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Distribution and abundance of toheroa in Southland, 2013–14

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The surf clam toheroa (*Paphies ventricosa*) is endemic to New Zealand, where it inhabits the intertidal zone on exposed sandy beaches in North and South Island regions. Toheroa are of great cultural importance, and have a long history of supporting customary, recreational and commercial fisheries. Owing to substantial population declines, toheroa are currently only targeted in limited customary fisheries.

The main toheroa populations in Southland are at Oreti and Bluecliffs beaches, where they have been regularly monitored since the late 1960s, including Ministry for Primary Industries (MPI) surveys. The present report documents the most recent MPI survey in Southland, conducted in 2013–14 at Oreti, Bluecliffs, and Orepuki beaches. The latter beach supports a small toheroa population that has not been part of the regular surveys before, but was the focus of a population study in 2008.

The primary aim of the survey was to estimate the population of toheroa with shell lengths ≥40 mm. The total population estimate for the population of these toheroa at the three Southland beaches was 1 489 000 (95% CI: 1 036 000–1 941 000) individuals in 2013–14. Oreti Beach continued to support the largest toheroa population in Southland, with an estimated population size of 1 395 000 (95% CI: 951 000–1 840 000) toheroa ≥40 mm shell length at this beach. Of these toheroa, an estimated 1 005 000 (95% CI: 644 000–1 367 000) individuals were ≥100 mm shell length. In addition, there were estimated to be 2 052 000 (95% CI: 755 000–3 348 000) juvenile toheroa (<40 mm shell length) at Oreti Beach. The population of larger toheroa at Oreti Beach appeared to be stable, with a similar estimated number of toheroa at ≥100 mm shell length to that in a previous survey in 2009 (980 000, 95% CI: 780 000–1 200 000); although this previous survey covered a smaller area of the beach, excluding the area known as the reserve. In contrast, the mean estimate of the number of juvenile toheroa (<40 mm shell length) was around one third the estimate from the 2009 survey (6 030 000, 95% CI: 3 056 000–9 005 000).

A marked change at Oreti Beach was that gravel was noted in many of the quadrats (23.8% of all quadrats, with no gravel or stones recorded in 2009). The increase in the occurrence of gravel may be associated with the decrease in juvenile toheroa. This notion was supported by statistical modelling of the number of toheroa within each quadrat at Oreti Beach, which indicated a negative association between counts of juvenile toheroa and the presence of gravel. A negative association was also found between juvenile toheroa and ghost shrimp burrow density. There was no association between large toheroa and these habitat characteristics.

Toheroa ≥40 mm shell length were present at high densities at the southern end of the beach, close to the entrance of New River Estuary, and also about 11–14 and 15–16 km along the beach; they were present at low densities in other areas. Across the beach, individuals in this size class were predominantly in the mid- to low-intertidal zone. Juvenile toheroa also showed the highest concentration in the southern part of Oreti Beach, but their spatial distribution extended across the entire intertidal zone, including the upper intertidal area in this and other parts of the beach. The size-frequency distribution of the Oreti Beach population was bimodal, with a distinct cohort of juveniles and a second cohort of individuals at shell lengths ≥80 mm. There were few toheroa at intermediate sizes. The decrease in juvenile toheroa at Oreti Beach may be related to episodic recruitment. Nevertheless, if the number of juveniles remains low, it would in turn lead to lower recruitment to the adult population.

In recent years, Bluecliffs Beach has been eroded, and the toheroa population there was small, with a total estimate of 65 000 (95% CI: 0–150 000) toheroa ≥40 mm shell length in two disjunct areas, including the western bay. The number of smaller juvenile toheroa at Bluecliffs Beach was not estimated. Although the sample size was small, the spatial distribution of toheroa at Bluecliffs Beach appeared to extend across most of the intertidal zone, from about 30 m distance from the toe of the dune to the low tide mark. The size frequency distribution was unimodal, with a strong cohort of juveniles and few individuals at

intermediate and large sizes.

The toheroa population at Orepuki Beach was also small, with an estimated 28 000 (95% CI: 10 000–46 000) toheroa ≥40 mm shell length at this beach. The population at this beach was dominated by juveniles, with 365 000 (95% CI: 211 000–519 000) toheroa <40 mm shell length. Toheroa were distributed along the entire survey area at Orepuki Beach, with the distribution of large toheroa restricted to the mid- and low-intertidal zone. In contrast, the spatial distribution of juvenile toheroa included the entire intertidal extent of the beach, other than the upper intertidal zone (within 50 m of the toe of the dune) in the northwestern part of the survey area. Toheroa at Orepuki Beach had a unimodal size distribution dominated by a strong cohort of juveniles, with few individuals at ≥40 mm shell length.

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1. INTRODUCTION

Marine invertebrate communities in coastal environments include species that are important for commercial and recreational fisheries, such as infaunal bivalves. In New Zealand, the latter group includes endemic species such as the surf clams toheroa *Paphies ventricosa* and its congeners tuatua (*Paphies donacina* and *Paphies subtriangulata*), which inhabit the intertidal zone of exposed, open beaches (Greenway 1969). In these dynamic coastal habitats, toheroa burrow into the sediment to 20–30 cm depth, while extending their siphons to the sediment-water interface to feed on phytoplankton during tidal immersion (Morton & Miller 1973).

Toheroa is a species of cultural significance to Māori, and has a long history of supporting significant commercial, recreational and customary fisheries in different parts of New Zealand (see review by Williams et al. 2013a). Prior to exploitation, toheroa was highly abundant in a number of regions, with the main populations in Northland (Ninety Mile, Dargaville and Muriwai beaches), and smaller populations in other regions such as Wellington (Kapiti and Horowhenua coasts), and Southland (Oreti Beach and Te Waewae Bay) (Greenway 1969, Akroyd et al. 2002, Heasman et al. 2012). The dense northern populations generally form distinct beds, whereas toheroa populations in Southland tend to be more dispersed across the intertidal area (Millar & Olsen 1995).

Toheroa populations throughout New Zealand have experienced marked declines, leading to the implementation of fisheries restrictions and closures. The only take currently permitted is under the customary care of kaitiaki.

Owing to its long-standing importance as a fishery species and its cultural significance, there have been a number of studies on toheroa over time, including stock assessments and monitoring surveys (e.g., Rapson 1952, Cassie 1955, Redfearn 1974, Morrison & Parkinson 2001, 2008, Beentjes & Gilbert 2006b, 2006a). In addition, there have been a number of initiatives to support toheroa populations, including the transplanting of a number of individuals at Orepuki Beach in Te Waewae Bay starting in the mid 1950s (Futter & Moller 2009, Futter 2011).

In recognition of the species' importance, Ministry for Primary Industries (MPI) has funded and supported toheroa surveys and related studies in different parts of New Zealand, including Southland. The three Southland beaches important for southern toheroa populations include Oreti and Bluecliffs beaches, which support the main South Island toheroa stocks (Figure 1). In addition, toheroa appear to have become re-established at Orepuki Beach following transplantation, providing another Southland population (Futter & Moller 2009, Futter 2011).

Toheroa at both Oreti and Bluecliffs beaches have been regularly surveyed since 1969 and 1966, respectively (Beentjes 2010a, 2010b, Williams et al. 2013a). The most recent toheroa surveys at these beaches were conducted in 2009 (Beentjes 2010a, 2010b). At Bluecliffs Beach, the recent survey revealed low toheroa abundance, which was attributed to the loss of habitat, as erosion of the beach greatly reduced the sandy area (Beentjes & Gilbert 2006a).

