generated.

2.2.2 Vessel and gear

The inner harbour beds 3, 4, and 5 were accessed using the NIWA vessel R.V. *Hoiho* vessel (Vessel registration MNZ 133584) skippered by Evan Baddock. *Hoiho* is a 5.1-m aluminium Stabicraft pontoon

Jetboat, equipped with an inboard 350 Mercury engine. Beds 1, 2, and 6 were accessed by vehicle from the shoreline.

Quadrats used to sample each station were made from steel alloy with dimensions of 300 x 300 x100 mm. Quadrats were excavated using garden spades and substrate was passed through 2-mm fine steel mesh sieves made from wood or alloy frames.

Garmin GPS and/or android devices uploaded with New Zealand Topo Maps Pro App were used to locate random stations to an accuracy of within about 1 metre.

Cockles were measured for length using Vernier callipers and weighed using electronic scales accurate to 0.01 g.

2.2.3 Sampling methods

Sampling methods were similar to those used in the 1999 survey (Breen et al. 1999). Sampling took place on either side of low tide with the deepest stations sampled at low tide. At each random station, located using the GPS device, the quadrat was haphazardly placed on the substrate and the proportion of the quadrat area occupied by *Zostera muelleri* (seagrass) was estimated and recorded. The quadrat contents were then excavated with a spade to a depth of at least 100 mm and transferred to the sieve. Seawater was necessary to wash out the sand/mud, leaving only cockles, other invertebrates, seaweed, and debris. All cockles were removed, transferred to a plastic bag, and labelled with the station number. If no cockles were found this was recorded as zero. If the station was too deep to sample this was recorded, and no sample attempted. [1]Anything deeper than about 30 cm was impractical to sample safely and accurately.

Samples were taken back to the laboratory in the Dunedin NIWA office and processed that day. Length (to the nearest millimetre) at the widest part of shell was measured for all cockles.

For beds 4 and 5, where the largest numbers of cockles were expected to be encountered (Breen et al. 1999), only cockles from randomly selected quadrats were weighed (to the nearest 0.1 g), aiming to generate about 800 individual weights for each bed. For the less dense beds (1, 2, 3, and 6), all cockles were weighed. In both cases only undamaged cockles were weighed. Cockles were returned alive the following day to their respective beds.

All lengths and weights were entered directly into customised excel spreadsheets. At the completion of the survey, data were entered into the Fisheries New Zealand *beach* database in accordance with the business rules.

2.3 Data analyses

2.3.1 Length-weight relationship

For cockles that were not individually weighed, the length-weight relationship determined for each bed was used to estimate the weight. The length-weight parameters a, b were used in the following equation:

$$w_l = al^b$$

This calculates the expected weight (g) for a cockle of length l (mm). These parameters were calculated from the coefficients of linear regressions of log(weight) on log(length) using all cockles for which length and weight were recorded: b is the slope of the regression line, and log(a) is its y-intercept.

[1] Sampled stations that were under water invariably had zero cockles, and so the loss of stations deemed as too deep to sample would have no impact on the biomass estimates.

2.3.2 Population biomass estimates

Biomass (tonnes) was estimated separately for each of the six Otago Harbour beds. Equations used to estimate population biomass, variance, coefficient of variation (CV), and 95% confidence intervals are taken from Breen et al. (1999). The population biomass for all cockles and those 30 mm and over (recruited) was estimated from the mean density of cockles per quadrat in each stratum and the area of each stratum. The area of each stratum was taken from Breen et al. (1999), except for the restratified bed 2 (Aramoana) where the area of the stratum was determined from the Station Generator Program (*Rand_stn* v1.00-2014-07-21).

The biomass estimates and their variances were calculated as follows:

in the *i*th stratum, the estimated biomass of size group *k* (all sizes, and 30 mm and over) is

$$B_{i,k} = mean_{i,k}\, A_i$$

where $mean_{i,k}$ is the mean biomass density (gram per quadrat) and A_i is the area of the stratum in quadrats (m^2 divided by 0.09).

The estimated variance of the $mean_{i,k}$, is

$$VC_{i,k} = var_{i,k}$$

where $var_{i,k}$ is the variance of the observed (or calculated) weights from the quadrats.

The biomass estimate for the size group *k* for the whole bed (= survey area) is the summation over all strata and is

$$B_k = \Sigma\, B_{i,k}$$

and the estimated variance of this estimate is

$$VB_k = \Sigma\, (A_i^{\,2}\, VC_{i,k} / n_i)$$

where n_i is the number of quadrats in $stratum_i$. Because the biomass estimate is converted from grams to tonnes, the variance estimate must also be converted by dividing by 10^{12}.

The CV is

$$\mathrm{CV} = sqrt\,(VB_k) \,/\, B_k$$

The 95% confidence intervals around the population estimates were calculated from ± 1.96 (*CV B)*

2.3.3 Population numbers estimates

The numbers of cockles were estimated in the same way as biomass for each of the six Otago Harbour beds. The population number for all cockles and those 30 mm and over (recruited) was estimated from the mean number of cockles per quadrat in each stratum and the area of each stratum.

The estimates of numbers and their variances were calculated as follows:

in the *i*th stratum, the estimated number of size group *k* (all sizes, and 30 mm and over) is

$$N_{i,k} = mean_{i,k}\, A_i$$

where $mean_{i,k}$ is the mean number density (numbers per quadrat) and A_i is the area of the stratum in quadrats (m^2 divided by 0.09).

The estimated variance of the $mean_{i,k}$, is

$$VC_{i,k} = var_{i,k}$$

where $var_{i,k}$ is the variance of the observed number from the quadrats.

The number estimate for the size group k for the whole bed (= survey area) is the summation over all strata and is

$$N_k = \Sigma \, N_{i,k}$$

and the estimated variance of this estimate is

$$VN_k = \Sigma \, (A_i^{\,2} \, VC_{i,k} / \, n_i)$$

where n_i is the number of quadrats in $stratum_i$

The CV is

$$\mathrm{CV} = sqrt \, (VN_k) \, / \, N_k$$

The 95% confidence intervals around the population estimates were calculated from ± 1.96 ($CV\,N$)

2.3.4 Bed density

The mean density (numbers and biomass) for all cockles and those 30 mm and over (recruited) was estimated for each of the six Otago Harbour beds.

For the whole bed, the estimated mean density of size group k is

$$Density_k = 11.111(mean_{,k})$$

Where $mean_k$ is the mean density (numbers and grams per quadrat) over all strata. The factor 11.111 scales from grams per quadrat to grams per square metre.

2.3.5 Scaled length frequencies

Length compositions were estimated using the NIWA program Catch-at-Age (Bull & Dunn 2002). The program scales the length frequency data by the area of the stratum, number of stations in each stratum, and catch weight. Bootstrap resampling (300 bootstraps) was used to calculate CV for proportions and numbers-at-length. That is, simulated data sets were created by resampling (with replacement) stations from each stratum, and cockles from each station for length.

2.3.6 Correlation analyses for seagrass

Correlation analyses were carried out for each bed and overall for all beds combined between seagrass (percentage quadrat cover) and the number of cockles and the weight of cockles. The statistical significance of the correlation was tested.

2.3.7 Data from 1999, 2007, 2012, and 2017 surveys

The 1999 survey recruited biomass (30 mm and over) estimates for each of the five beds was taken from tables 15, 17, 19, 21, and 23 of Breen et al. (1999), but there were no estimates of total biomass, numbers, or mean density in the report and no attempt was made to estimate these parameters. Data from the 1999 survey of the five Otago Harbour beds are stored in the Fisheries New Zealand *beach* database under attribute survey = *otago9801*. The 1999 survey length frequency data were extracted and scaled in the current analyses, using the methods described above for the 2020 survey.

The 2007, 2012, and 2017 surveys of the Sanitation Areas 1804 and 1805 are currently not in the Fisheries New Zealand *beach* database and total and recruited biomass (30 mm and over) estimates were taken from tables 4.1.2 and 4.1.3 of Stewart (2017). The raw length frequency data were obtained from Ryder Consulting but because there were no other ancillary survey data (catch, strata areas, station) provided, the length data could not be scaled.

3. RESULTS

3.1 2020 Otago Harbour survey

Six cockle beds in Otago Harbour were surveyed with 58 to 93 stations (quadrats) per bed sampled and a total of 453 stations for all beds combined (Table 1). For Harwood, all planned phase 2 stations were sampled. A total of 22 stations (4.6%) were deemed too deep to sample and of these 3 were at Port Chalmers and 19 at St Leonards. Tide heights ranged from 0.19 to 0.42 m above the lowest astronomical tide level which is at 0 m. The proportion of cockles that were individually weighed in each bed ranged from 32 to 100% with a total of 3676 cockles weighed (Table 1). The length weight coefficients used to convert length to weight for each bed are shown in Table 2.

3.1.1 Population estimates, density, distribution, and size

Bed 1 (Harwood)

A total of 8717 g or 787 cockles was sampled from 93 stations at Harwood (Table 1).

The overall estimated biomass of all cockles at Harwood was 1639 t with a CV of 14.8% (Table 3) and varied greatly by stratum from 14 to 931 t (Appendix 1a). The overall biomass of recruited cockles at Harwood was 1251 t with a CV of 18.6% (Table 3) and varied greatly by stratum from 0 to 632 t (Appendix 1a). Recruited biomass was 76% of the total biomass (Table 3).

The overall number of all cockles at Harwood was 156.1 million with a CV of 15.9% (Table 4) and varied greatly by stratum from 4 to 91 million (Appendix 1b). The overall number of recruited cockles at Harwood was 59.7 million with a CV of 17.4% (Table 4) and varied greatly by stratum from 0 to 30 million (Appendix 1b). Recruited biomass was 38.2% of the total biomass (Table 4).

Mean density of cockles at Harwood by weight was 1041 g m^{-2} and 784 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 94 cockles m^{-2} and 784 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 93 stations sampled at Harwood, 45 (48.4%) had zero cockles and 59 (63.4%) had zero recruited cockles (Figure 3 – Harwood). Cockles were found in all strata, but density was highest in strata 1 and 5 (Figure 3 – Harwood).

The length frequency distribution for Harwood is generally unimodal with a small juvenile peak at about 8 mm and sizes ranged from 6 to 53 mm with a mean of 28 mm (Figure 4 – Harwood). There were more than twice as many pre-recruited than recruited cockles.

Bed 2 (Aramoana)

A total of 10 182 g or 459 cockles was sampled from 77 stations at Aramoana (Table 1).

The overall estimated biomass of all cockles at Aramoana was 2130 t with a CV of 17.2% (Table 3) and varied greatly by stratum from 31 to 718 t (Appendix 2a). The overall biomass of recruited cockles at Aramoana was 2000 t with a CV of 17.2% (Table 3) and varied greatly by stratum from 29 to 698 t (Appendix 2a). Recruited biomass was 94% of the total biomass (Table 3).

The overall number of all cockles at Aramoana was 117 million with a CV of 21.3% (Table 4) and varied greatly by stratum from 1.5 to 34 million (Appendix 2b). The overall number of recruited cockles at Aramoana was 87.1 million with a CV of 18.2% (Table 4) and varied greatly by stratum from 1.3 to 25 million (Appendix 2b). Recruited biomass was 74.4% of the total biomass (Table 4).

Mean density of cockles at Aramoana by weight was 1469 g m^{-2} and 1 426 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 66 cockles m^{-2} and 55 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 77 stations sampled at Aramoana, 27 (35.1%) had zero cockles and 29 (37.7%) had zero recruited cockles (Figure 3 – Aramoana). Cockles were found in all strata, but density was highest in strata 9, 10, and 11 (Figure 3 – Aramoana).

The length frequency distribution for Aramoana was generally unimodal with a small juvenile peak at about 5 mm and sizes ranged from 4 to 55 mm with a mean of 33 mm (Figure 4 – Aramoana). The length distribution was dominated by recruited cockles, which comprised 83% of the lengths.

Bed 3 (Port Chalmers)

A total of 13 620 g or 446 cockles was sampled from 58 stations at Port Chalmers (Table 1).

The overall estimated biomass of all cockles at Port Chalmers was 3715 t with a CV of 19.0% (Table 3) and varied greatly by stratum from 0 to 1295 t (Appendix 3a). The overall biomass of recruited cockles at Port Chalmers was 3675 t with a CV of 19.1% (Table 3) and varied greatly by stratum from 0 to 1289 t (Appendix 3a). Recruited biomass was 98.9% of the total biomass (Table 3).

The overall number of all cockles at Port Chalmers was 149 million with a CV of 16.9% (Table 4) and varied greatly by stratum from 0 to 54 million (Appendix 3b). The overall number of recruited cockles at Port Chalmers was 138 million with a CV of 17.2% (Table 4) and varied greatly by stratum from 0 to 53 million (Appendix 3b). Recruited biomass was 92.4% of the total biomass (Table 4).

Mean density of cockles at Port Chalmers by weight was 2609 g m^{-2} and 2584 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 105 cockles m^{-2} and 98 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 58 stations sampled at Port Chalmers, 27 (46.5%) had zero cockles and 28 (48.3%) had zero recruited cockles (Figure 3 – Port Chalmers). Cockles were found in all strata except 1, 2, and 8, and density was highest in strata 4 and 5 (Figure 3 – Port Chalmers).

The length frequency distribution for Port Chalmers was strongly unimodal with no clear juvenile peaks and sizes ranged from 5 to 57 mm with a mean of 38 mm (Figure 4 – Port Chalmers). The length distribution was dominated by recruited cockles, which comprised 93% of the lengths.

Bed 4 (Sawyers Bay)

A total of 32 688 g or 2671 cockles was sampled from 86 stations at Sawyers Bay (Table 1).

The overall estimated biomass of all cockles at Sawyers Bay was 5353 t with a CV of 11.1% (Table 3) and varied greatly by stratum from 18 to 898 t (Appendix 4a). The overall biomass of recruited cockles at Sawyers Bay was 4384 t with a CV of 11.4% (Table 3) and varied greatly by stratum from 18 to 830 t (Appendix 4a). Recruited biomass was 81.9% of the total biomass (Table 3).

The overall number of all cockles at Sawyers Bay was 475 million with a CV of 13.3% (Table 4) and varied greatly by stratum from 0.5 to 101 million (Appendix 4b). The overall number of recruited cockles at Sawyers Bay was 247 million with a CV of 12.1% (Table 4) and varied greatly by stratum from 0.5 to 43 million (Appendix 4b). Recruited biomass was 52.0% of the total biomass (Table 4).

Mean density of cockles at Sawyers Bay by weight was 4223 g m^{-2} and 3618 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 345 cockles m^{-2} and 194 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 86 stations sampled at Sawyers Bay, 17 (19.8%) had zero cockles and 24 (27.9%) had zero recruited cockles (Figure 3 – Sawyers Bay). Cockles were found in all strata, and densities were generally similar throughout all strata (Figure 3 – Sawyers Bay).

The length frequency distribution for Sawyers Bay was unimodal with a well-defined juvenile peak at about 7 mm and sizes ranged from 3 to 50 mm with a mean of 28 mm (Figure 4 – Sawyers Bay). The length distribution was almost evenly split between pre-recruited and recruited cockles.

Bed 5 (St Leonards)

A total of 29 797 g or 1986 cockles was sampled from 73 stations at St Leonards (Table 1).

The overall estimated biomass of all cockles at St Leonards was 10 141 t with a CV of 10.7% (Table 3) and varied greatly by stratum from 11 to 2827 t (Appendix 5a). The overall biomass of recruited cockles at St Leonards was 9294.7 t with a CV of 11.0% (Table 3) and varied greatly by stratum from 0 to 2500 t (Appendix 5a). Recruited biomass was 91.7% of the total biomass (Table 3).

The overall number of all cockles at St Leonards was 634 million with a CV of 12.6% (Table 4) and varied greatly by stratum from 2.5 to 180 million (Appendix 5b). The overall number of recruited cockles at St Leonards was 452 million with a CV of 11.4% (Table 4) and varied greatly by stratum from 0 to 129 million (Appendix 5b). Recruited biomass was 71.2% of the total biomass (Table 4).