Orepuki Beach has not been part of a regular monitoring programme to date. Nevertheless, the toheroa population at this beach was assessed in December 2008 as part of a university study (Futter & Moller 2009, Futter 2011). Toheroa at Orepuki Beach experienced a large die-off in July 2009, resulting in a 10–15% population reduction (Robertson & Stevens 2012).

The present study continues the series of toheroa population surveys in Southland. Its overall objective was "to determine the distribution of toheroa (*Paphies ventricosa*) beds, and the abundance and size structure of toheroa on Oreti, Bluecliffs and Orepuki beaches" in 2013–14.

2. METHODS

The overall methodology for sampling toheroa at Southland beaches was consistent with recent toheroa population assessments conducted for MPI (e.g., Beentjes & Gilbert 2006b, 2006a, Beentjes 2010a,

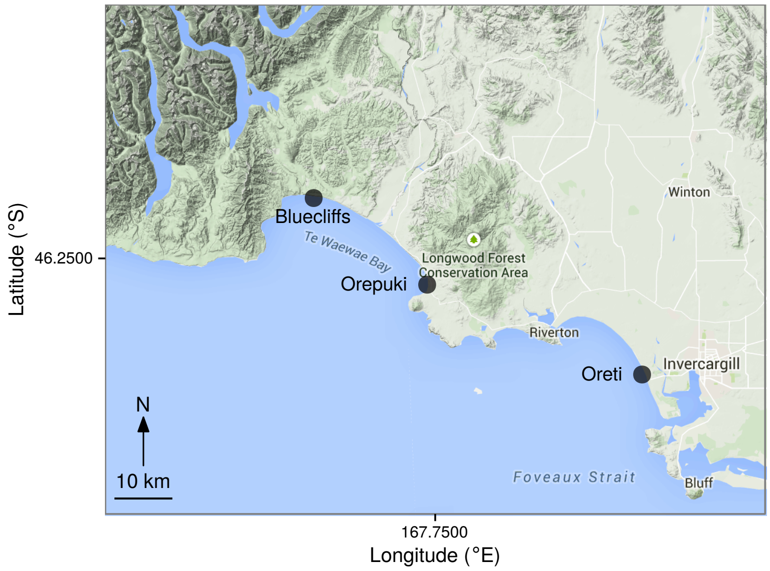


Figure 1: Locations of toheroa populations in Southland that were included in the surveys in 2013–14.

2010b). It involved a two-phase stratified random transect sampling design, as used in the previous surveys. Each beach was divided into sections, or strata. Within each stratum, transects were placed across the beach, running from the toe of the dune to the low tide level, with regularly spaced quadrats (every 5 m) dug along each transect. The design goal of the survey was to estimate the toheroa abundance within the sampled areas, with an overall coefficient of variation of less than 20%, for the total number of toheroa $\geq$40 mm shell length.

Estimation of the number of toheroa at each beach followed methods used in previous surveys (e.g., Carbines & Breen 1999, Beentjes et al. 2003, Beentjes & Gilbert 2006b, Beentjes 2010b). The estimation of the number of toheroa within each size class was based on scaling up from the counts in each quadrat to account for the fraction of each transect that was sampled, and then to account for the fraction of the length of each stratum that was covered by the width of the transects. The uncertainty was calculated using an analytical expression, appropriate for stratified random sampling (Cochran 1977).

Formally, if a quadrat, q, had a number of toheroa, n_{qc}, in size class, c, then the total estimated number of toheroa, $\hat{n}_{tc}$, in that size class in transect t, was estimated as:

$$\hat{n}_{tc} = \frac{1}{f} \sum_{q \in t} n_{qc}, \tag{1}$$

where f was the fraction of the transect that was sampled (the ratio of the quadrat size to the distance between quadrats), and the sum was over all the quadrats in the transect. The estimated total number of toheroa, $\hat{N}_c$, in size class c at the beach was then:

$$\hat{N}_c = \sum_s \mathsf{Mean}_s(\hat{n}_{tc}) \frac{l_s}{w}, \tag{2}$$

where l_s was the length (in metres) of stratum s, w was the width of the transects, and the mean, Mean_s was calculated over all transects in stratum s. Abundance was separately estimated within each stratum, and then summed over all the strata at the beach. Estimation of abundance was carried out for different size classes, including toheroa $<$40 mm shell length (juveniles), and individuals at $\geq$40 mm, 40–99 mm, $\geq$80 mm, and $\geq$100 mm shell lengths. These size classes were chosen for comparison with previous reporting.

During the sampling, selected transects were sieved using a 5-mm mesh, allowing counting of toheroa that were larger than 5 mm shell length. For estimation of the number of toheroa <40 mm shell length, only data from the sieved transects were included. The number of juveniles was estimated for Oreti and Orepuki beaches (but not for Bluecliffs Beach as only transects in stratum 1 could be sieved), and the whole beach was treated as a single stratum for the purposes of this estimation. The total number of toheroa at each beach was then calculated by combining the separate estimates of toheroa that were <40 mm and ≥40 mm shell length.

These estimates assumed that the transects crossed through the zone of the beach where toheroa are found (so that there were no toheroa beyond the end of the transects). There was no extrapolation in the counts beyond the length of the transects, or beyond the defined strata, so the estimates are restricted to this sampling region. The length of the strata was calculated at the toe of the dune, and there will be some error in scaling up from the transects to the whole strata, caused by the curvature in the beach. Following previous studies (e.g., Beentjes 2010b), it was assumed that this effect was inconsequential.

The variance of the estimate was calculated as follows (Cochran 1977):

$$\hat{V}_c = \sum_s \mathsf{Var}_s(\hat{n}_{tc}) \frac{1}{t_s} \left(\frac{l_s}{w}\right)^2, \tag{3}$$

where t_s was the number of transects in stratum s, and the variance, Var_s was calculated over all the transects in stratum s. The uncertainty in the estimates was expressed as the coefficient of variation, $\mathsf{CV}_c = \sqrt{V_c}/N_c$. A 95% confidence interval for the mean abundance estimates was calculated as $\hat{N}_c(1 \pm 1.96\mathsf{CV}_c)$, by assuming that the error in the mean was normally distributed. In presentation of the confidence intervals for strata with uncertain estimates, the lower confidence interval was truncated at zero if it would otherwise have been negative.

To allocate the transects to the strata, the area-mean-squared approximation was used (Francis 1984), with the gain in adding a transect to a stratum being:

$$\mathsf{AM}^2 = \mathsf{Mean}_s(\hat{n}_t)^2 \frac{l_s^2}{t_s(t_s+1)}, \tag{4}$$

where $\hat{n}_t$ was here the number of toheroa ≥40 mm shell length. During allocation of transects at each beach, four transects were first allocated to each stratum (with the exception of a single small stratum at Orepuki Beach that only had three transects allocated to it); any remaining first-phase transects were allocated to strata to sequentially maximise the area-mean-squared, based on previous toheroa sampling. Following first-phase sampling, second-phase transects were allocated using the results from the first-phase.

2.1 Survey methods

The strata sampled at each beach, i.e., the different areas sub-dividing each beach alongshore, were determined based on previous survey data and pre-survey reconnaissance at each beach. Based on this information, there were some changes to the determination of strata compared with the previous surveys.

At Oreti Beach, these changes included the merging of the previous strata 3 and 4 (new stratum 3), and strata 5 and 6 (new stratum 4)(Figure 2). In addition, the southern boundary of the survey area was extended to include the area close to New River estuary as an additional stratum (stratum 1). This area is known as “the reserve”, and the southern boundary of this stratum was defined by the edge of the broad beach. These changes resulted in a total of seven strata at Oreti Beach. Additionally, the western boundary of the sampling region was extended beyond the mouth of Waimatuku Stream, to where the beach narrowed.

The minimum number of transects per stratum was four, one more transect than used previously (Beentjes 2010b). Based on applying the area-mean criterion to the past survey data, a fifth transect was allocated

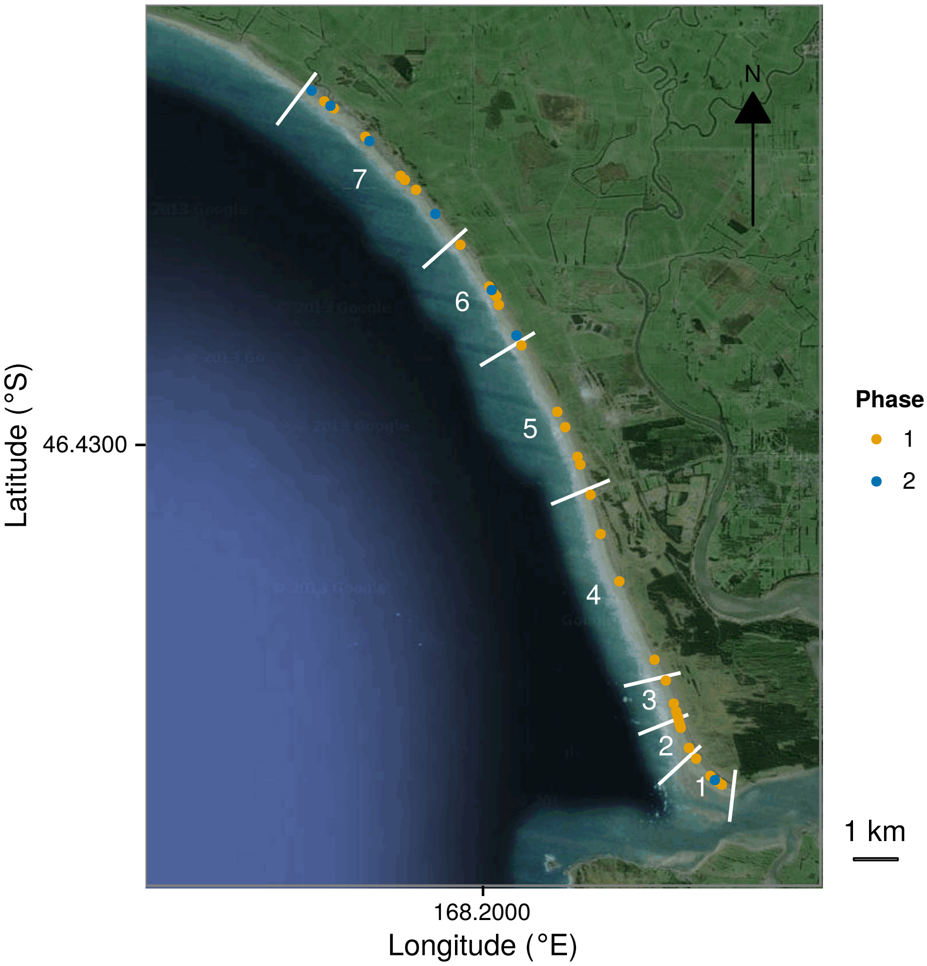


Figure 2: Sampling strata at Oreti Beach used for surveying toheroa in 2013–14, including starting points for phase 1 and 2 transects.

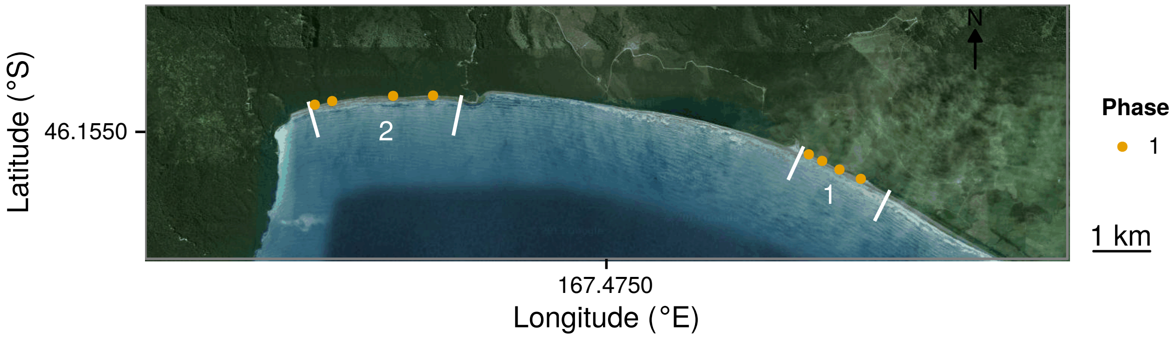


Figure 3: Sampling strata at Bluecliffs Beach used for surveying toheroa in 2013–14, including starting points for phase 1 transects.

in each of strata 2, 5, 6, and 7, with a sixth transect in stratum 7 (Figure 2). This transect allocation in phase 1 resulted in a total of 33 transects; seven transects were held for allocation in phase 2.

At Bluecliffs Beach, a marked reduction in toheroa distribution and abundance in recent surveys was attributed to habitat degradation through the erosion of a significant proportion of the beach (e.g., Beentjes 2010a). For this reason, the sampling effort in the present survey was reduced to two disjoint strata; these strata were an area at Rowallan Burn (1.7 km) and another area in the western bay (2.6 km)(Figure 3).

In-between these two strata, the upper beach was covered in cobbles, and was not suitable toheroa habitat. The western bay stratum did not support a discernible toheroa population in 2008 (Beentjes 2010a), and has not been included in recent systematic surveys; however, it was identified by locals as an area where toheroa were found (D. Templeton, pers. comm.). The survey at Bluecliffs Beach followed the overall sampling design, based on the random allocation of transects, with four transects being sampled in each stratum. No phase 2 transects were allocated. At this beach, logistical reasons prevented the sieving of transects in stratum 2. For this reason, no estimate of juvenile abundance was made for Bluecliffs Beach.

At Orepuki Beach, the toheora population was not previously included in MPI surveys, but was assessed as part of a university study in December 2008 (Futter 2011). Considering the data from this assessment and information from pre-survey reconnaissance, the sampling extent at Orepuki Beach was divided into three strata (300, 700, and 900 m long)(Figure 4). Within each stratum, the starting positions of the transects were randomly allocated, with an initial three, four, and four transects allocated in phase 1. Three transects were allocated in phase 2.

The allocation of transects was carried out by assigning transect start positions along a line that traced the toe of the dune (using satellite imagery in a geographic information system), with the restriction that the start positions were a minimum of 20 m apart. The initial phase 1 transects, and potential phase 2 transects were allocated before the field survey began. Two of the phase 1 transects from each stratum were randomly allocated to be sieved. Nevertheless, for logistical reasons, it was not possible to sieve two transects in stratum 2 at Bluecliffs Beach.