Mean density of cockles at St Leonards by weight was 4563 g m^{-2} and 4163 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 302 cockles m^{-2} and 213 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 73 stations sampled at St Leonards, 6 (8.2%) had zero cockles and 10 (13.7%) had zero recruited cockles (Figure 3 – St Leonards). Cockles were found in all strata, but densities were highest is strata 1 and 7 (Figure 3 – St Leonards).

The length frequency distribution for St Leonards was unimodal with a well-defined juvenile peak at about 9 mm and sizes ranged from 5 to 53 mm with a mean of 33 mm (Figure 4 – St Leonards). The length distribution was dominated by recruited cockles, which comprised 70% of the lengths.

Bed 6 (Te Rauone Beach)

A total of 7380 g or 349 cockles was sampled from 66 stations at Te Rauone Beach (Table 1).

The overall estimated biomass of all cockles at Te Rauone Beach was 69.1 t with a CV of 20.6% (Table 3) and varied greatly by stratum from 0 to 39 t (Appendix 6a). The overall biomass of recruited cockles at Te Rauone Beach was 66.9 t with a CV of 20.5% (Table 3) and varied greatly by stratum from 0 to 37 t (Appendix 6a). Recruited biomass was 96.4% of the total biomass (Table 3).

The overall number of all cockles at Te Rauone Beach was 3.2 million with a CV of 21.6% (Table 4) and varied greatly by stratum from 0.012 to 1.9 million (Appendix 6b). The overall number of recruited cockles at Te Rauone Beach was 2.5 million with a CV of 20.0% (Table 4) and varied greatly by stratum from 0 to 1.5 million (Appendix 6b). Recruited biomass was 76.8% of the total biomass (Table 4).

Mean density of cockles at Te Rauone Beach by weight was 1242 g m^{-2} and 1203 g m^{-2} for all cockles and recruited cockles, respectively (Table 5). Density of cockles by number was 59 cockles m^{-2} and 47 cockles m^{-2} for all cockles and recruited cockles, respectively (Table 5).

Of the 66 stations sampled at Te Rauone Beach, 35 (53.0%) had zero cockles and 44 (66.7%) had zero recruited cockles (Figure 3 – Te Rauone Beach). Cockles were found in all strata, but there were almost no recruited cockles in strata 4, 6, and 7. Cockles were most dense in stratum 1 which accounted for 56% of the total biomass for Te Rauone Beach (Figure 3 - Te Rauone Beach).

The relatively small numbers of cockles sampled at Te Rauone Beach has resulted in a length frequency distribution which is spikey and less representative than for other beds. The distribution was generally unimodal with no clear juvenile peaks and sizes ranged from 7 to 54 mm with a mean of 35 mm (Figure 4

– Te Rauone Beach). The length distribution was dominated by recruited cockles, which comprised 80% of the lengths.

3.1.2 Correlation analyses for seagrass

Seagrass was statistically positively correlated with cockle density in four of the six beds (1, 2, 5, and 6) and the correlations were greater for cockle density by number than by weight (Table 6). The correlations were negative for beds 3 and 4 but were not significant. The highest correlation was for Te Rauone Beach where the highest density of cockles was in stratum 1, which is also dominated by seagrass.

3.2 Comparison between beds in 2020

The biomass, numbers, and density of cockles within Otago Harbour all increase from the outer to the inner harbour (Figures 5–7). The two inner harbour beds 4 and 5 have similar densities (Figure 7) and, along with Harwood, have the highest proportions of juvenile or pre-recruited cockles, most clearly represented by cockle numbers in Figure 6. The length frequency distributions are most similar for the inner beds 4 and 5 and differ from those of the other four beds (see Figure 4).

3.3 Comparison between surveys

3.3.1 1999 and 2020 surveys

The recruited biomass estimates for the five beds surveyed in both 1999 and 2020 are compared in Figure 8. Biomass declined for all beds in 2020 and this is likely to be statistically significant for all beds except Sawyers Bay where there is considerable overlap in the confidence intervals. The decline in recruited biomass by bed has ranged from 21% at Sawyers Bay to 62% at Harwood, and the all harbour recruited biomass has declined by 12 368 t or 37.5% since 1999 (Table 7). The percent of stations that had no recruited cockles (zero catch) has not changed to any extent between 1999 and 2020, except for Aramoana where there were proportionally less zero catches in 2020 (Figure 9). The all cockles relative zero percentages between years are similar except for Harwood where 1999 has about half as many zero catches resulting from good recruitment of juveniles in that year.

The length compositions are remarkably similar within the five beds between 1999 and 2020 with pre-recruited sizes showing the most variability, whereas each of the beds appears to exhibit a characteristic distributional shape (Figure 10). For example, Port Chalmers has a strong narrow mode between about 30 and 40 cm, whereas Sawyers Bay has a less defined broader mode with a defined left-hand tail and a strong recruitment pulse in 2020 (Figure 10).

3.3.2 All surveys (1999, 2007, 2012, 2017, and 2020)

As mentioned in the introduction, Port Chalmers and Sawyers Bay are the commercially fished beds that fall within the larger Fisheries New Zealand Sanitation Areas 1804 and 1805. These beds were surveyed in 2007, 2012, and 2017 by Southern Clams Ltd (SCL) to assess the impact of harvesting on the cockle population (Stewart 2008, 2013, 2017). In both beds, the areas surveyed in 1999 and 2020 (Fisheries New Zealand surveys) were larger than for the intervening years surveys (Figure 11). However, for Port Chalmers, strata 1 and 2 yielded zero biomass in 2020 and the overlapping area is where cockle density was highest (see Figure 3), so the population surveyed is effectively the same although the scaling of catches by stratum area is larger for 1999 and 2020. For Sawyers Bay, the overlapping area is also where density is highest, with the exception of stratum 6 (see Figure 3), but only a small fraction of this stratum was surveyed in 2007 to 2017. Hence, for both areas if surveys were conducted at the same time using the different stratifications (i.e., NIWA and SCL), the biomass would likely be slightly higher for the NIWA surveys, particularly for Sawyers Bay. Given these points, the recruited biomass trends shown for all five surveys as a time series plot should be treated cautiously (Figure 12). Notwithstanding these caveats, there is a clear trend of declining biomass at Port Chalmers, but for Sawyers Bay there is no trend. There have been statistically significant fluctuations in biomass between some of the SCL surveys given the much smaller CVs (5–8%) and non-overlapping confidence intervals (Figure 12). This suggests that biomass in this 10-year period has not been stable and had there been more surveys carried out over the 20 years period in all beds it seems likely that these fluctuations would have been observed.

The characteristic distributional shape of length compositions, similar within each of the five beds, is more evident over the five surveys and there are no clear long-term temporal changes in shape or maximum size (see Figure 10). Port Chalmers stands apart from the other beds, displaying a consistently strong narrow mode between about 30 and 40 mm and no evidence of strong recruitment (Figure 10).

4. DISCUSSION

The 2020 survey of five beds in Otago Harbour is the second Fisheries New Zealand survey in the time series of abundance and population structure of cockles after a previous survey in 1999 (Breen et al. 1999). Surveys by a commercial cockle harvester (Southern Clams Ltd) were carried out in 2007, 2012, and 2017 in commercial beds 3 and 4 and biomass estimates and size compositions are presented in this report for comparative purposes. The 2020 survey also included an additional much smaller cockle bed (bed 6, Te Rauone Beach) which is within the mātaitai and of customary importance to Te Rūnanga ō Ōtākou.

4.1 Survey precision

The objectives of the project were met and although not formally specified, a CV of 20% or less for recruited biomass was targeted and achieved for all beds; the CVs are Harwood – 18.6%, Aramoana – 17.2%, Port Chalmers – 19.1%, Sawyers Bay – 11.4%, St Leonards – 11.0%, and Te Rauone Beach -– 20.5% (see Table 3). These CVs in 2020 are similar to those achieved in the 1999 survey for Harwood, Aramoana, Sawyers Bay, and St Leonards, but because stations in 2020 were optimally allocated to strata based on simulations from the 1999 survey data, less effort was required (i.e., 533 stations in 1999 compared with 387 in 2020). The exception was Port Chalmers where the 1999 CV was 10.6% using 90 stations compared with 2020 when it was nearly double this at 19.1% using 58 stations. The simulations did not take into account the decline in abundance that has occurred, and which can result in patchier distributions that reduce survey precision around biomass estimates. In the 2017 survey of Port Chalmers, SCL used nearly three times as many stations as in 2020 (n=158) and achieved a low CV of 6.8% (Stewart 2017). Future survey design would benefit from including the SCL limited survey catch data for Port Chalmers and Sawyers Bay in the simulations to the optimise effort to achieve the target CV.

In 2020 all cockles from all beds were measured for length, and for the three smaller beds all individual cockles were weighed and used to estimate biomass from the mean density of cockles per quadrat in each stratum and the area of each stratum. For the two largest beds where cockles were subsampled for weight, a length-weight relationship was used to estimate total weight and biomass following the method of Breen et al. (1999). This approach allows biomass to be estimated for any size class desired and is preferable to the methods often used in cockle surveys in Otago which have weighed all cockles in predetermined discrete size classes, but have not measured all cockles for length (eg., Stewart 2017). Further, by measuring all cockles the length frequency distributions are better estimated.

4.2 Trends in biomass and density

The key finding from the 2020 survey is that there have been statistically significant declines in biomass in all Otago Harbour beds except Sawyers Bay (see Figure 12) since 1999 and, overall, the entire harbour recruited biomass has declined by 37% (see Table 7). Despite this, other characteristics of the population have remained stable including higher biomass in the inner harbour beds, the spatial distribution of cockles within beds, the length frequency distribution within beds, and the presence/absence index (percent of zero catches) of recruited cockles. The biomass declines are therefore proportional to the decline in density (weight or numbers per square metre) and not to a change in size composition or retraction in spatial distribution driven by available habitat or recruitment. The reasons for the decline in density are unknown and given the length of time between surveys it is plausible that biomass and density has fluctuated more than the five survey time series of biomass estimates indicate (see Figure 12). St Leonards is probably the least accessible and least fished bed in terms of customary and recreational harvest and can be regarded as a virgin population. It also holds the largest cockle biomass and has the highest density of the beds surveyed (see Tables 3 and 5). The biomass at St Leonards has declined by 26% since 1999 and this cannot be ascribed to exploitation. All other beds surveyed are either commercially fished or have an unquantified level of customary and recreational harvest.

4.3 Size composition and recruitment

The recruited component of the length distributions is remarkably consistent between years within each bed despite variable recruitment pulses (see Figure 10) and this is consistent with high mortality of juveniles. Recruitment events in one bed seem to be largely independent of those in the other beds, which suggests that the processes of egg dispersal, larval settlement, and survival within the harbour are complex and may differ for each bed. Length at age estimates from Waitati Inlet indicate that growth is initially rapid, taking about 4 years to reach recruited size (30 mm), after which growth slows and the recruited cockles comprise the bulk of age classes from 4+ to 20 years (Stewart 2006). Annual surveys of Otago Harbour would be required to determine if recruitment strength is related to the size of the adult population. Recent North Island cockle surveys, some of which have been carried out every two years, show no clear correlation between recruitment and the adult population (Berkenbusch & Neubauer 2019). Variable recruitment and high mortality of juveniles is typical of other infaunal New Zealand shellfish such as toheroa (*Paphies ventricosa*) and tuatua (*P. subtriangulata*) for which the adult population size is seldom correlated with recruitment strength (Williams et al. 2013, Beentjes 2020).

4.4 Te Rauone Beach

The small customary bed surveyed for the first time in 2020 (bed 6, Te Rauone Beach) had relatively low densities of cockles, similar to those of neighbouring outer harbour beds Aramoana and Port Chalmers (see Figure 7). Further, the bulk of the cockles were found in a small area in the southwest end of the beach. Discussions with members Te Rūnanga ō Ōtākou before the survey was stratified suggested that we would find cockles throughout strata 1–6 (see Figure 3, Te Rauone Beach) (Natalie Karaitiana pers. comm.). Perceptions are that the abundance of cockles from this bed has declined over many years and that, although customary and recreational harvest may have contributed to the decline, there are other factors such as dynamic sediment processes that may be more influential. The beach is narrow and sits adjacent to the main shipping channel at the harbour entrance where it is subjected to the increasing low amplitude, low frequency wakes from large cruise vessels and container ships, as well as high amplitude wakes from smaller faster vessels. Erosion of the beach dune toe at the northeast end is occurring where the beach is much steeper and residents report that the beach profile and sediment loads can vary over short periods. In semi-sheltered low energy beaches the wakes of ships can have a significant impact on the dynamic of the shoreline, particularly if they differ from the direction and intensity of natural wave events (Parnell & Kofoed-Hansen 2001, Parnell et al. 2007, Soomere et al. 2009). The impacts of these wakes on the cockle population cannot be quantified, but it seems reasonable to assume that any process that causes major changes to the sediment load and locations over short time frames is likely to result in incidental mortality.

4.5 Seagrass

Seagrass meadows are regarded as some of the most productive ecological systems in the world and require very high light levels and clear water to thrive (see review of seagrass in Morrison et al. 2014). Seagrass typically occupies the intertidal (up to mid-tide level) and subtidal waters as deep as 12 m. The benefits of seagrass to the environment are numerous and include slowing current flow, stabilising sediment, refuge from predation, providing nursery habitats, and trapping of nutrients (Alfaro 2006, Morrison et al. 2014, Lohrer et al. 2016). Seagrass meadows in New Zealand are considered to be in decline (Turner & Schwarz 2006).

Surveys of seagrass beds using benthic core sampling were inconclusive as to whether seagrass acts as a nursery habitat for cockles (Morrison et al. 2014). Lohrer et al. (2016), however, found a positive correlation between seagrass cover and cockle density. In the 1999 survey, Breen et al. (1999) found no relationship between the presence of seagrass in quadrats and cockle density, although there are no details of the analytical methods used. Nonetheless, at the request of the Ministry of Fisheries (now

Fisheries New Zealand) in 1999, the biomass was also estimated from the survey area that had no or little seagrass and used only quadrats with less than 200 g of seagrass to re-estimate what was termed biomass correcting for seagrass. The estimates were lower by 5–33% than the ‘all quadrats’ estimate, with no change for Port Chalmers where seagrass was not observed.

Given that there was a positive correlation between seagrass cover and cockle density in 2020 it is surprising that this was not found in 1999. The two beds with no correlation in 2020 are also those with the least seagrass cover (see Table 6). The reason for the positive correlation in 2020 is unclear but Lohrer et al. (2016) have shown that cockles also benefit seagrass by providing nitrogen (dark ammonium efflux) and contributing to the gross primary production. To some extent, the correlation in this study is likely to be a result of the interaction effect of shore height where cockles and seagrass are most dense at the optimum submergence zones.

4.6 Comparison with other New Zealand cockle populations

The total population of cockles in Otago Harbour in 2020 was estimated at 1535 million with 986 million recruited individuals (see Table 4), not including Waitati Inlet, Papanui Inlet, and Purakanui Inlets which also have substantial populations (Fisheries New Zealand 2019). By comparison, surveys of 12 northern North Island key areas in 2018–19 yielded considerably fewer cockles with estimates of 3 to 222 million cockles (all sizes), and none with more than 3 million of recruited size (Berkenbusch & Neubauer 2019). Further, the highest all sizes cockle densities for these North Island beds were only half that of those at Sawyers Bay and St Leonards, and the recruited density ranged from less than 1 to 15 cockles per square metre, which is very low compared with the densities in any of the Otago Harbour beds (see Table 5). For one of the largest beds in the North Island (Snake Bank in Whangarei Harbour) the most recent biomass estimate of recruited cockles in 2009 was 815 t (Williams et al. 2009), about two-thirds of the 2020 estimated biomass of Harwood, the sparsest of the five main beds in Otago Harbour. In addition, cockles from all these North Island areas are considerably smaller than those in and around Otago Harbour, with the majority of individuals being less than the recruited size of 30 mm (Morrison & Browne 1999, Williams et al. 2009, Berkenbusch & Neubauer 2019). The reasons for the lower densities and smaller sizes of cockles are unknown, but this appears to be widespread in the North Island. A series of eight cockle surveys in Port Levy (Banks Peninsula) between 1997 and 2006, however, revealed size compositions of cockles similar to those in and around Otago Harbour (Voller 2006). Ecological considerations

Cockles are a major component of both infaunal biomass in Otago Harbour and surrounding inlets and the loss or major reduction of this species could have consequences for the water quality because cockles collectively filter vast quantities of water each tidal cycle removing organic particulate matter and phytoplankton (Beentjes 1984). For example, the loss of cockle (*Cerastoderma edule*) and mussel beds (*Mytilus edulis*) in the Dutch Wadden Sea in 1990 was followed by an increase in diatom and chlorophyll concentrations late that year; this increase was considered to be a result of the sudden mortality of these suspension feeding bivalves (Beukema & Cadbe 1996). The sustainability of the cockle populations in New Zealand are known to be affected by factors such as sediment properties, salinity, and contamination (Morrison & Browne 1999, Marsden & Adkins 2010). The health of the Otago Harbour cockle populations will depend on maintaining a high standard of water quality in the future.

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7. TABLES

Table 1: Effort and catch data for the 2020 Otago Harbour cockle survey.

Bed	Name	Area (km^2)	Phase 1	Phase 2	Total	*N*	Catch wt (g)	Number weighed
1	Harwood	2.575	79	14	93	787	8 717	772
2	Aramoana	2.170	77		77	459	10 182	458
3	Port Chalmers	1.836	58		58	546	13 620	541
4	Sawyers Bay	1.419	86		86	2 671	32 688	848
5	St Leonards	2.838	73		73	1 986	29 979	708
6	Te Rauone Beach	0.091	66		66	349	7 380	349
Totals		10.929	439	14	453	6 798	102 566	3 676

Table 2: Length-weight coefficients for the 2020 Otago Harbour cockle survey used to convert length into weight. W = aL^b where W is weight (g) and L is length (mm). Outliers were removed when determining these coefficients.

Bed	Name	Coefficients *a*	*b*	*n*
1	Harwood	0.000205	3.1615	770
2	Aramoana	0.000328	3.0500	454
3	Port Chalmers	0.000353	3.0426	537
4	Sawyers Bay	0.000258	3.1053	830
5	St Leonards	0.000189	3.1921	701
6	Te Rauone Beach	0.000302	3.0644	343

Table 3: Biomass estimates (t) of all cockles and recruited cockles (30 mm and over) for the 2020 Otago Harbour cockle survey. The proportion of biomass that is recruited is shown as Rec (%). CI, confidence intervals; CV, coefficient of variation; Te Rauone, Te Rauone Beach.

			All cockles			Recruited			
Bed	Name	Area (km^2)	Biomass (t)	95%CI ±	CV (%)	Biomass (t)	95%CI ±	CV (%)	Rec (%)
1	Harwood	2.575	1 639	475	14.7	1 251	457	18.6	76.3
2	Aramoana	2.170	2 130	721	17.3	2 000	675	17.2	93.9
3	Port Chalmers	1.836	3 715	1 386	19.0	3 675	1 374	19.0	98.9
4	Sawyers Bay	1.419	5 353	1 165	11.1	4 384	978	11.4	81.9
5	St Leonards	2.838	10 141	2 138	10.7	9 295	2 000	10.9	91.7
6	Te Rauone	0.091	69	28	20.6	67	27	20.5	96.4
Totals		10.929	23 047			20 672			89.7

Table 4: Numbers estimates (millions) of all cockles and recruited cockles (30 mm and over) for the 2020 Otago Harbour cockle survey. The proportion that is recruited is shown as Rec (%). CI, confidence intervals; CV, coefficient of variation; Te Rauone, Te Rauone Beach.

			All cockles			Recruited			
Bed	Name	Area (km^2)	Number (millions)	95%CI ±	CV (%)	Number (millions)	95%CI ±	CV (%)	Rec (%)
1	Harwood	2.575	156.1	48.7	15.9	59.7	20.4	17.4	38.2
2	Aramoana	2.170	117.0	48.7	21.3	87.1	31.1	18.2	74.4
3	Port Chalmers	1.836	149.4	49.7	17.0	138.0	46.7	17.3	92.4
4	Sawyers Bay	1.419	474.8	123.7	13.3	246.9	58.6	12.1	52.0
5	St Leonards	2.838	634.4	156.5	12.6	451.8	101.2	11.4	71.2
6	Te Rauone	0.091	3.3	1.4	21.6	2.5	1.0	20.9	76.8
Totals		10.929	1 535.0			986.0			64.2

Table 5: Mean density of all cockles and recruited cockles (30 mm and over) for the 2020 Otago Harbour cockle survey.

		$g\ m^{-2}$		Cockles m^{-2}	
Bed	Name	All cockles	Recruited	All cockles	Recruited
1	Harwood	1 041	784	94	73
2	Aramoana	1 469	1 426	66	55
3	Port Chalmers	2 609	2 584	105	98
4	Sawyers Bay	4 223	3 618	345	194
5	St Leonards	4 563	4 163	302	213
6	Te Rauone Beach	1 242	1 203	59	47
Totals		2 516	2 267	167	107

Table 6: Correlation between seagrass (*Zostera muelleri*) percent quadrat cover and cockle density for the 2020 Otago Harbour cockle survey. Seagrass cover is the percentage of all sampled quadrats. *r*, correlation coefficient; *n*, number of quadrats sampled. ** statistically significant at level of 0.01; * statistically significant at level of 0.05.

		Cockles				Seagrass
		Number		Weight		cover (%)
Bed 1	*n*	93		93		21.1
	r	0.634	**	0.238	*	
Bed 2	*n*	77		77		9.6
	r	0.457	**	0.264	*	
Bed 3	*n*	58		58		8.5
	r	-0.249		-0.255		
Bed 4	*n*	86		86		2.6
	6	-0.173		-0.189		
Bed 5	*n*	73		73		21.8
	r	0.247	*	0.205		
Bed 6	*n*	66		66		25.6
	r	0.457	**	0.504	**	
	n	453		453		14.8
All beds	*r*	0.137	**	0.094	*	

Table 7: Biomass estimates of recruited cockles (30 mm and over) for the 1999 and 2020 Otago Harbour cockle surveys. The decline in biomass (in tonnes and %) between these two surveys is shown. The 1999 survey data are from Breen et al. (1999).

		Recruited biomass (t)			
Bed	Name	1999	2020	Decline	Decline (%)
1	Harwood	3 324	1 251	2 073	62.4
2	Aramoana	3 414	2 000	1 414	41.4
3	Port Chalmers	8 091	3 675	4 416	54.6
4	Sawyers Bay	5 546	4 384	1 162	21.0
5	St Leonards	12 599	9 295	3 304	26.2
Totals		32 974	20 606	12 368	37.5

8. FIGURES

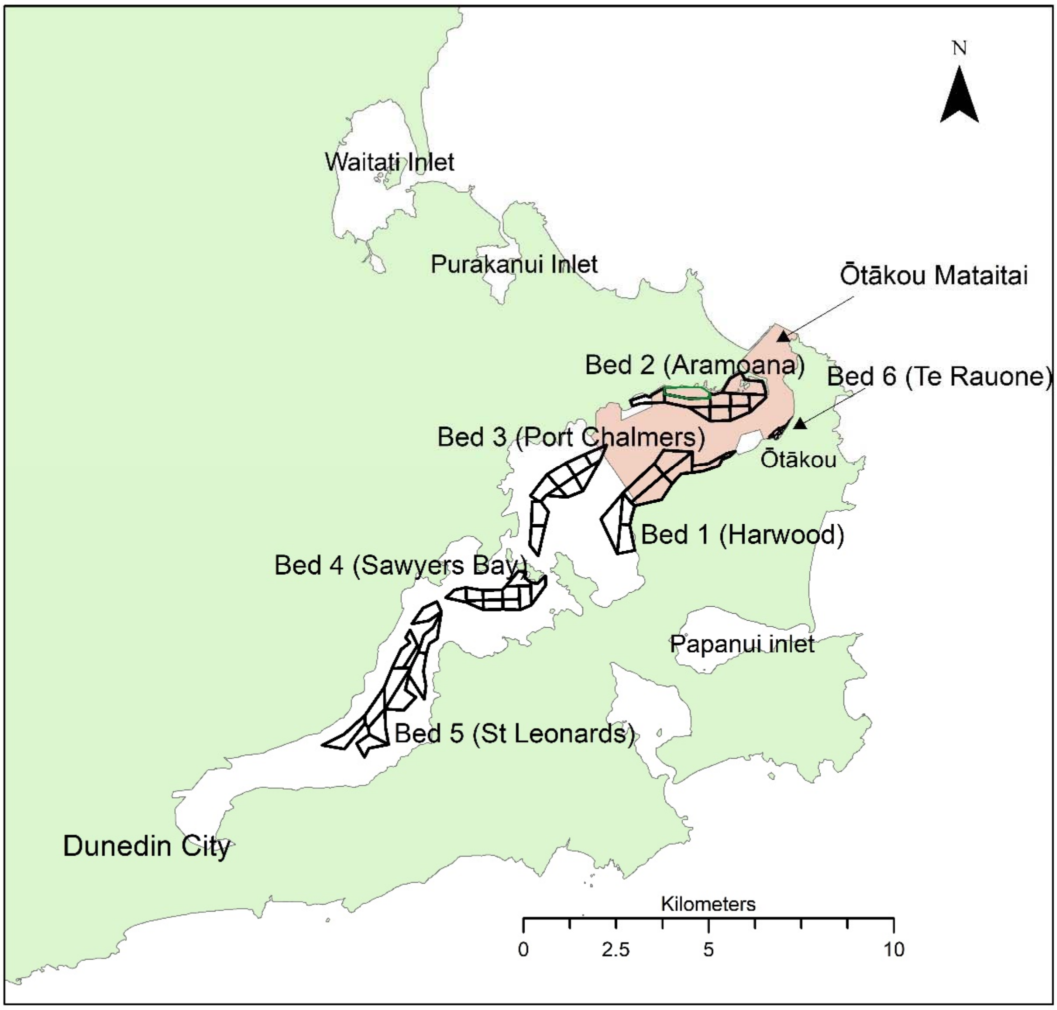


Figure 1: Otago Peninsula showing the six cockle beds within the Otago Harbour surveyed in 2020 and the Ōtākou Mātaitai (brown shaded area).

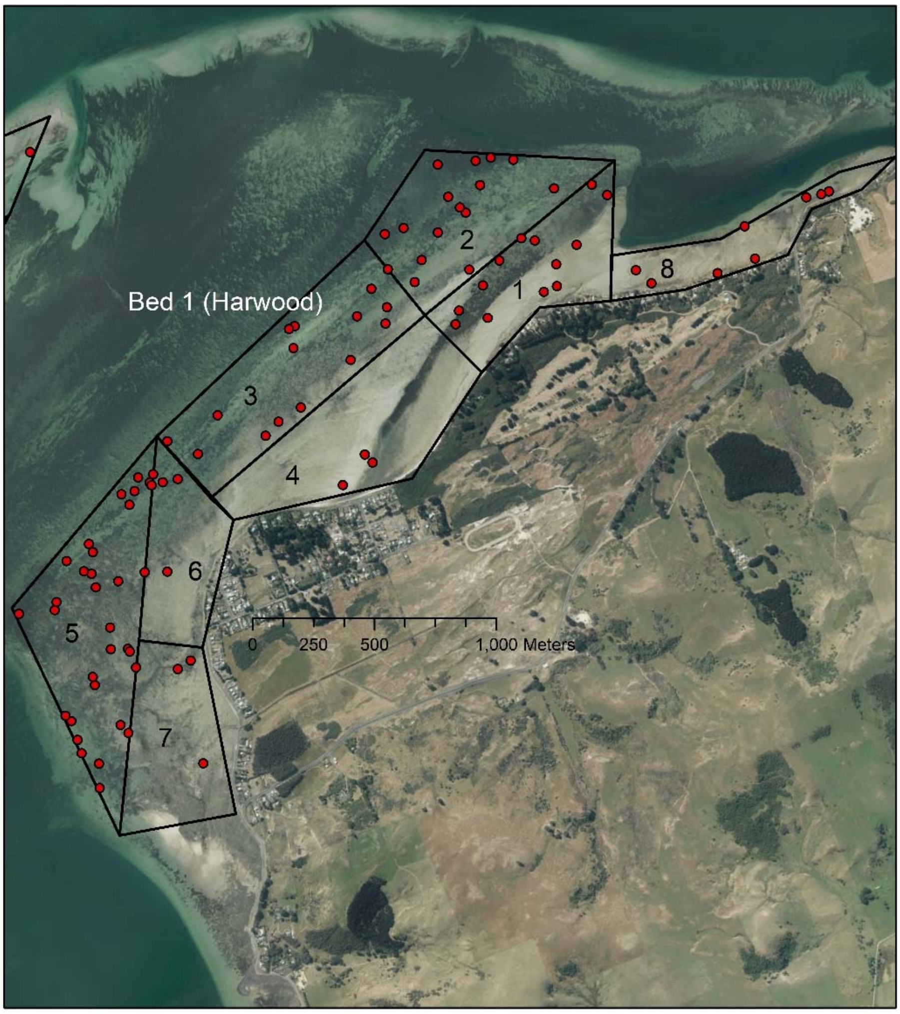
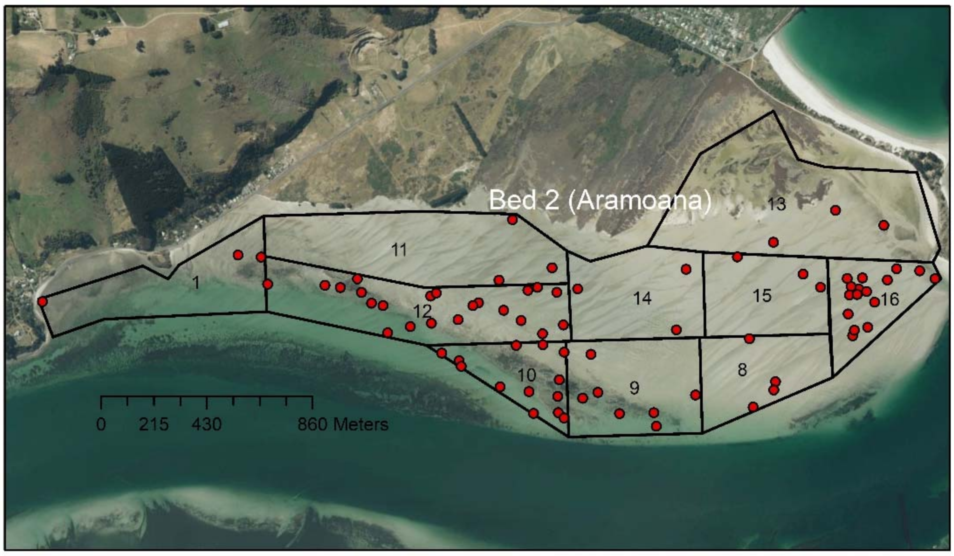


Figure 2: Strata and locations (red dots) of the stations sampled in each of the six beds in the Otago Harbour 2020 cockle survey. [Continued on next 2 pages]