Within each stratum, each transect was run from the toe of the dune, through the global positioning system (GPS) position that marked the transect, across the beach to the low water mark. Along each transect, quadrats were evenly spaced at 5-m intervals, with the first quadrat being 5 metres from the toe of the dune. The size of the sampling quadrat was 0.5 m by 0.5 m, excavated to 30 cm sediment depth. The surface area covered by the quadrat size was smaller than the 1.0 m by 0.5 m quadrat used in previous southern surveys (but the same dimension as quadrats in a recent northern toheroa survey, see Williams et al. 2013a). This reduction in quadrat size was based on an analysis of data from the 2009 survey at Oreti Beach that showed that the smaller quadrat size would still allow for the design criterion

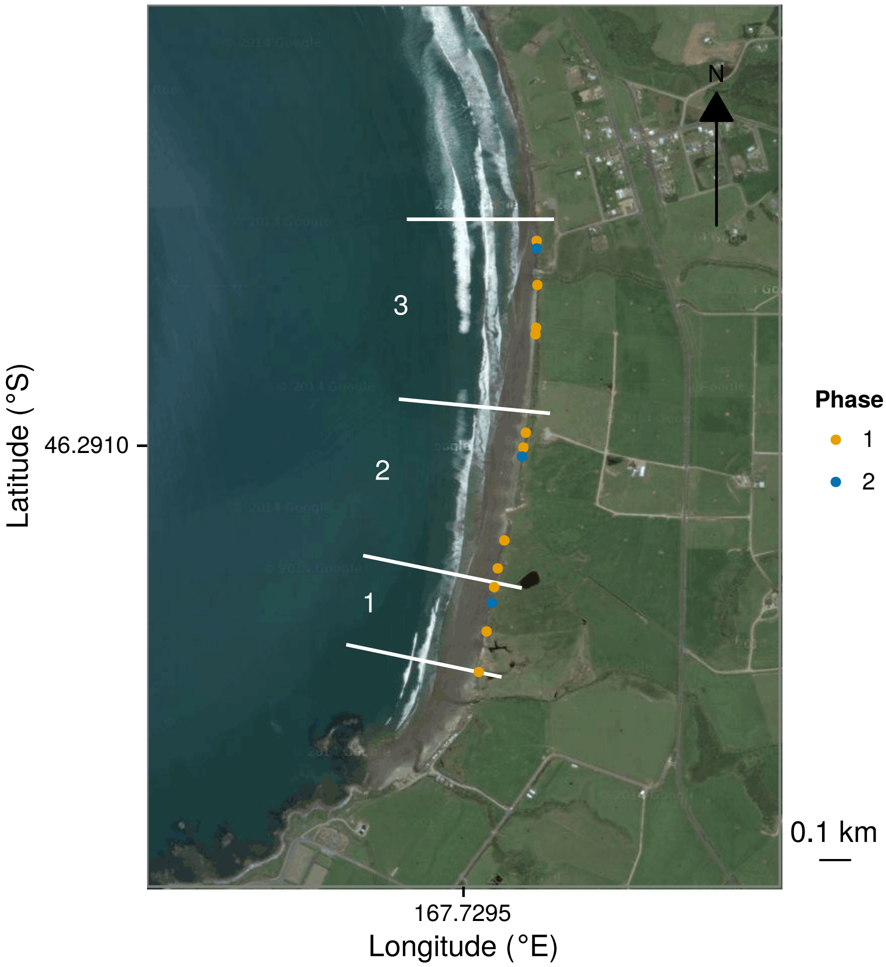


Figure 4: Sampling strata at Orepuki Beach used for surveying toheroa in 2013–14, including starting points for phase 1 and 2 transects.

of the survey (a coefficient of variation of less than 20% for toheroa ≥40 mm shell length) to be met.

2.2 Toheroa sampling

The field sampling was conducted over a period of several consecutive days at low tide between February and April 2014. The sampling dates were chosen to coincide with periods of low tide that had the lowest tidal height over that period, generally <0.5 m above chart datum. Sampling at Oreti Beach (phase 1) was conducted on 28 February to 6 March 2014, and (phase 2) on 25 and 30 April 2014. Bluecliffs Beach was sampled on 28 and 29 April 2014, and Orepuki Beach on 26 and 27 April 2014.

Field sampling of toheroa involved locating the start of each transect at the toe of the dune using GPS units (see Appendix A for transect locations). GPS units were also used to record the location of each sampling point along each transect. Within each quadrat along the transects, all sediment was excavated (to 30 cm depth) and carefully sorted at the sediment surface to detect any toheroa (i.e., ≥40 mm shell length). All toheroa in the quadrats were counted and their shell length was measured (with the measurement rounded down to the nearest whole millimetre), before returning them to the sediment. When individuals were damaged during excavation, their shell length was estimated.

On transects that were sieved to assess the juvenile toheroa population component, the sediment from each quadrat was directly transferred into box sieves and sieved on 5-mm mesh. All toheroa retained on the mesh were counted and measured in the field, before they were returned to the sediment.

2.3 Assessment of habitat characteristics

At each sampling point, the sediment in the quadrat was qualitatively assessed using broad categories: gravel (over 2 mm grain size), and sand. In addition, on one sieved transect per stratum, sediment samples were collected for subsequent sediment grain size and organic content analyses. These samples were taken using a benthic core (5-cm diameter, 10-cm depth) directly adjacent to the quadrats along the transects, but at 10-m intervals (i.e., at every second toheroa quadrat). These sediment samples were taken to provide baseline information, allowing the monitoring of changes in sediment composition at the beaches over time.

The same transects (one of the sieved transects in each stratum) were also used to determine the slope of the beach, using field surveying techniques and GPS units.

The sediment samples were subsequently analysed for sediment grain size and organic content. Sediment grain size analysis consisted of a combination of wet and dry sieving to determine the proportion of different grain size fractions, ranging from sediment fines (silt and clay, <63 µm grain size) to different sand size classes, i.e., very fine to very coarse sands (125–2000 µm grain size) (Eleftheriou & McIntyre 2005). Each sediment sample was also analysed for organic content, based on loss on ignition (4 hours at 550°C).

2.4 Ghost shrimp sampling

In view of their potential influence on toheroa populations, the present survey included an assessment of burrowing ghost shrimp abundance in the field sampling. This assessment consisted of an initial step that established the relationship between the number of burrow openings or mounds versus the number of ghost shrimp present by excavating and sieving a set of sediment cores (0.5 m by 0.5 m to 0.5 m depth, the maximum ghost shrimp burrow depth), after recording the number of burrow openings within each core. Sediment within each core was subsequently excavated and sieved on 1-mm mesh. All ghost shrimp retained on the mesh were counted (and measured; total length to the nearest millimetre) in the field before returning them to the benthos. The second part of this assessment involved the recording of the number of ghost shrimp burrow holes in each toheroa quadrat.

At Oreti Beach, nine cores were taken for ghost shrimp across areas of different burrow hole densities. There were no discernible ghost shrimp populations at Orepuki and Bluecliffs beaches for assessing the ratio of the number of burrow holes to the number of ghost shrimp.