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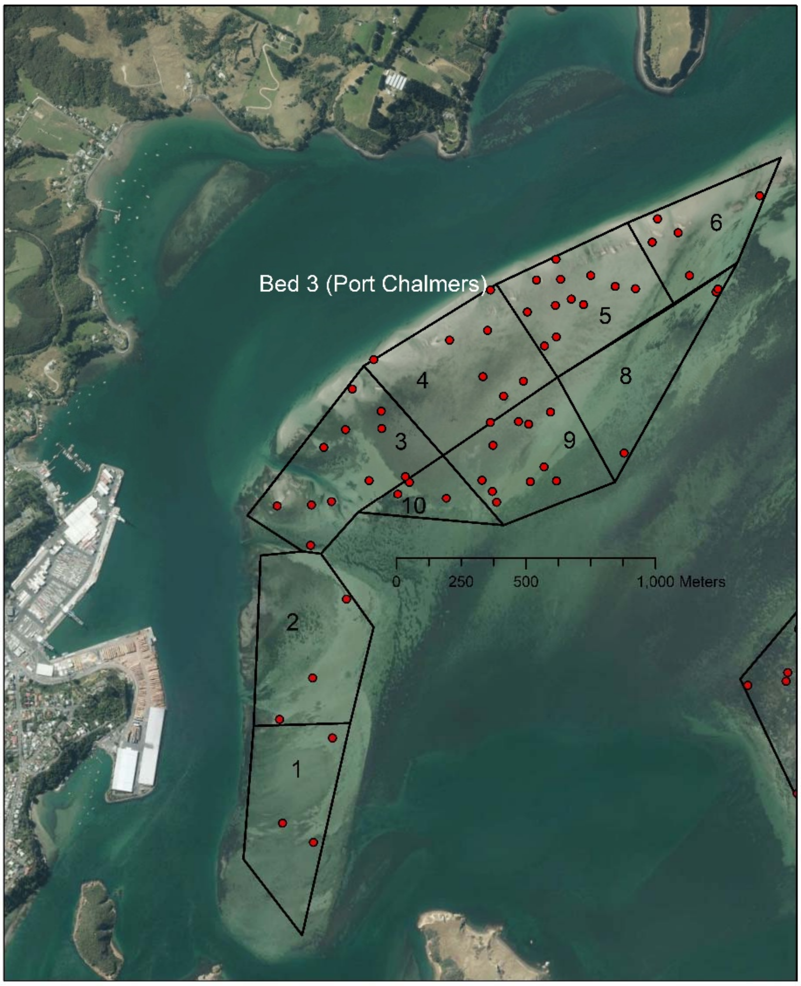

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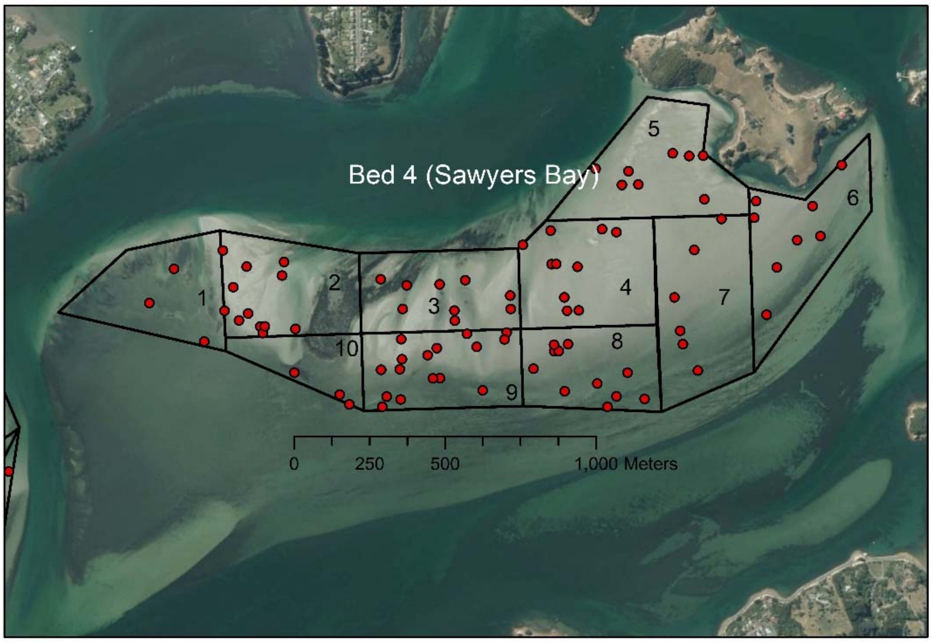

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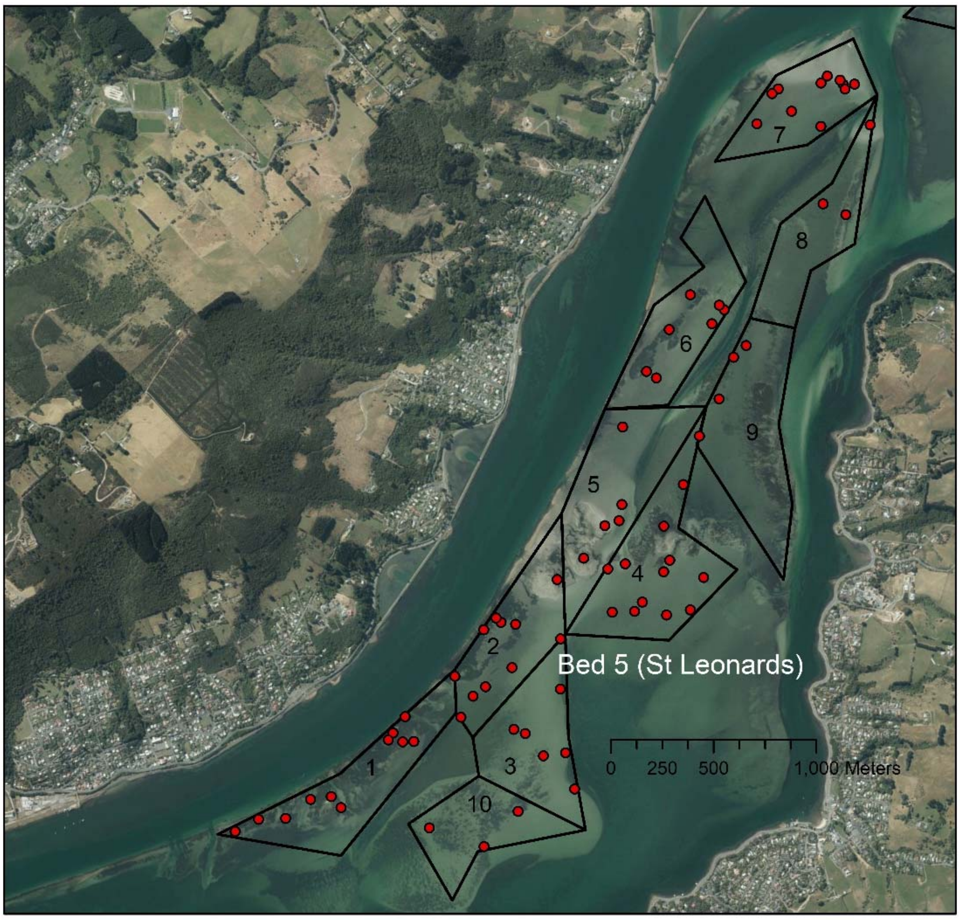

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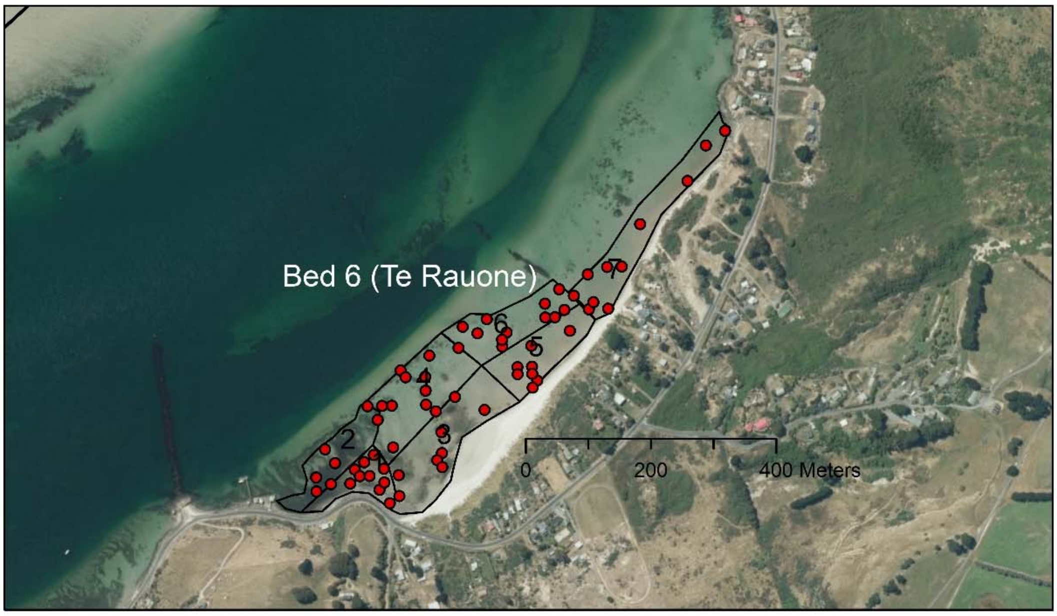


Figure 2 – ***continued.***

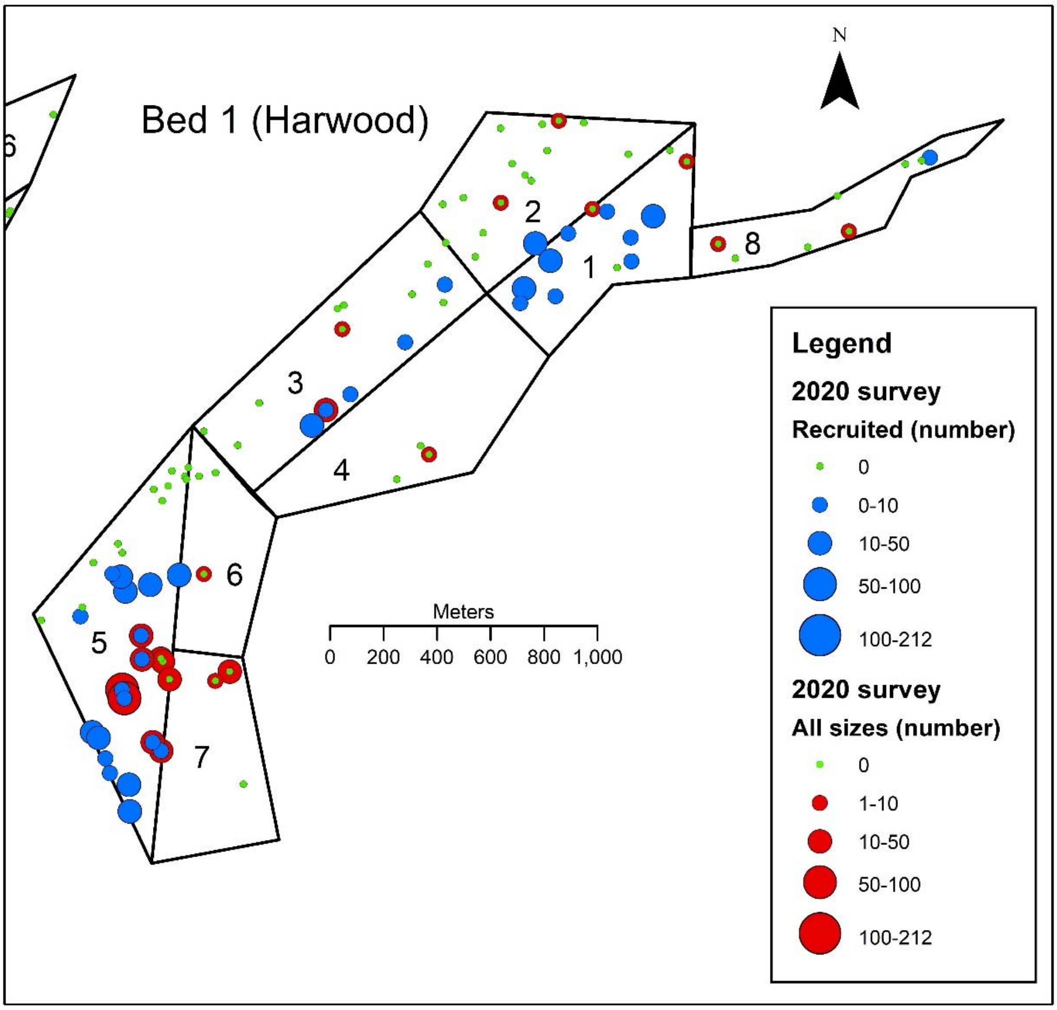


Figure 3: Catch rate plots for numbers of all cockles and recruited cockles (30 mm and over) in Beds 1 to 6 in 2020. The red circles (all cockles) sit under the blue circle (recruited) and are shown only when there were cockles at the station less than 30 mm in length. A red circle over a green dot indicates that all cockles were less than 30 mm. [Continued on next 5 pages]

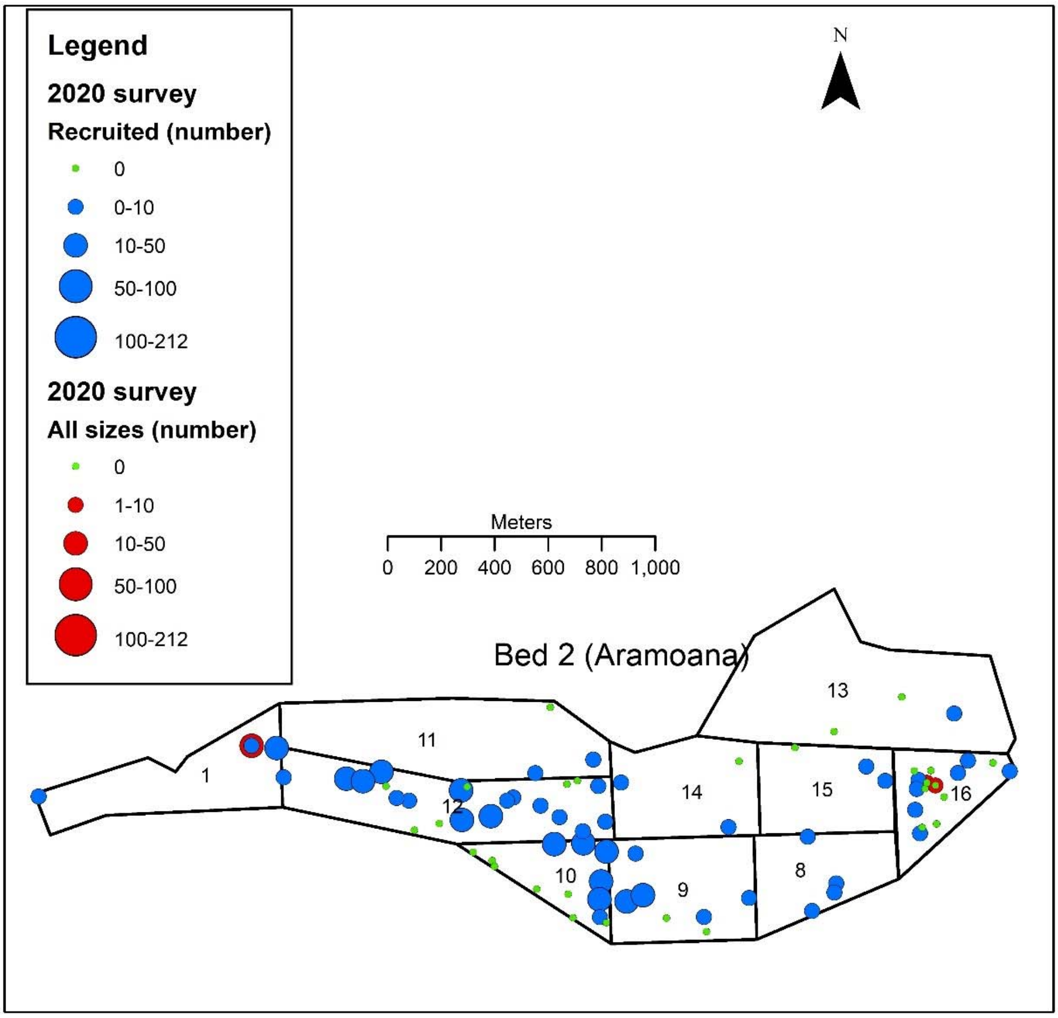
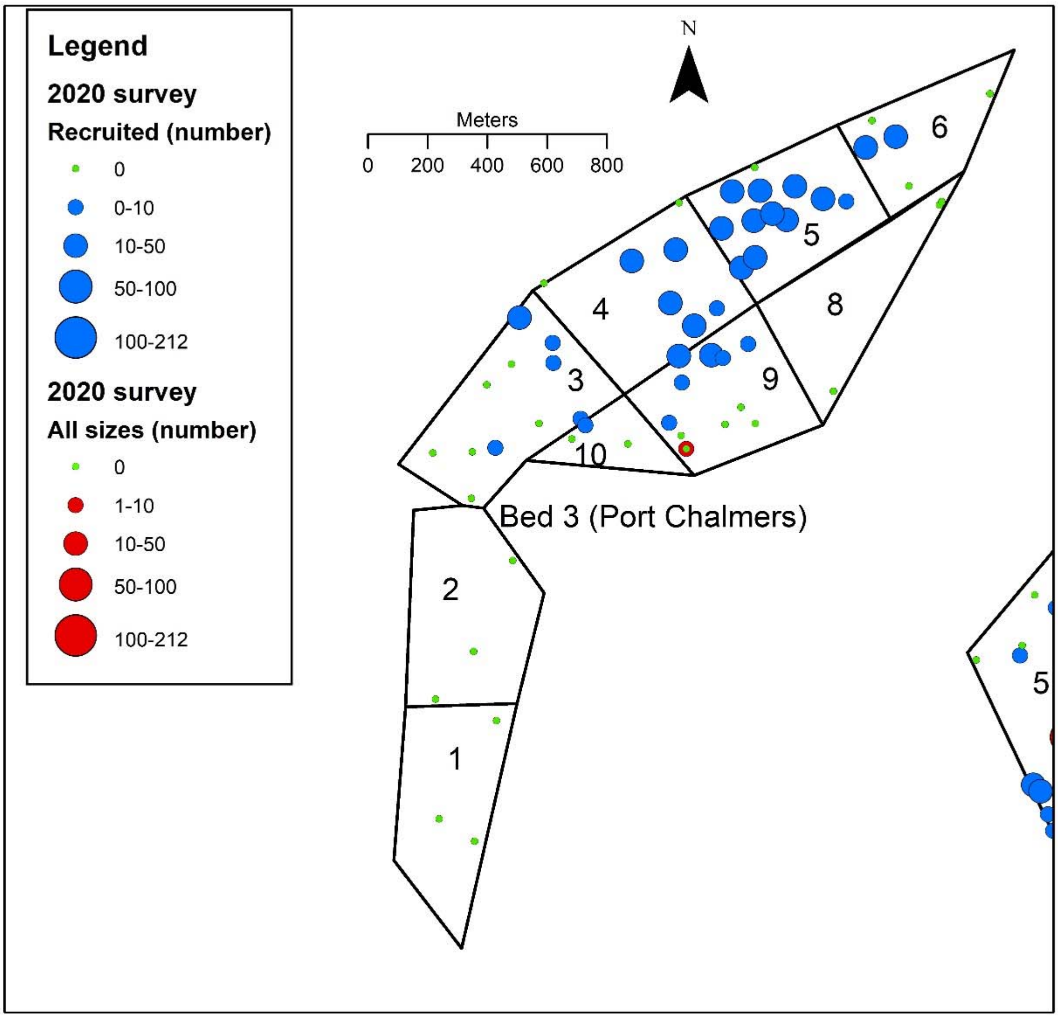