2.5 Predicting the distribution of toheroa at Oreti Beach

A Generalized Additive Model (GAM) was used to estimate the density of toheroa within each quadrat at Oreti Beach. The number of toheroa in each quadrat, n_q, were assumed to be drawn from a Poisson distribution, $n_q \sim \mathsf{Poisson}(\mu_q)$, with the mean of the Poisson, μ_q, depending on the distance along the beach (distance), the distance across the beach (quadrat number), the presence of gravel (recorded qualitatively for each quadrat), whether or not the quadrat was sieved, and the number of ghost shrimp burrows that were counted. The distance along the beach and the quadrat number were included as penalised regression spline functions, with the GAM estimating the position and number of knots in the splines. The presence of gravel, and whether the quadrat was sieved, were included as Boolean factors. The number of ghost shrimp burrows was included as linear effect. The mean of the Poisson was represented as a linear sum of these effects, with a logarithmic link function. Schematically,

$$\mathsf{log}(\mu_q) \sim s(\mathsf{distance}) + s(\mathsf{quadrat}) + \beta_s \mathsf{sieved} + \beta_g \mathsf{gravel} + \beta_b \mathsf{burrows}, \qquad (5)$$

where μ_q is the mean number of toheroa in quadrat q, s is a spline function, and the β coefficients were estimated during the model fit.

The GAM was fitted separately for toheroa $<$40 mm shell length, and for toheroa $\geq$40 mm shell length, using the “R” package “mgcv” (version 1.8-3) (Wood 2011). The models were then used to predict the distribution along and across the beach, and to investigate the relationship between the toheroa counts and the factors included in the models. In particular, the models allowed exploration of the association between gravel and toheroa, and between ghost shrimp burrows and toheroa.

3. RESULTS

The toheroa survey in 2013–14 included 40 transects at Oreti Beach (phases 1 and 2), eight transects at Bluecliffs Beach, and 14 transects (phases 1 and 2) at Orepuki Beach (Table 1). Across the three beaches surveyed, the sizes of strata varied considerably, with lengths ranging from 301 to 4881 m, depending on the beach length, toheroa density, and previous strata. The different widths of the beaches determined the lengths of the transects. Oreti Beach was characterised by relatively long transects, with average transect length in each stratum ranging between 182 and 229 m. In comparison, the mean transect lengths at Bluecliffs Beach were 106 and 112 m, and at Orepuki Beach they ranged from 106 to 139 m.

3.1 Gravel

All of the beaches included some quadrats with gravel (qualitatively assessed during sampling; see Appendix A). The highest percentage of quadrats with gravel was at Bluecliffs Beach, where 33.9% of the quadrats were recorded with gravel. At Oreti Beach, 23.8% of the quadrats were recorded with gravel (see examples in Figure 5), while at Orepuki Beach, 2.8% of the quadrats were recorded with gravel or stones. A similar occurrence of gravel at Oreti Beach was not recorded in the 2009 survey, which characterised 99.5% of the quadrats at this beach as sand, with some quadrats characterised as coarse sand, but no quadrats recorded as containing gravel or stones (Beentjes 2010b). By stratum, the highest percentage of quadrats with gravel at Oreti Beach was recorded in stratum 2 (62%) and adjacent stratum 3 (49%), and at the northern end of the beach, in stratum 7 (34%) (Table 1).

3.2 Toheroa abundance estimates

The strata with the highest mean estimated number of large toheroa ($\geq$40 mm shell length) were at Oreti Beach (Table 2). At this beach, the highest estimated number of toheroa in this size class was 390 000 (95% CI: 82 000–699 000) toheroa in stratum 7, at the northern end of the survey area. Estimated numbers were also comparatively high in the other strata at the northern end of the beach, particularly stratum 6 with 270 000 (95% CI: 108 000–432 000) large toheroa. (Note, however, that the power of the survey to distinguish differences in abundance between individual strata was low, due to the small number of transects in each stratum; and the survey was not designed for the purpose of estimating abundance within each stratum.) The estimated density was highest for strata at the southern end of the

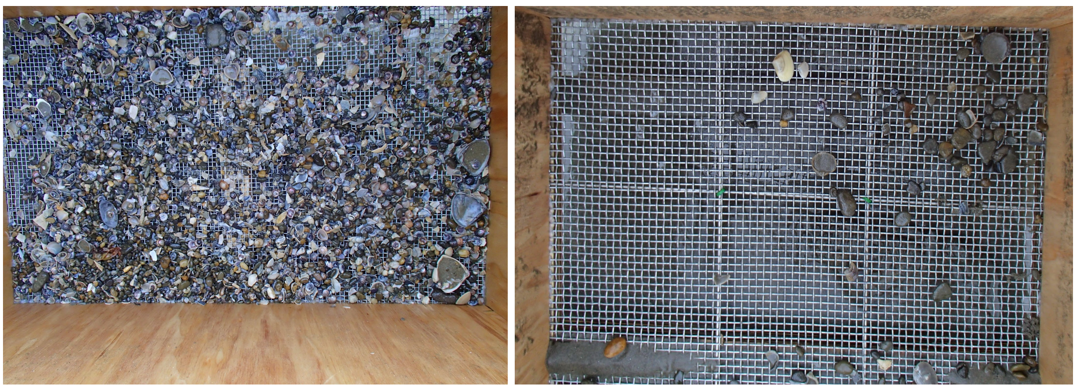


Figure 5: Example photographs, showing gravel from two Oreti Beach quadrats. The photographs show material left after sieving quadrats in stratum 2 (left) and stratum 3 (right). The mesh of the sieve is 5 mm. Three juvenile toheroa are visible in the right-hand photograph.

Table 1: Strata used for estimating toheroa abundance at Southland beaches in 2013–14. For each beach and stratum, information includes the stratum length (along the beach), the width of the beach (the mean length of the transects), the number of transects per phase and in total, the number of quadrats sampled, and the percentage of quadrats with gravel in each stratum. Two transects were sieved in each stratum, with the exception of stratum 2 at Bluecliffs Beach, which had no sieved transects.

Beach	Stratum	Length (m)	Width (m)	Transects			Quadrats	Gravel (%)
				Phase 1	Phase 2	Total		
Oreti	1	1258	229	4	1	5	234	0
	2	869	197	5	0	5	202	62
	3	1008	206	4	0	4	169	49
	4	4634	205	4	0	4	168	8
	5	3717	201	5	0	5	206	0
	6	2781	182	5	2	7	262	11
	7	4881	221	6	4	10	452	34
Bluecliffs	1	1686	112	4	0	4	94	45
	2	2668	106	4	0	4	89	22
Orepuki	1	301	139	3	1	4	115	0
	2	575	123	4	1	5	128	0
	3	624	106	4	1	5	111	9

beach, close to New River Estuary. Strata 1, 2, and 3 all had mean densities of large toheroa ($\geq$40 mm shell length) that exceeded 100 individuals per linear metre of beach. These values were higher than the mean densities of large toheroa at the other beaches. At Oreti Beach, the lowest mean densities were in strata 4 and 5, which were close to the main entrance of the beach, at the border of strata 4 and 5.

At Oreti Beach, there were an estimated 2 052 000 (95% CI: 755 000–3 348 000) toheroa with shell lengths <40 mm, around twice as many juveniles as large toheroa (Table 3). In contrast, at Orepuki Beach, the population was dominated by juveniles, with 365 000 (95% CI: 211 000–519 000) toheroa <40 mm shell length, around ten times as many juveniles as large toheroa. The density of juvenile toheroa (individuals per linear metre of beach) was highest at Orepuki Beach, with an estimated 243 (95% CI: 140–346) toheroa per linear metre of beach. The mean density of juveniles at this beach was over twice the mean density of juveniles at Oreti Beach. Estimates of juvenile toheroa at Bluecliffs Beach were not made, as no transects in stratum 2 were sieved, owing to difficulties with accessing the western bay. In the two sieved transects that were sampled at Bluecliffs Beach (in stratum 1), however, only two toheroa with shell lengths <40 mm were found in 48 quadrats, suggesting that juvenile density was low.