Figure 3 – *continued.*



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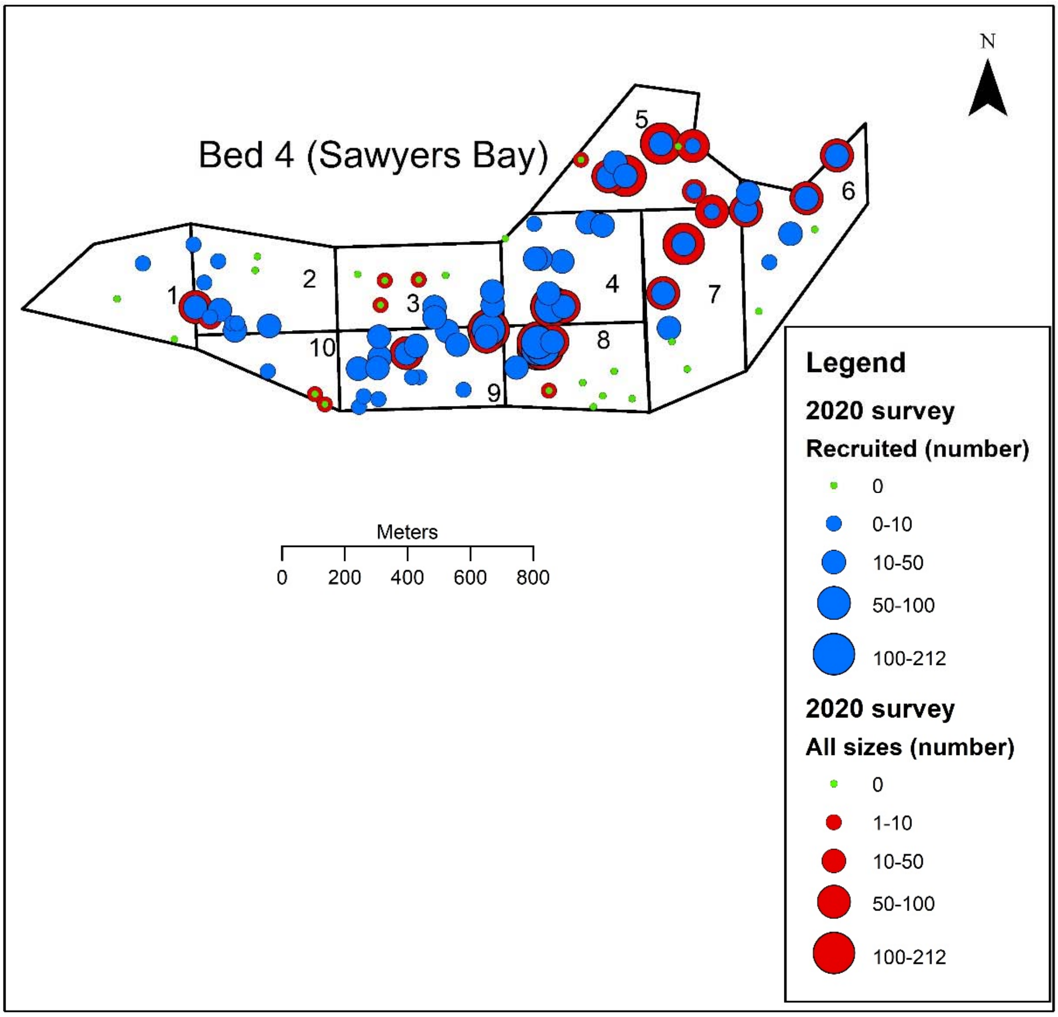

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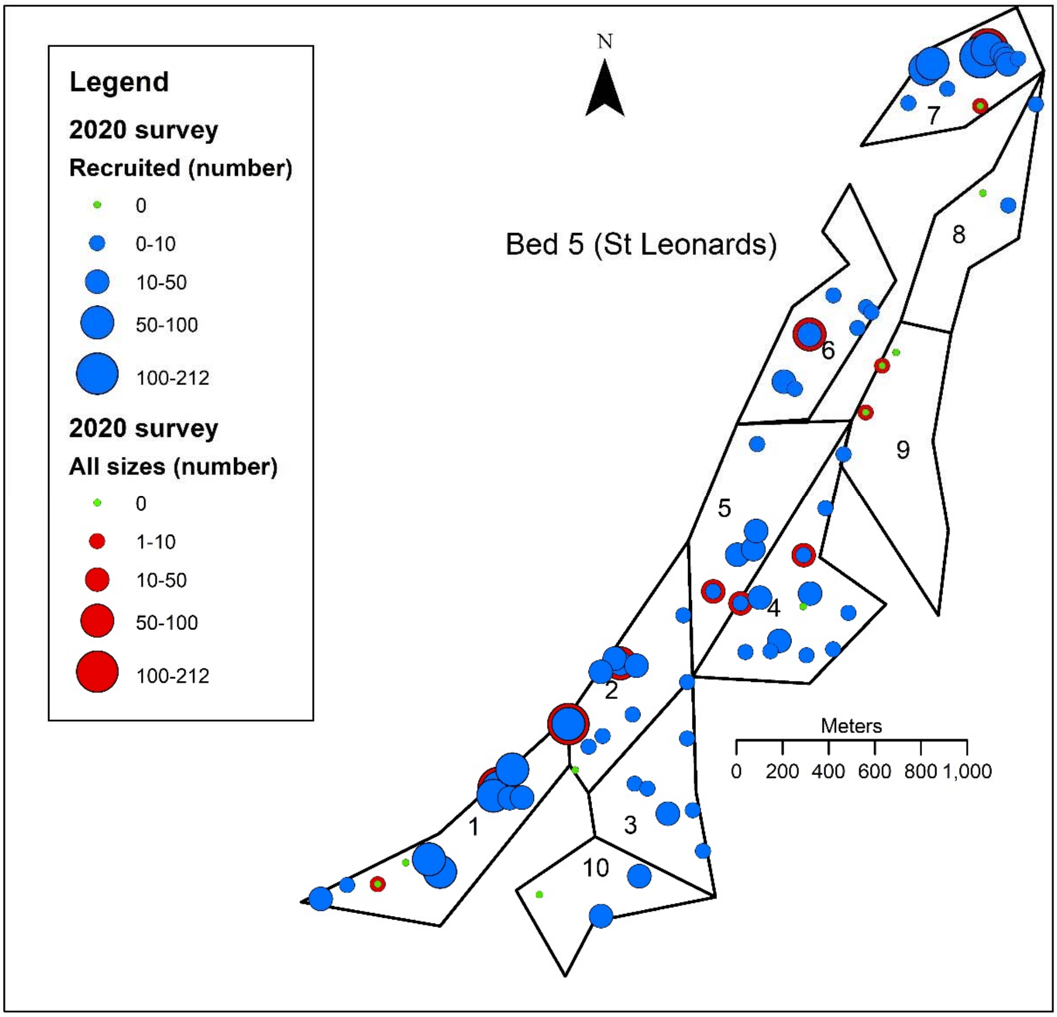


Figure 3 – *continued.*

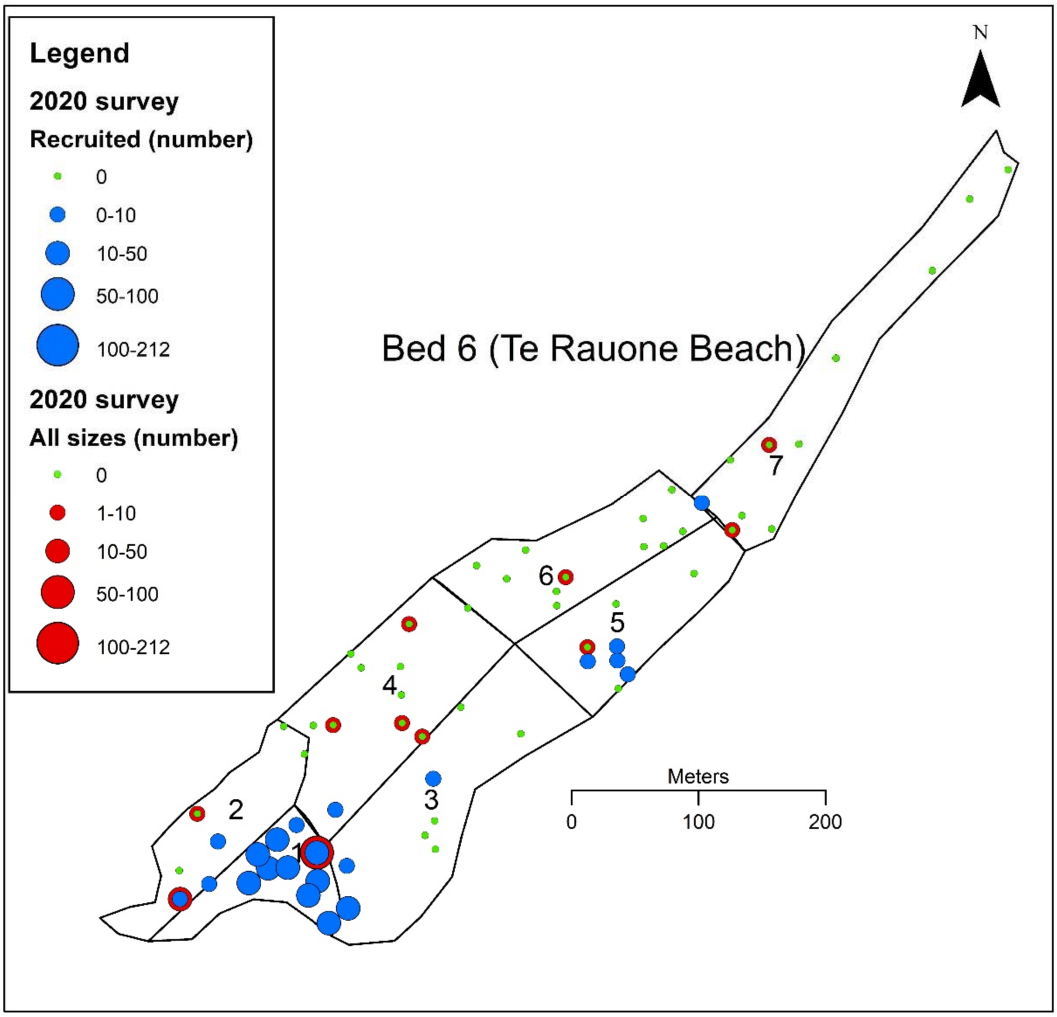


Figure 3 – *continued.*

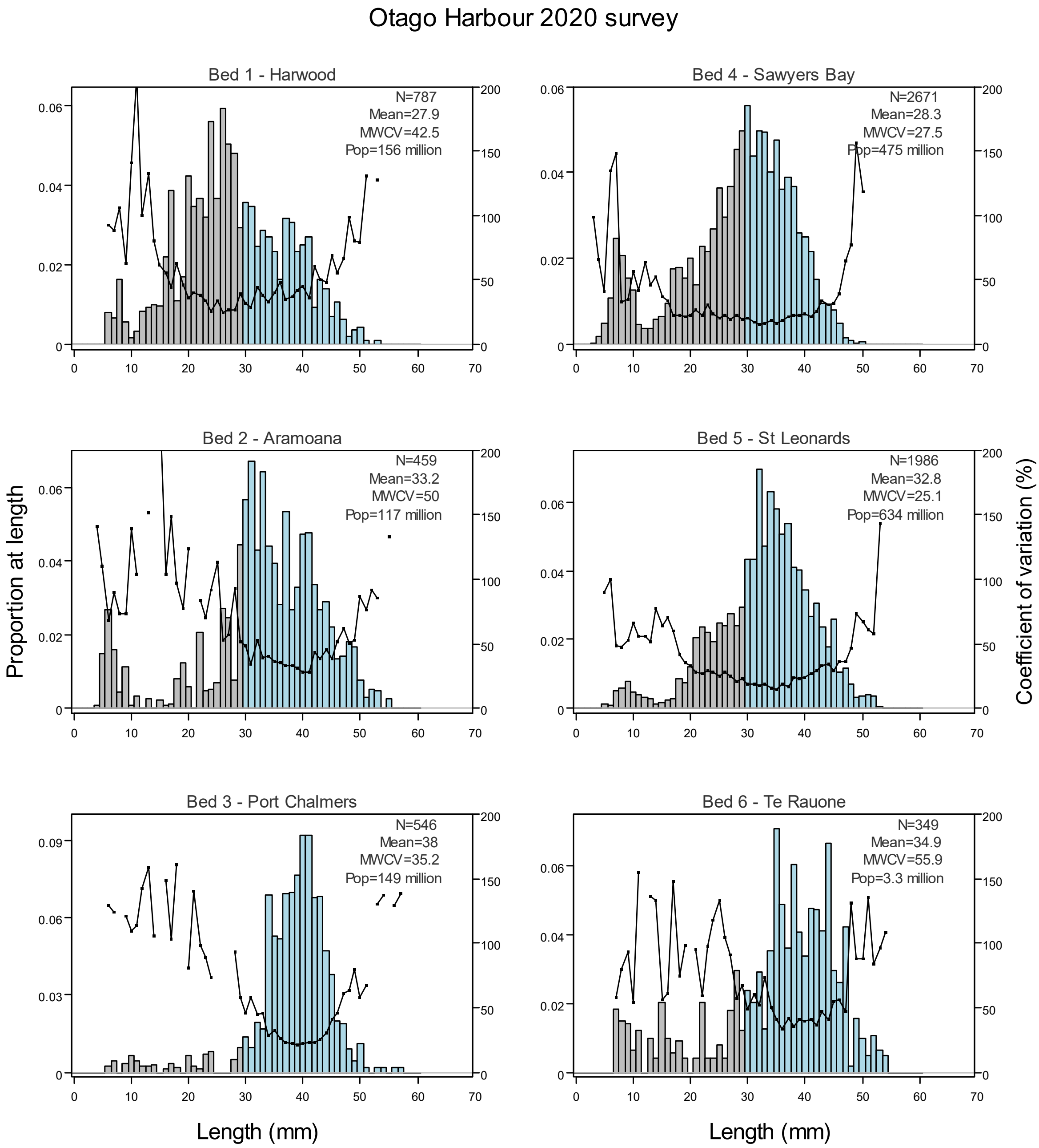


Figure 4: Scaled length frequency distributions and coefficient of variation for the six beds in the Otago Harbour 2020 cockle survey. The blue bars are recruited lengths (30 mm and over). N, numbers sampled; mean, mean length; MWCV, mean weighted coefficient of variation (%); Pop, population estimate.