The total number of large toheroa ($\geq$40 mm shell length) at Oreti Beach was 1 395 000 (95% CI: 951 000–1 840 000), compared with only 65 000 (95% CI: 0–150 000) toheroa in this size class at Bluecliffs Beach, and 28 000 (95% CI: 10 000–46 000) at Orepuki Beach (Table 4). Across all the surveyed Southland beaches there were 1 489 000 (95% CI: 1 036 000–1 941 000) large toheroa, and so over 90% of the large toheroa at these beaches were at Oreti Beach. To allow comparisons with previous surveys at Oreti Beach which did not sample toheroa in the reserve area at the southern end (i.e., stratum 1 in the 2013–14 survey), estimates for this beach were also derived without this area. Estimates of abundance were also made for other size classes of toheroa (40–99, $\geq$80, and $\geq$100 mm shell lengths), as these sizes classes have previously been used to characterise the populations.

Table 2: Estimated abundance and density of toheroa in each stratum with shell lengths ≥40 mm at Southland beaches in 2013–14. Included are the number of toheroa counted in the sampled quadrats (N), estimated mean abundance (number of toheroa) with 95% confidence interval (CI) and coefficient of variation (CV), and the estimated mean density (number of toheroa per linear metre of beach) with 95% CI.

Beach	Stratum	N	Abundance			Density	
			Mean	95% CI	CV (%)	Mean	95% CI
Oreti	1	28	141 000	34 000–247 000	38.5	112	27–197
	2	27	94 000	56 000–132 000	20.8	108	64–152
	3	27	136 000	42 000–231 000	35.5	135	41–229
	4	8	185 000	20 000–351 000	45.6	40	4–76
	5	12	178 000	15 000–342 000	46.8	48	4–92
	6	34	270 000	108 000–432 000	30.6	97	39–155
	7	40	390 000	82 000–699 000	40.3	80	17–143
Bluecliffs	1	3	25 000	0–57 000	63.8	15	0–34
	2	3	40 000	0–118 000	100.0	15	0–44
Orepuki	1	9	14 000	1 000–26 000	45.8	45	5–85
	2	2	5 000	0–10 000	61.2	8	0–18
	3	4	10 000	0–22 000	61.2	16	0–35

Table 3: Estimated abundance and density of juvenile toheroa (shell length <40 mm) at Southland beaches in 2013–14, based on counts from sieved transects. Included are the number of sieved transects, number of sampled quadrats, number of juvenile toheroa counted in the sampled quadrats (N), estimated mean abundance (number of toheroa) with 95% confidence interval (CI) and coefficient of variation (CV), and the estimated mean density (number of toheroa per linear metre of beach) with 95% CI. Juvenile abundance was not estimated at Bluecliffs Beach as no transects were sieved in stratum 2.

Beach	Transects	Quadrats	N	Abundance			Density	
				Mean	95% CI	CV (%)	Mean	95% CI
Oreti	14	613	75	2 052 000	755 000–3 348 000	32.2	107	39–175
Bluecliffs	2	48	2					
Orepuki	6	151	73	365 000	211 000–519 000	21.6	243	140–346

Table 4: Estimated number of toheroa at the three Southland beaches surveyed in 2013–14. Included are the mean estimate, 95% confidence interval (CI), and the coefficient of variation (CV) for each of the different size classes for the three surveyed beaches, and for all three beaches combined. Estimates are only presented for the size classes and beaches where they were able to be calculated. Also presented are estimates for Oreti Beach excluding stratum 1 and toheroa ≥80 mm shell length at all three beaches to allow comparisons with previous estimates.

Beach	Size	Mean	95% CI	CV (%)
Oreti	< 40 mm	2 052 000	755 000–3 348 000	32.2
	≥ 40 mm	1 395 000	951 000–1 840 000	16.2
	40–99 mm	390 000	228 000–552 000	21.2
	≥ 80 mm	1 290 000	854 000–1 725 000	17.2
	≥ 100 mm	1 005 000	644 000–1 367 000	18.4
	All	3 447 000	2 076 000–4 817 000	20.3
Oreti (ex. stratum 1)	≥ 40 mm	1 254 000	823 000–1 686 000	17.5
	40–99 mm	365 000	205 000–525 000	22.4
	≥ 80 mm	1 164 000	741 000–1 586 000	18.5
	≥ 100 mm	890 000	539 000–1 240 000	20.1
Bluecliffs	≥ 40 mm	65 000	0–150 000	66.1
	40–99 mm	57 000	0–138 000	72.4
	≥ 80 mm	8 000	0–25 000	100.0
	≥ 100 mm	8 000	0–25 000	100.0
Orepuki	< 40 mm	365 000	211 000–519 000	21.6
	≥ 40 mm	28 000	10 000–46 000	32.5
	40–99 mm	20 000	5 000–35 000	38.3
	≥ 80 mm	16 000	1 000–31 000	46.5
	≥ 100 mm	8 000	0–18 000	66.0
	All	393 000	238 000–548 000	20.2
All beaches	≥ 40 mm	1 489 000	1 036 000–1 941 000	15.5
	40–99 mm	467 000	285 000–649 000	19.9
	≥ 80 mm	1 314 000	878 000–1 750 000	16.9
	≥ 100 mm	1 022 000	659 000–1 384 000	18.1

3.3 Spatial distribution of toheroa

The distribution of toheroa across the intertidal area varied, depending on the beach and on the toheroa size class (Figure 6). Large toheroa ($\geq$40 mm shell length) had the highest densities in the low intertidal areas. There were few individuals in this size class in the upper intertidal zone, i.e., within 50 m of the toe of the dune. At Oreti Beach, large toheroa were present from this distance downshore across the intertidal area, with a peak close to the low tide mark. Oreti and Orepuki beaches had high densities of juvenile toheroa in the high intertidal area, with a peak at around 50 m from the toe of the dune. The highest densities were at Orepuki Beach in the upper intertidal zone. Few individual toheroa were sampled at Bluecliffs Beach, and so patterns in the density across the beach are not clear. The apparent peak at the low intertidal zone at Bluecliffs Beach was based on few quadrats (Figure 6b).

At Oreti Beach, large toheroa were concentrated at the southern end of the beach, close to the entrance of New River Estuary (Figure 7). Densities were also relatively high in two other areas along the beach, about 11–13 km and 15–16 km from the southern end. Individuals in this size class were present at low densities in other areas, including around the main beach entrance, about 8 km from the southern end. In the southern area, large toheroa were particularly abundant about 2 km from the estuary entrance (in stratum 2), and were predominantly in the low intertidal zone. In comparison, in the two northern areas that also had high densities of large toheroa, the distribution of the latter extended into the mid-intertidal zone.

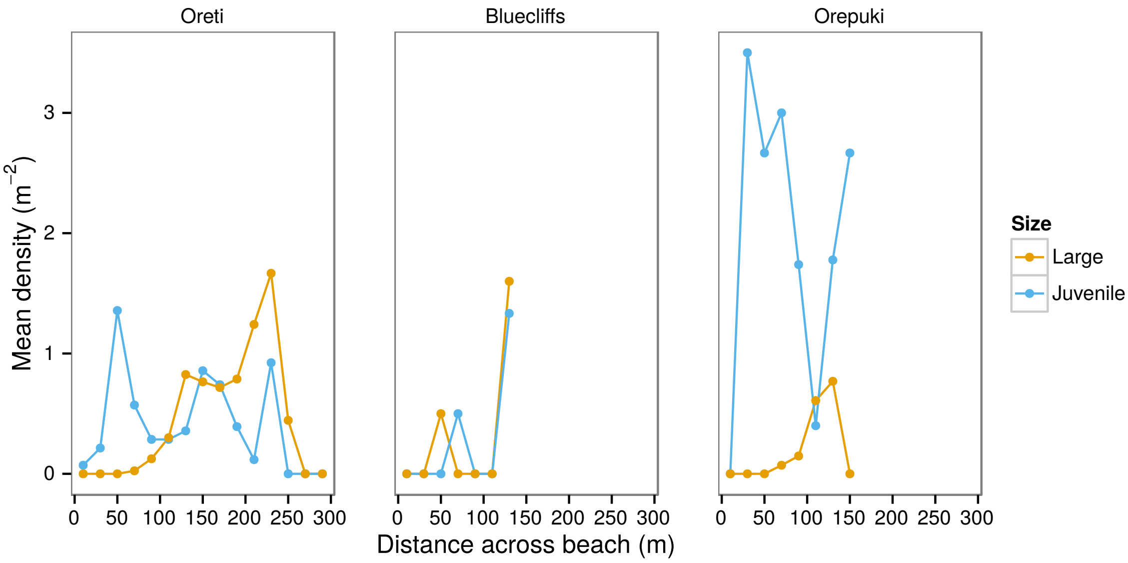
Juvenile toheroa at Oreti Beach were also concentrated in the southern area, with highest densities close to low water about 1 km from the estuary entrance. Further along the beach, however, at about 2 km from the estuary, juveniles were more widely distributed across the entire intertidal area, including the upper intertidal zone, close to the toe of the dune. Similarly, along other sections of the beach where juveniles were present, their distribution was spread across most of the intertidal extent; there were high densities of juveniles in the upper intertidal about 8 km (stratum 5) and about 18 km (stratum 7) along the beach.

At Bluecliffs Beach, few individuals were sampled, with all the sampled individuals being in the mid- and low-intertidal areas (Figure 8). At Orepuki Beach, the few large individuals that were present at this beach were in the low intertidal zone, especially in the eastern end of the survey area (Figure 9). In contrast, juveniles were widely distributed and abundant along the beach, although their densities were highest on the eastern transects (stratum 1). In this eastern area, juvenile toheroa were also the most widely spread across the intertidal extent of the beach, with high densities extending into the upper intertidal zone. Further along the beach (i.e., in strata 2 and 3), there were no or few juvenile toheroa within 50 m distance of the dune.

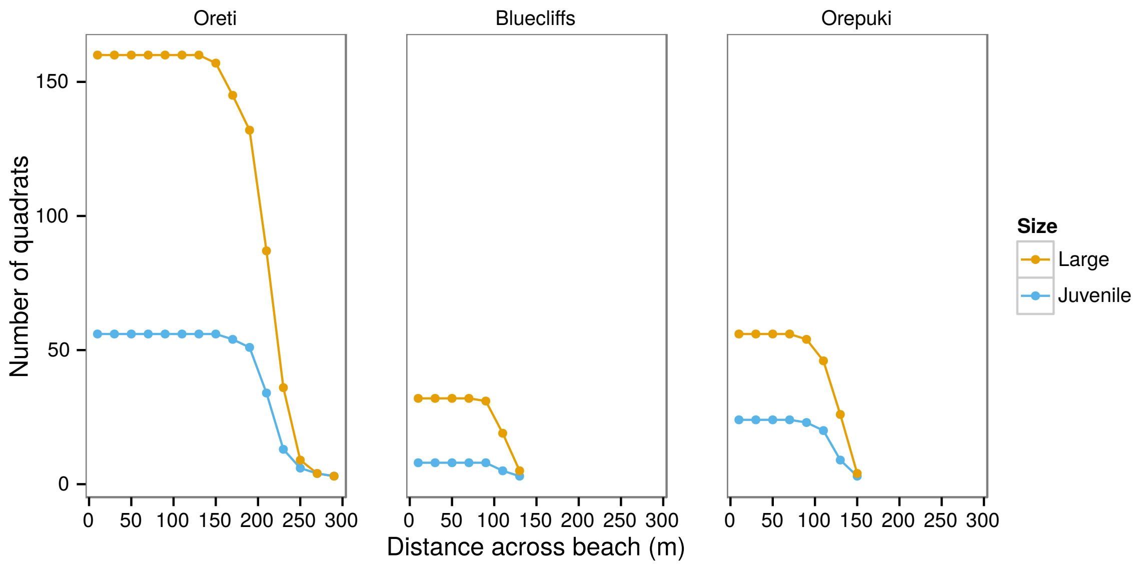
3.4 Toheroa size distributions

The size-frequency distributions of toheroa revealed some differences in population structure across the beaches surveyed (Figure 10). At Oreti Beach, the toheroa population was bimodal, with a small cohort of juveniles, and a second, larger cohort of toheroa that exceeded 80 mm shell length (up to a maximum length of 130 mm shell length; two recorded shell lengths of 170 mm and 180 mm, respectively, were assumed to be transcription errors). The modal lengths (using millimetre resolution, and pooling sieved and non-sieved transects) were 10 mm and 120 mm shell length for the juvenile and large cohorts, respectively. In contrast, the toheroa populations at the other two beaches largely consisted of a single cohort of juveniles, and included some medium-sized toheroa; the modal sizes were $<$40 mm shell length. Overall, there were few medium-sized and large individuals at Bluecliffs and Orepuki beaches.

Comparing size-frequency data from the non-sieved and sieved transects showed similar patterns in the size structure of the toheroa populations. Data from the sieved transects resulted in a stronger cohort of juveniles at all beaches. Nevertheless, the size-frequency data consistently indicated a strongly bimodal toheroa population at Oreti Beach, and unimodal populations at Bluecliffs and Orepuki beaches.