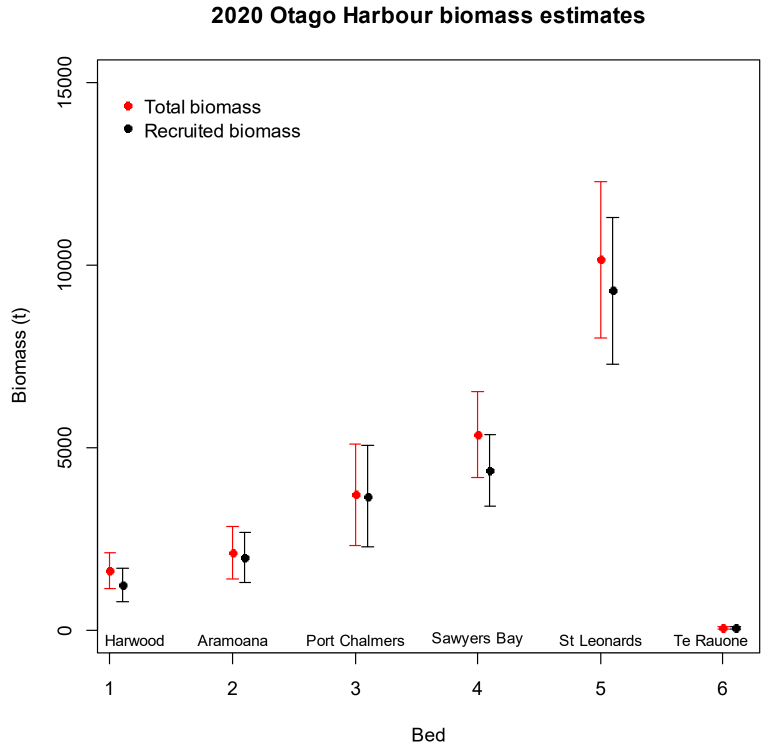


Figure 5: Biomass estimates (t) for all cockles and recruited cockles (30 mm and over) for the 2020 Otago Harbour cockle survey. Error bars are 95% confidence intervals.

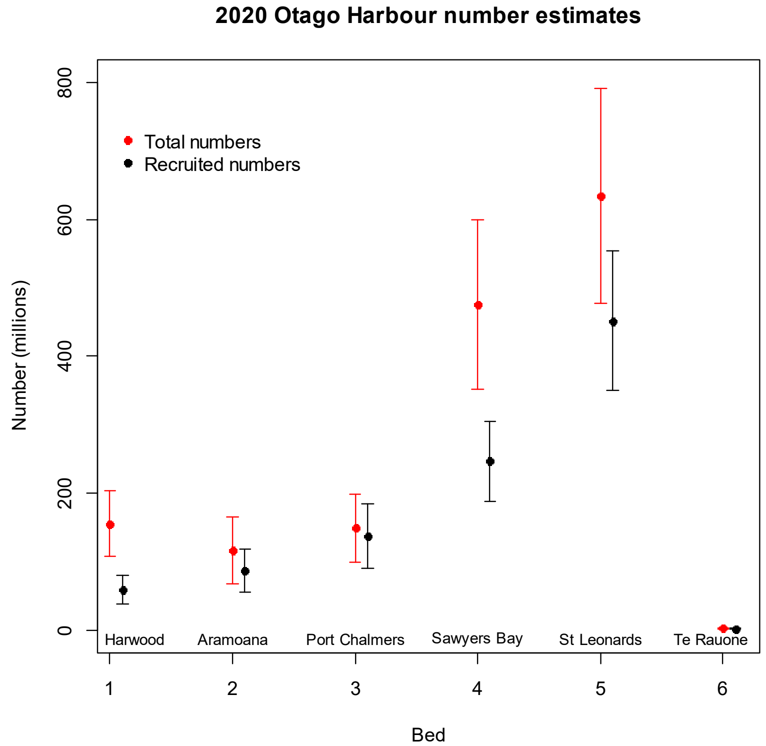


Figure 6: Numbers estimates for all cockles and recruited cockles (30 mm and over) for 2020 Otago Harbour cockle survey. Error bars are 95% confidence intervals.

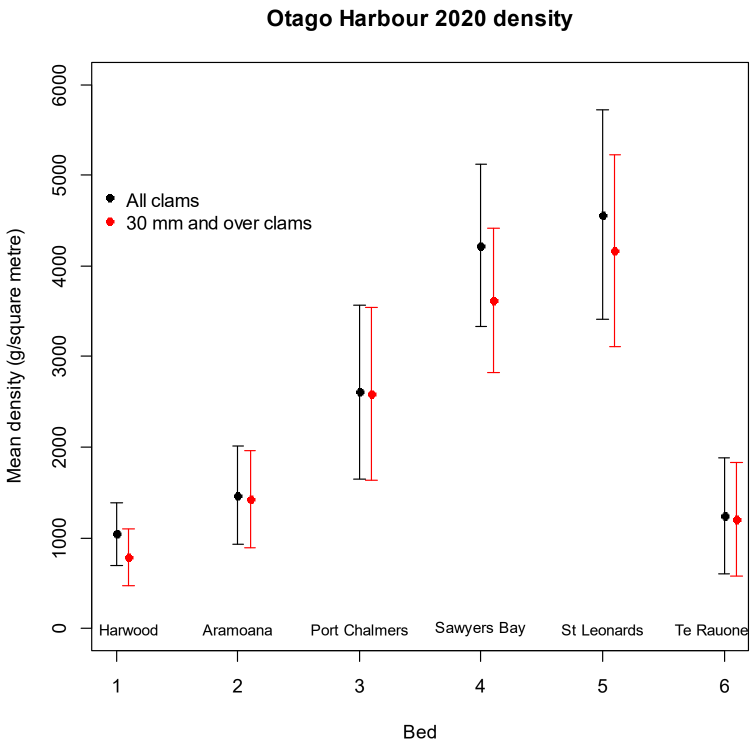


Figure 7: Density (grams per m^2) for all cockles and recruited cockles (30 mm and over) for 2020 Otago Harbour cockle survey. Error bars are 95% confidence intervals.

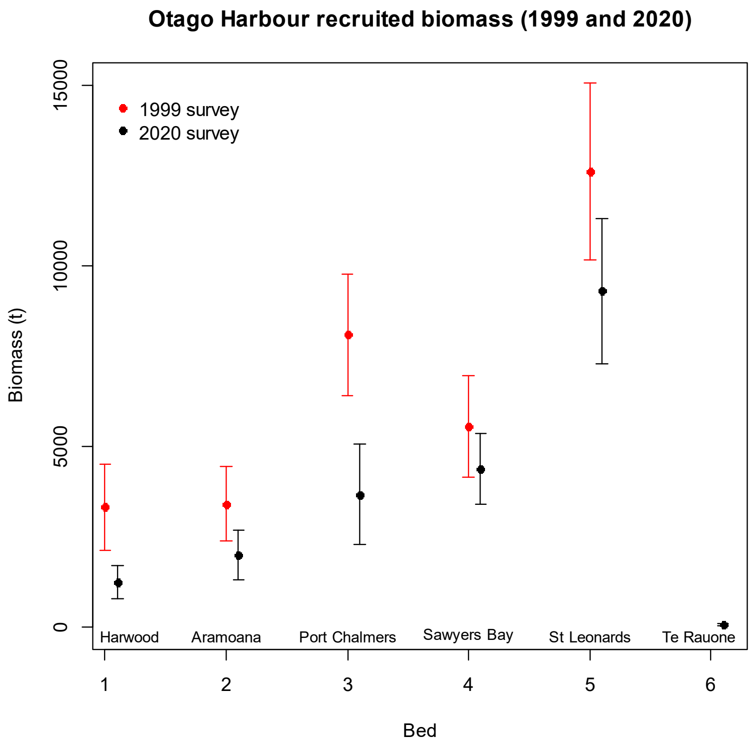


Figure 8: Biomass estimates (t) for recruited cockles (30 mm and over) for the 1999 and 2020 Otago Harbour cockle surveys. Error bars are 95% confidence intervals. 1999 estimates are from Breen et al. (1999)

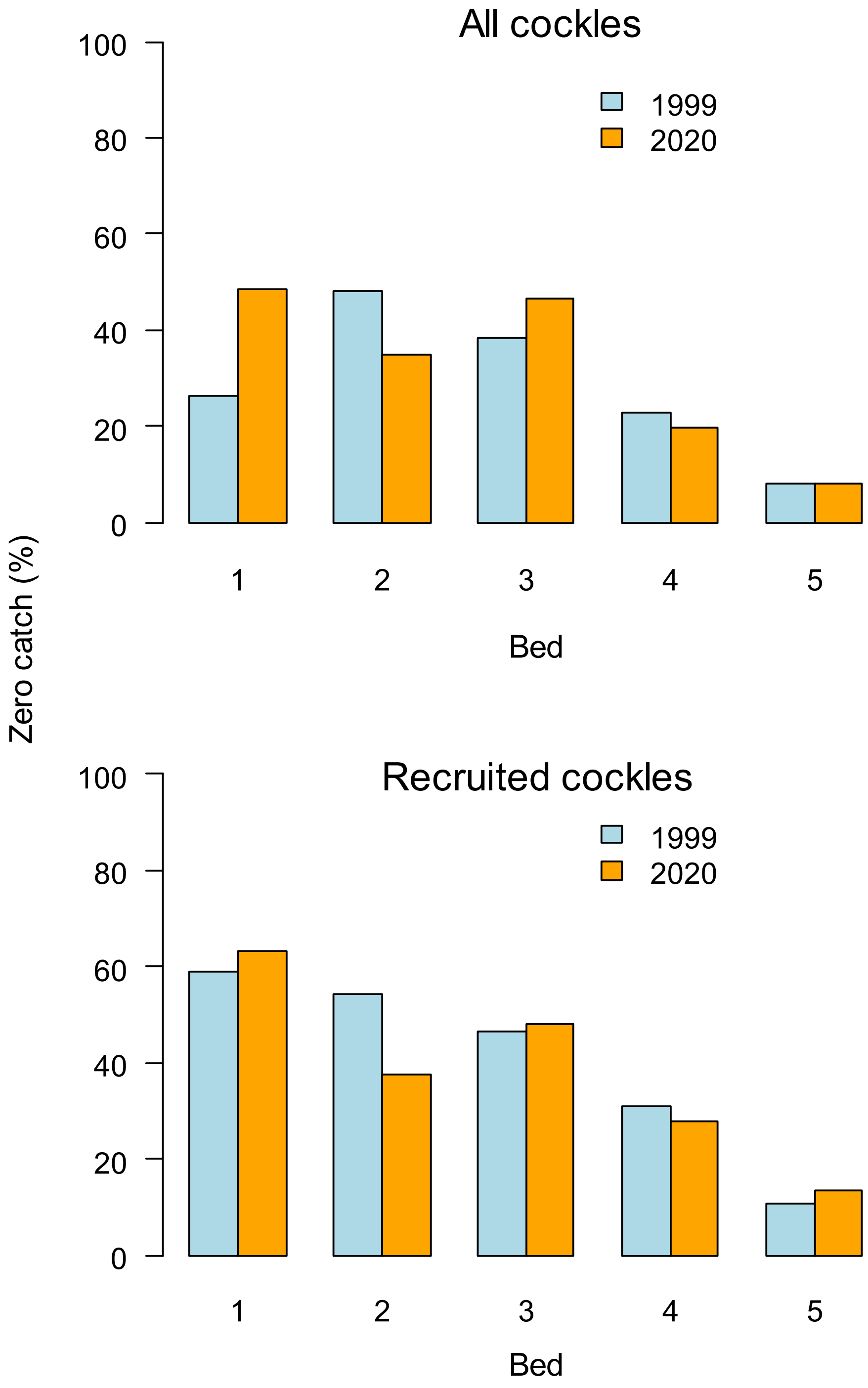


Figure 9: Zero catch (%) of all cockles and recruited cockles (30 mm and over) for the 1999 and 2020 Otago Harbour cockle surveys. Bed 1, Harwood; bed 2, Aramoana; bed 3, Port Chalmers; bed 4, Sawyers Bay; bed 5, St Leonards.

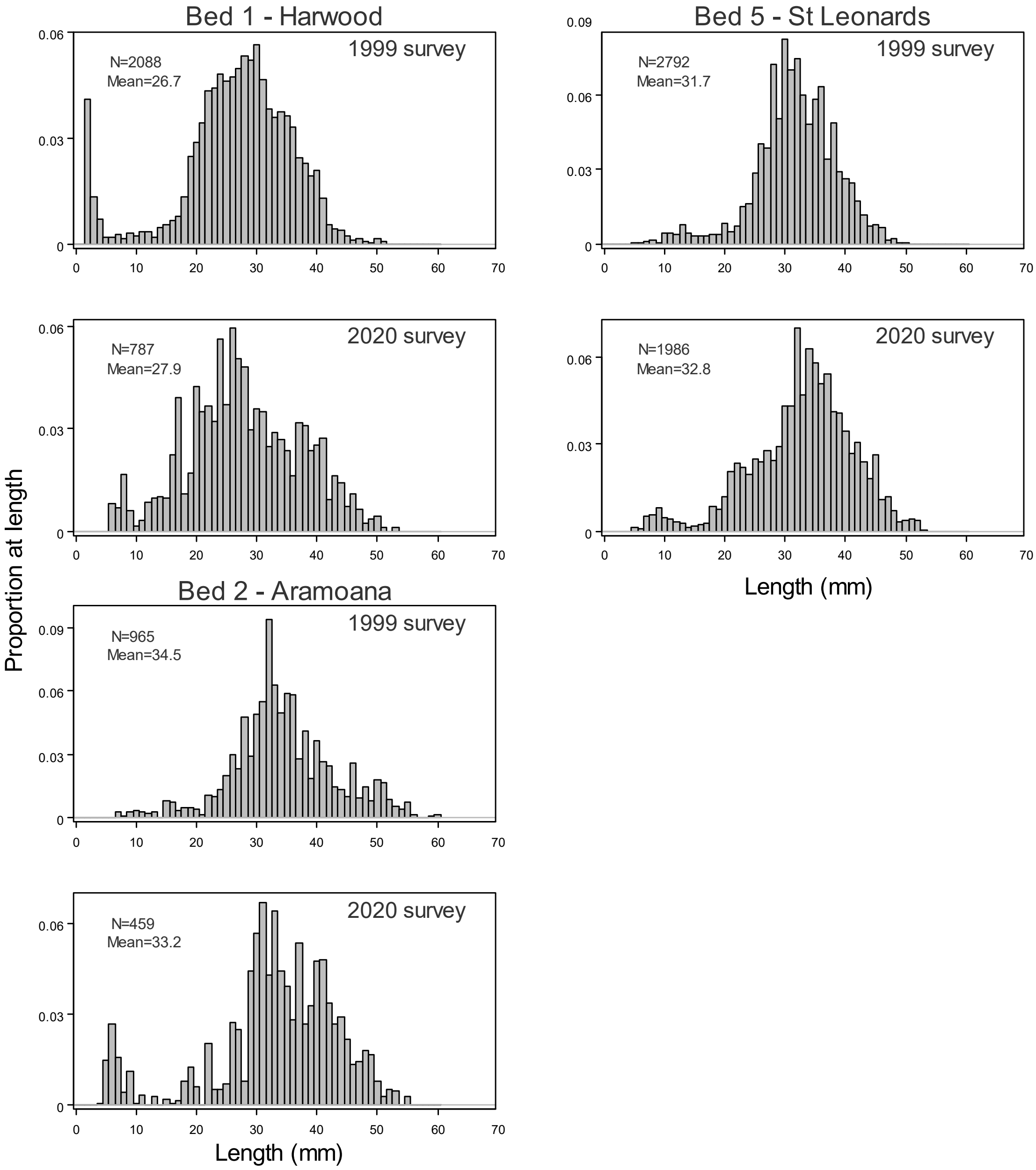


Figure 10: Time series scaled length frequency distributions for five cockle beds in the Otago Harbour. For beds 1, 2, and 5 there are two surveys (1999 and 2020, Fisheries New Zealand surveys) and for beds 3 and 4 there are five surveys (1999 and 2020 as well as the 2007, 2012, and 2017 Southern Clams Ltd surveys). N, numbers sampled; mean, mean length. **[Continued on next page]**

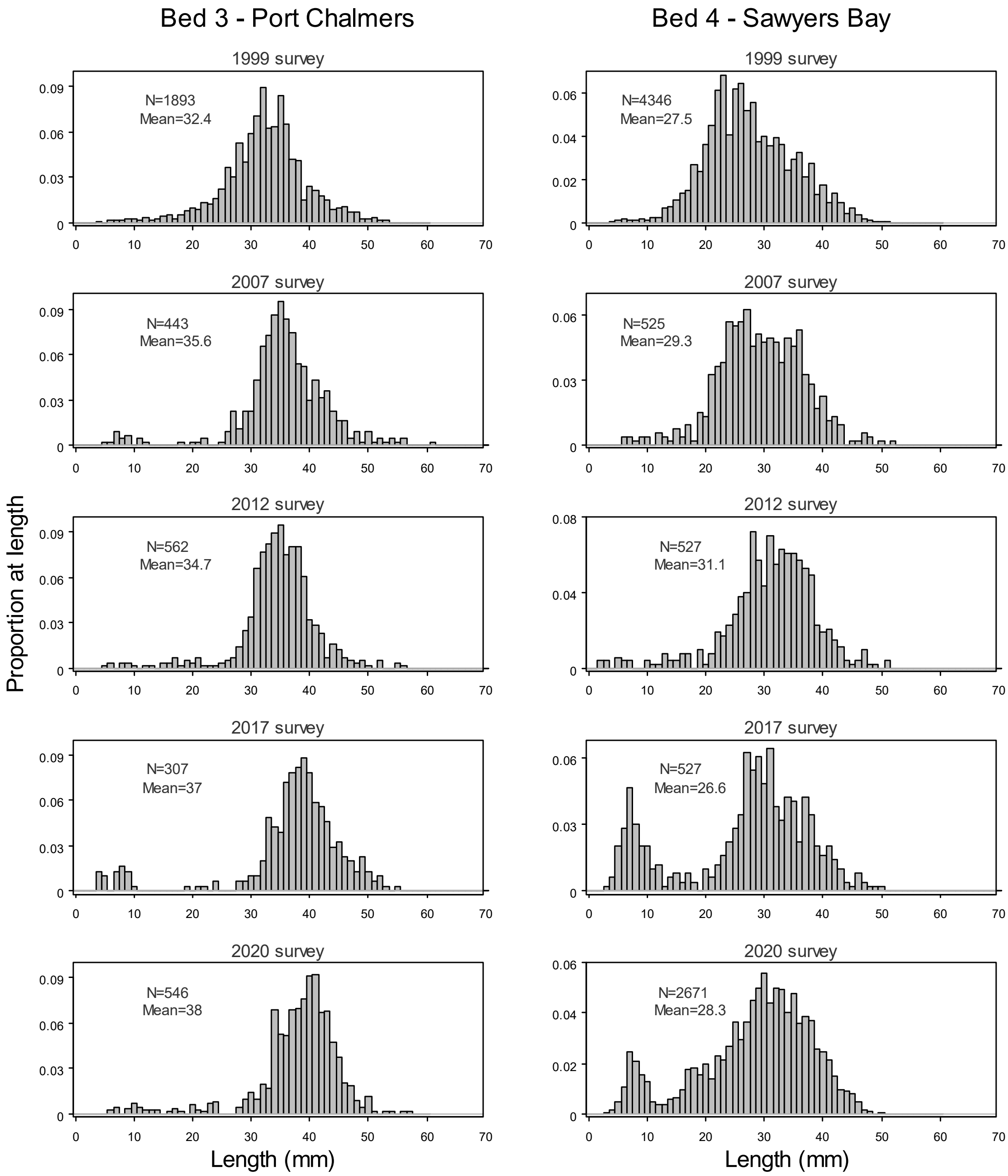
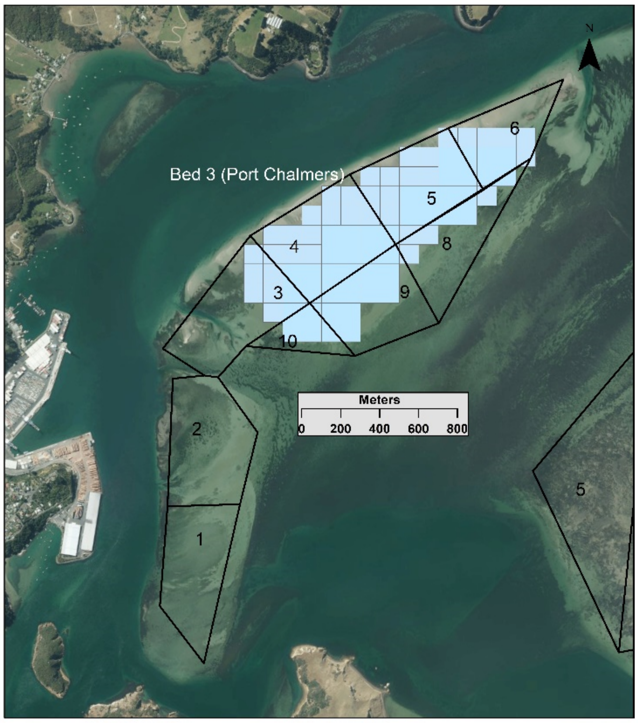


Figure 10 – ***continued.***



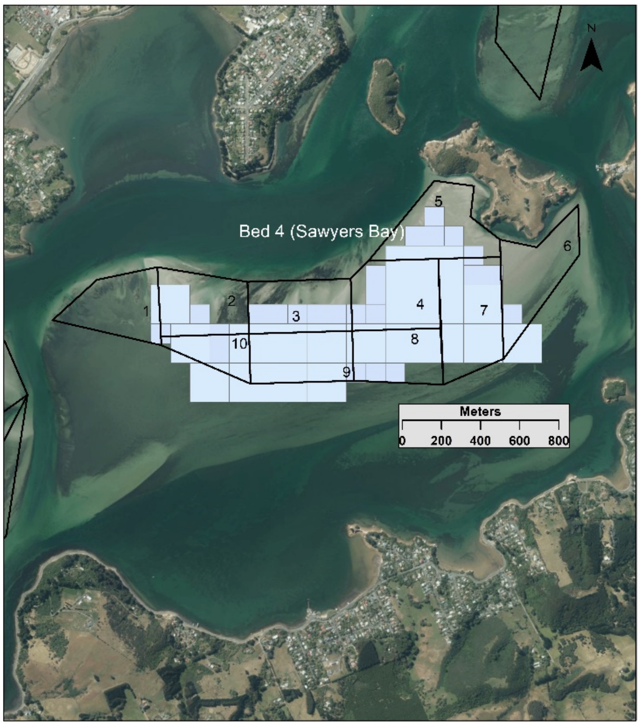


Figure 11: Port Chalmers (top panel) and Sawyers Bay (bottom panel). Strata used in the 1999 and 2020 surveys are the polygons bounded by thick black lines and numbered 1–8 for Port Chalmers and 1–10 for Sawyers Bay. Strata used by Southern Clams Ltd in 2007, 2012, and 2017 surveys are overlaid and shaded in light blue.

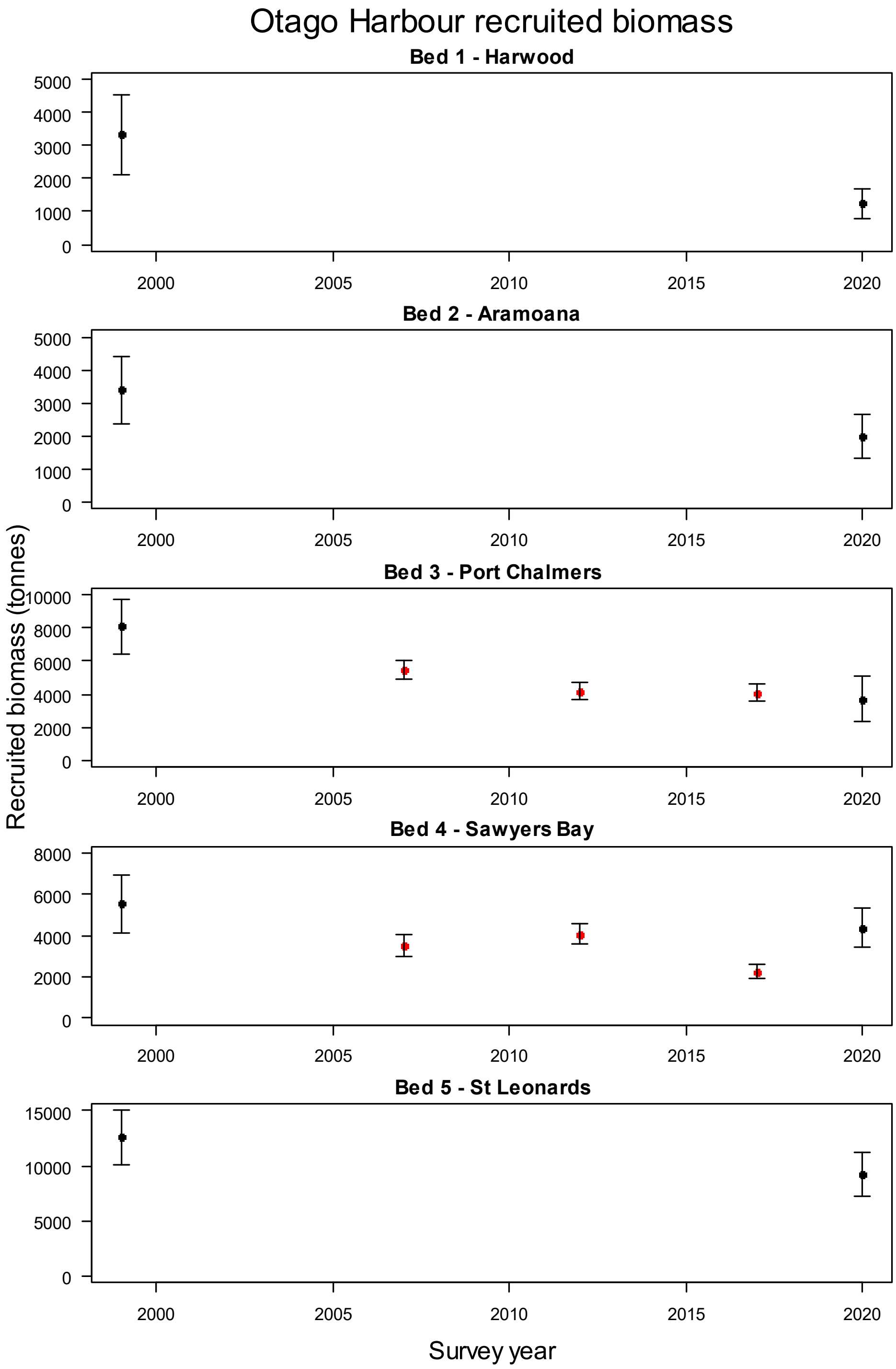


Figure 12: Time series biomass estimates (t) for recruited cockles (30 mm and over) in Otago Harbour. For beds 1, 2, and 5 there are two surveys (1999 and 2020, Fisheries New Zealand surveys) and for bed 3 and 4 there are five surveys (1999 and 2020 as well as the 2007, 2012, and 2017 Southern Clams Ltd surveys). The red points denote the Southern Clams Ltd surveys in which the survey areas differed from those in 1999 and 2020 (see text for explanation). Error bars are 95% confidence intervals.

9. APPENDICES

Appendix 1: Bed 1 (Harwood). (1a) Biomass estimates and (1b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). *A_i* is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

1a

All cockles

	Sampling units					
Stratum	km^2	*Ai*	*n*	mean g $quadrat^{-1}$	Var	Biomass (t)
1	0.282	3 129 222	13	96.5	15 545	301.9
2	0.350	3 889 667	16	21.8	7 425	84.7
3	0.428	4 755 556	14	47.6	5 432	226.2
4	0.402	4 471 889	3	3.1	29	14.0
5	0.440	4 893 111	33	190.3	40 833	931.1
6	0.215	2 393 000	3	7.3	162	17.6
7	0.276	3 062 667	3	12.7	184	39.0
8	0.182	2 021 333	8	12.4	1 152	25.1
Totals	2.575	28 616 445	93	93.7	Biomass	1 639.5
					CV	14.8%
					±95%CI	475.3

Recruited (30 mm and over)

	Sampling units					
Stratum	km^2	*Ai*	*n*	mean g $quadrat^{-1}$	Var	Biomass (t)
1	0.282	3 129 222	13	93.7	15 143	293.3
2	0.350	3 889 667	16	21.4	7 302	83.1
3	0.428	4 755 556	14	45.9	5 032	218.3
4	0.402	4 471 889	3	0.0	0	0.0
5	0.440	4 893 111	33	129.2	37 801	632.4
6	0.215	2 393 000	3	0.0	0	0.0
7	0.276	3 062 667	3	0.0	0	0.0
8	0.182	2 021 333	8	12.1	1 162	24.4
Totals	2.575	28 616 445	93	70.6	Biomass	1 251.4
					CV:	18.60%
					±95%CI	457.4

1b

All cockles

Stratum	Km^2	Sampling units *Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.282	3 129 222	13	5.9	52	18 534 623
2	0.350	3 889 667	16	1.2	16	4 618 980
3	0.428	4 755 556	15	3.0	27	14 266 668
4	0.402	4 471 889	2	1.0	2	4 471 889
5	0.440	4 893 111	33	18.7	433	91 338 072
6	0.215	2 393 000	3	1.7	8	3 988 333
7	0.276	3 062 667	3	5.7	54	17 355 113
8	0.182	2 021 333	8	0.8	2	1 516 000
	2.575	28 616 445	93	8.5	Number	156 089 677
					CV:	15.90%
					±95%CI	48 654 450

Recruited (30 mm and over)

Stratum	Km^2	Sampling units *Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.282	3 129 222	13	3.8	22	12 035 469
2	0.350	3 889 667	16	0.9	14	3 646 563
3	0.428	4 755 556	14	2.8	21	13 247 620
4	0.402	4 471 889	3	0.0	0	0
5	0.440	4 893 111	33	6.1	60	29 803 494
6	0.215	2 393 000	3	0.0	0	0
7	0.276	3 062 667	3	0.0	0	0
8	0.182	2 021 333	8	0.5	2	1 010 667
	2.575	28 616 445	93	6.6	Number	59 743 813
					CV:	17.40%
					±95%CI	20 418 245

Appendix 2: Bed 2 (Aramoana). (2a) Biomass estimates and (2b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). A_i is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

2a

All cockles

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.197	2 188 889	3	137.9	11 121	301.8
8	0.144	1 600 000	4	45.1	228	72.1
9	0.203	2 255 556	7	199.0	55 264	448.8
10	0.106	1 177 778	13	174.4	53 464	205.5
11	0.320	3 555 556	3	32.3	1 811	114.7
12	0.280	3 111 111	22	230.9	92 402	718.5
13	0.430	4 777 778	3	31.3	2 945	149.7
14	0.200	2 222 222	3	17.2	305	38.1
15	0.160	1 777 778	3	17.2	229	30.6
16	0.130	1 444 444	16	34.6	229	49.9
	2.170	24 111 111	77	132.2	Biomass	2 129.8
					CV:	17.2%
					±95%CI	720.8

Recruited (30 mm and over)

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.197	2 188 889	3	98.7	4 766	216.0
8	0.144	1 600 000	4	45.1	228	72.1
9	0.203	2 255 556	7	198.1	54 596	446.9
10	0.106	1 177 778	13	173.5	53 000	204.3
11	0.320	3 555 556	3	32.3	1 811	114.7
12	0.280	3 111 111	22	224.5	89 010	698.5
13	0.430	4 777 778	3	27.7	2 302	132.3
14	0.200	2 222 222	3	17.2	305	38.1
15	0.160	1 777 778	3	16.1	194	28.6
16	0.130	1 444 444	16	33.9	3 395	48.9
	2.170	24 111 111	77	128.3	Biomass	2 000.4
					CV:	17.2%
					±95%CI	674.8

2b

All cockles

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.197	2 188 889	3	15.7	146	34 292 593
8	0.144	1 600 000	4	1.0	0	1 600 000
9	0.203	2 255 556	7	7.0	67	15 788 889
10	0.106	1 177 778	13	8.8	163	10 418 803
11	0.32	3 555 556	3	1.3	2	4 740 741
12	0.28	3 111 111	22	9.5	120	29 414 141
13	0.43	4 777 778	3	3.3	33	15 925 926
14	0.2	2 222 222	3	0.7	0	1 481 481
15	0.16	1 777 778	3	1.0	1	1 777 778
16	0.13	1 444 444	16	1.1	2	1 534 722
	2.17	24 111 111	77	6.0	Number	116 975 074
					CV:	21.30%
					±95%CI	48743360

Recruited (30 mm and over)

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.197	2 188 889	3	8.3	32	18 240 741
8	0.144	1 600 000	4	1.0	0	1 600 000
9	0.203	2 255 556	7	6.7	63	15 144 444
10	0.106	1 177 778	13	7.9	124	9 331 624
11	0.32	3 555 556	3	1.3	2	4 740 741
12	0.28	3 111 111	22	7.9	90	24 606 061
13	0.43	4 777 778	3	2.0	12	9 555 556
14	0.2	2 222 222	3	0.7	0	1 481 481
15	0.16	1 777 778	3	0.7	0	1 185 185
16	0.13	1 444 444	16	0.9	2	1 263 889
	2.17	24 111 111	77	4.9	Number	87 149 722
					CV:	18.20%
					±95%CI	31136942

Appendix 3: Bed 3 (Port Chalmers). (3a) Biomass estimates and (3b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). A_i is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

3a

All cockles

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g $quadrat^{-1}$	Var	Biomass (t)
1	0.219	2 433 333	3	0.0	0	0.0
2	0.254	2 822 222	3	0.0	0	0.0
3	0.250	2 777 778	11	97.0	23 351	269.5
4	0.254	2 822 222	8	353.9	80 337	998.7
5	0.229	2 544 444	12	508.9	95 715	1 294.8
6	0.163	1 811 111	5	487.0	520 440	881.9
8	0.191	2 122 222	3	0.0	0	0.0
9	0.204	2 266 667	10	111.8	19 512	253.5
10	0.072	800 000	3	20.8	1 294	16.6
	1.836	20 400 000	58	234.8	Biomass	3 715.1
					CV:	19.0%
					±95%CI	1 385.5

Recruited (30 mm and over)

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g $quadrat^{-1}$	Var	Biomass (t)
1	0.219	2 433 333	3	0.0	0	0.0
2	0.254	2 822 222	3	0.0	0	0.0
3	0.250	2 777 778	11	95.8	22 492	266.1
4	0.254	2 822 222	8	345.9	77 323	976.1
5	0.229	2 544 444	12	506.8	94 969	1 289.5
6	0.163	1 811 111	5	483.4	513 846	875.4
8	0.191	2 122 222	3	0.0	0	0.0
9	0.204	2 266 667	10	111.4	19 617	252.5
10	0.072	800 000	3	19.2	1 106	15.4
	1.836	20 400 000	58	232.6	Biomass	3 675.0
					CV:	19.1%
					±95%CI	1374.0

3b

All cockles

Stratum	Sampling units Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.219	2 433 333	3	0.0	0	0
2	0.254	2 822 222	3	0.0	0	0
3	0.250	2 777 778	11	2.9	31	8 080 808
4	0.254	2 822 222	8	17.9	201	50 447 222
5	0.229	2 544 444	12	21.3	162	54 069 444
6	0.163	1 811 111	5	15.4	490	27 891 111
8	0.191	2 122 222	3	0.0	0	0
9	0.204	2 266 667	10	3.7	21	8 386 667
10	0.072	800 000	3	0.7	1	533 333
	1.836	20 400 000	58	9.4	Number	149 408 586
					CV:	16.9%
					±95%CI	49 667 271

Recruited (30 mm and over)

Stratum	Sampling units Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.219	2 433 333	3	0.0	0	0
2	0.254	2 822 222	3	0.0	0	0
3	0.250	2 777 778	11	2.4	17	6 565 657
4	0.254	2 822 222	8	15.3	157	43 038 889
5	0.229	2 544 444	12	20.8	151	52 797 222
6	0.163	1 811 111	5	15.0	467	27 166 667
8	0.191	2 122 222	3	0.0	0	0
9	0.204	2 266 667	10	3.6	22	8 160 000
10	0.072	800 000	3	0.3	0	266 667
	1.836	20 400 000	58	8.8	Number	137 995 101
					CV:	17.2%
					±95%CI	46 673 771

Appendix 4: Bed 4 (Sawyers Bay). (4a) Biomass estimates and (4b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). A_i is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

4a

All cockles

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.137	1 522 222	3	12.0	434	18.3
2	0.140	1 555 556	12	307.2	91 526	477.9
3	0.139	1 544 444	9	297.2	158 121	459.0
4	0.156	1 733 333	10	518.1	153 920	898.1
5	0.169	1 877 778	8	453.4	143 102	851.4
6	0.150	1 666 667	8	338.2	105 649	563.7
7	0.190	2 111 111	6	318.4	93 963	672.2
8	0.127	1 411 111	11	437.5	313 982	617.4
9	0.139	1 544 444	16	496.9	131 939	767.5
10	0.072	800 000	3	34.0	2077	27.2
	1.419	15 766 667	86	380.1	Biomass	5 352.6
					CV:	11.1%
					±95%CI	1 165.2

Recruited (30 mm and over)

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.137	1 522 222	3	12.0	434	18.3
2	0.140	1 555 556	12	298.2	89 507	463.9
3	0.139	1 544 444	9	289.8	153 573	447.6
4	0.156	1 733 333	10	478.8	132 719	830.0
5	0.169	1 877 778	8	322.0	105 746	604.7
6	0.150	1 666 667	8	260.2	82 356	433.7
7	0.190	2 111 111	6	167.1	27 064	352.7
8	0.127	1 411 111	11	355.7	212 649	501.9
9	0.139	1 544 444	16	458.5	103 751	708.1
10	0.072	800 000	3	28.8	2494	23.1
	1.419	15 766 667	86	325.7	Biomass	4 384.0
					CV:	11.4%
					±95%CI	977.6

4b

All cockles

Stratum	Sampling units Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.137	1 522 222	3	0.3	0	507 407
2	0.140	1 555 556	12	15.9	269	24 759 259
3	0.139	1 544 444	9	14.3	353	22 137 037
4	0.156	1 733 333	10	38.2	980	66 213 333
5	0.169	1 877 778	8	53.8	2166	100 930 556
6	0.150	1 666 667	8	32.3	890	53 750 000
7	0.190	2 111 111	6	43.2	2061	91 129 630
8	0.127	1 411 111	11	45.4	3347	64 013 131
9	0.139	1 544 444	16	32.3	931	49 808 333
10	0.072	800 000	3	2.0	1	1600 000
	1.419	15 766 667	86	31.1	Number	474 848 687
					CV:	13.3%
					±95%CI	123 683 638

Recruited (30 mm and over)

Stratum	Sampling units Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.137	1 522 222	3	0.3	0	507 407
2	0.140	1 555 556	12	12.3	149	19 185 185
3	0.139	1 544 444	9	12.9	322	19 906 173
4	0.156	1 733 333	10	24.9	426	43 160 000
5	0.169	1 877 778	8	20.6	393	38 729 167
6	0.150	1 666 667	8	18.1	347	30 208 333
7	0.190	2 111 111	6	13.5	192	28 500 000
8	0.127	1 411 111	11	24.5	976	34 508 081
9	0.139	1 544 444	16	20.5	254	31 661 111
10	0.072	800 000	3	0.7	1	533 333
	1.419	15 766 667	86	17.5	Number	246 898 791
					CV:	12.1%
					±95%CI	58 618 489

Appendix 5: Bed 5 (St Leonard). (5a) Biomass estimates and (5b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). A_i is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

5a

All cockles

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.301	3 344 444	12	845.2	331 922	2826.9
2	0.263	2 922 222	10	265.7	60 549	776.4
3	0.269	2 988 889	6	238.7	54 609	713.4
4	0.354	3 933 333	13	259.0	48 755	1 018.8
5	0.337	3 744 444	5	240.9	14 577	902.0
6	0.280	3 111 111	7	250.3	57 198	778.7
7	0.231	2 566 667	11	714.8	408 914	1 834.7
8	0.235	2 611 111	3	137.6	23 454	359.4
9	0.350	3 888 889	3	2.8	6	10.9
10	0.218	2 422 222	3	379.5	138 702	919.3
	2.838	31 533 333	73	410.7	Biomass	10 140.7
					CV:	10.7%
					±95%CI	2 138.0

Recruited (30 mm and over)

	Sampling units					
Stratum	Km^2	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.301	3 344 444	12	762.1	292 569	2 548.9
2	0.263	2 922 222	10	233.6	50 460	682.8
3	0.269	2 988 889	6	236.5	55 110	706.8
4	0.354	3 933 333	13	241.6	40 281	950.4
5	0.337	3 744 444	5	207.7	11 432	777.7
6	0.280	3 111 111	7	215.4	33 541	670.2
7	0.231	2 566 667	11	656.2	328 023	1 684.2
8	0.235	2 611 111	3	137.6	23 454	359.4
9	0.350	3 888 889	3	0.0	0	0.0
10	0.218	2 422 222	3	377.5	136 444	914.3
	2.838	31 533 333	73	374.7	Biomass	9 294.7
					CV:	11.0%
					±95%CI	1 999.6

5b

All cockles

Stratum	Sampling units Km^2	Sampling units *Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.301	3 344 444	12	54.3	1 941	181 436 111
2	0.263	2 922 222	10	19.5	402	56 983 333
3	0.269	2 988 889	6	7.5	52	22 416 667
4	0.354	3 933 333	13	13.0	200	51 133 333
5	0.337	3 744 444	5	17.8	77	66 651 111
6	0.280	3 111 111	7	20.4	671	63 555 556
7	0.231	2 566 667	11	58.5	4 106	150 266 667
8	0.235	2 611 111	3	3.0	13	7 833 333
9	0.350	3 888 889	3	0.7	0	2 592 593
10	0.218	2 422 222	3	13.0	139	31 488 889
	2.838	31 533 333	73	27.2	Number	634 357 593
					CV:	12.6%
					±95%CI	156 484 874

Recruited (30 mm and over)

Stratum	Sampling units Km^2	Sampling units *Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.301	3 344 444	12	38.5	766	128 761 111
2	0.263	2 922 222	10	13.9	223	40 618 889
3	0.269	2 988 889	6	7.2	54	21 420 370
4	0.354	3 933 333	13	9.9	95	39 030 769
5	0.337	3 744 444	5	11.0	31	41 188 889
6	0.280	3 111 111	7	13.7	217	42 666 667
7	0.231	2 566 667	11	38.8	1502	99 633 333
8	0.235	2 611 111	3	3.0	13	7 833 333
9	0.350	3 888 889	3	0.0	0	0
10	0.218	2 422 222	3	12.7	129	30 681 481
	2.838	31 533 333	73	19.2	Number	451 834 843
					CV:	11.4%
					±95%CI	101 201 249

Appendix 6: Bed 6 (Te Rauone Beach). (6a) Biomass estimates and (6b) number estimates by stratum and overall for all cockles and recruited (30 mm and over). A_i is the area of the stratum in quadrats (m^2 divided by 0.09); *n*, is the number of quadrats; g, weight of cockles in grams; *N*, number of cockles; Var, variance of the mean; CV, coefficient of variation; CI, confidence interval.

6a

All cockles

	Sampling units					
Stratum	Km²	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.0065	72 517	11	532.9	102 344	38.6
2	0.0092	102 166	6	93.6	37 725	9.6
3	0.0187	208 311	8	69.4	14 853	14.4
4	0.0170	189 218	11	4.5	152	0.9
5	0.0113	125 033	8	35.7	2 901	4.5
6	0.0121	133 941	11	0.0	0	0.0
7	0.0167	185 583	11	5.9	339	1.1
	0.0915	1 016 769	66	111.8	Biomass	69.1
					CV:	20.6%
					±95%CI	27.9

Recruited (30 mm and over)

	Sampling units					
Stratum	Km²	*Ai*	*n*	Mean g quadrat^{-1}	Var	Biomass (t)
1	0.0065	72 517	11	516.9	97 871	37.5
2	0.0092	102 166	6	92.9	37 394	9.5
3	0.0187	208 311	8	64.3	12 333	13.4
4	0.0170	189 218	11	3.8	157	0.7
5	0.0113	125 033	8	35.7	2 902	4.5
6	0.0121	133 941	11	0.0	0	0.0
7	0.0167	185 583	11	5.6	342	1.0
	0.0915	1 016 769	66	108.3	Biomass	66.6
					CV:	20.5%
					±95%CI	26.7

6b

All cockles

Stratum	Sampling units					
	Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.0065	72 517	11	25.6	234	1 859 064
2	0.0092	102 166	6	2.3	23	238 386
3	0.0187	208 311	8	4.1	64	859 283
4	0.0170	189 218	11	0.6	1	120 411
5	0.0113	125 033	8	1.1	2	140 663
6	0.0121	133 941	11	0.1	0	12 176
7	0.0167	185 583	11	0.3	0	50 614
	0.0915	1 016 769	66	5.3	Number	3 280 597
					CV:	21.6%
					±95%CI	1 389 405

Recruited (30 mm and over)

Stratum	Sampling units					
	Km^2	*Ai*	*n*	Mean *N* quadrat^{-1}	Var	Numbers
1	0.0065	72 517	11	21.5	160	1 562 405
2	0.0092	102 166	6	1.8	16	187 304
3	0.0187	208 311	8	3.0	31	624 933
4	0.0170	189 218	11	0.1	0	17 202
5	0.0113	125 033	8	0.9	2	109 404
6	0.0121	133 941	11	0.0	0	0
7	0.0167	185 583	11	0.1	0	16 871
	0.0915	1 016 769	66	4.3	Number	2 518 118
					CV:	20.9%
					±95%CI	1 032 956