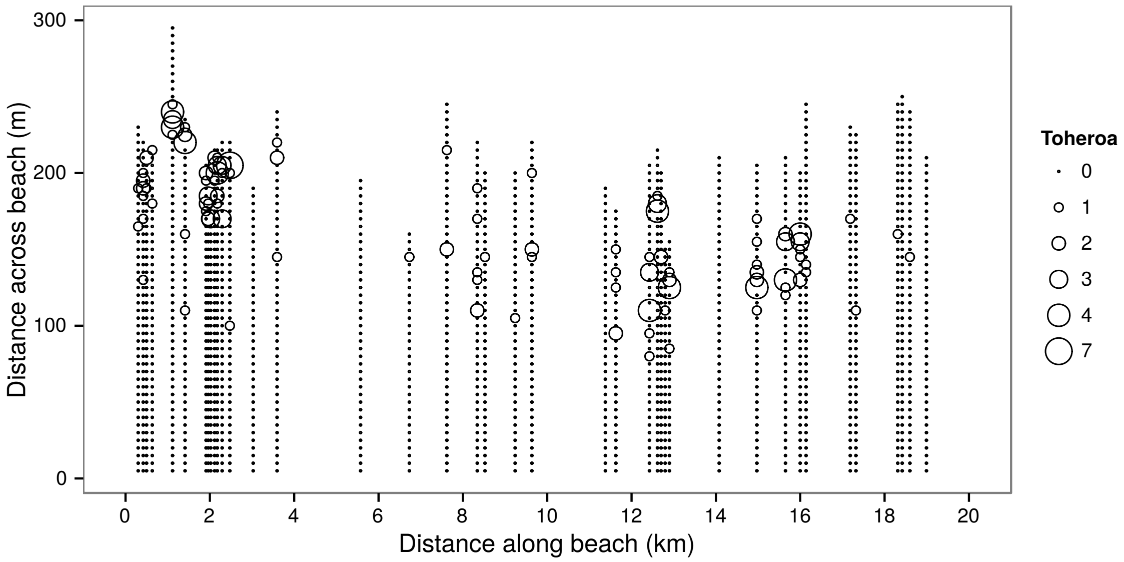


(a) Toheroa density

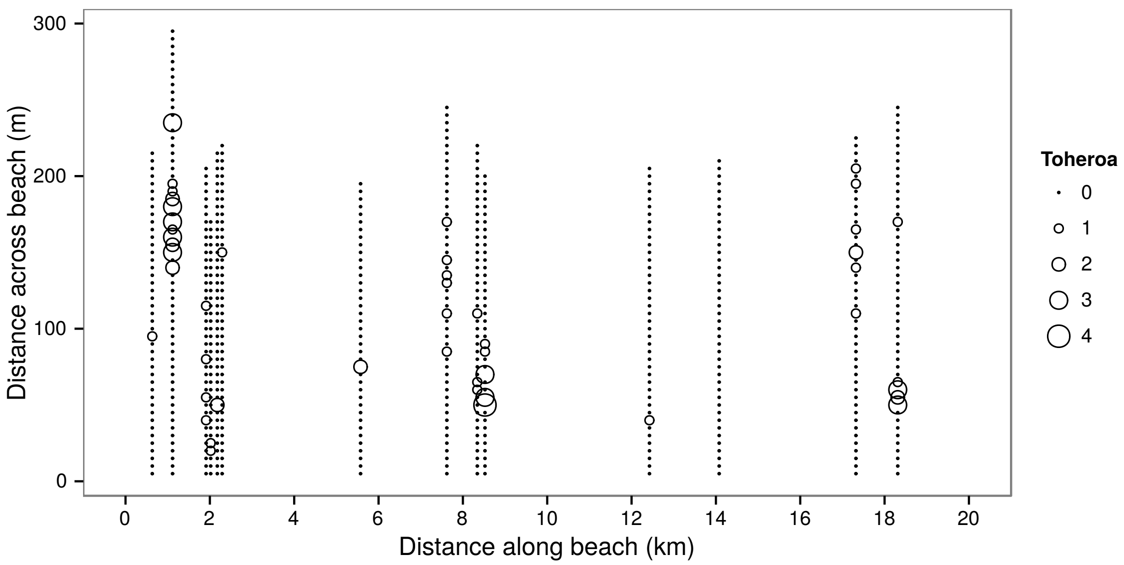


(b) Number of quadrats

Figure 6: Mean density of toheroa (m^{-2}) for large toheroa ($\geq$40 mm shell length) and juveniles (<40 mm shell length), by distance across the beach (from the toe of the dune). Presented are (a) the mean density (averaged in 20-m bands), and (b) the number of quadrats sampled. Data for large toheroa were based on all sampled quadrats, while data for juvenile toheroa were based on sieved transects only.

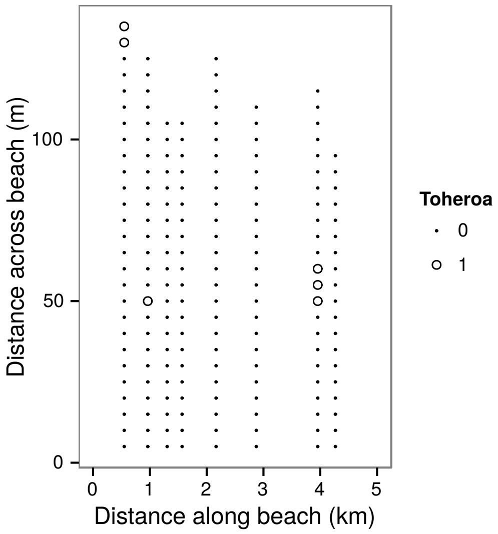


(a) Large toheroa

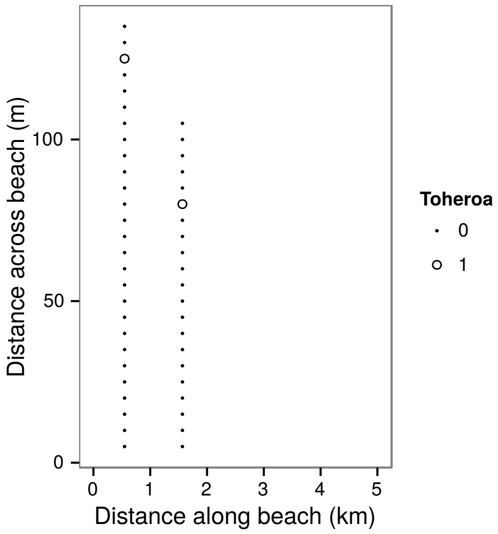


(b) Juvenile toheroa

Figure 7: Distribution of toheroa at Oreti Beach, by distance along the beach (from New River Estuary) and distance across the beach (from the toe of the dune). Dots indicate the position of sampled quadrats, and circle sizes correspond with the number of toheroa sampled. Large toheroa were ≥40 mm shell length and juvenile toheroa were <40 mm shell length. Data for large toheroa were based on all sampled quadrats, while data for juvenile toheroa were based on sieved transects only.

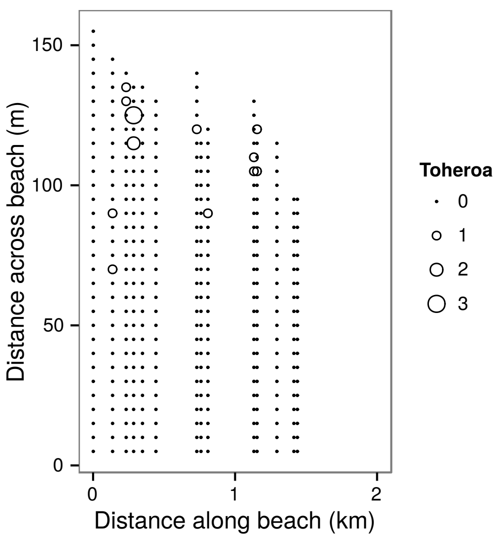


(a) Large toheroa

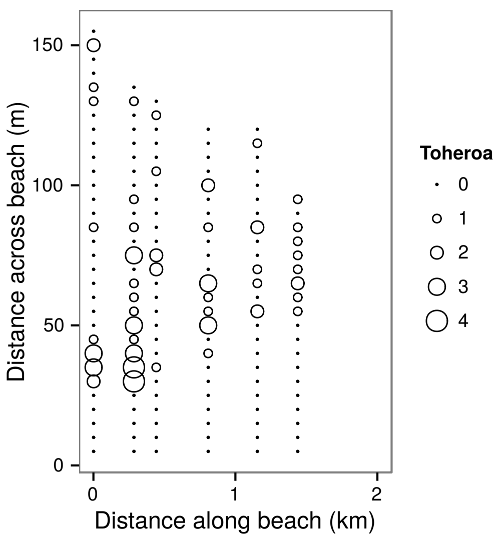


(b) Juvenile toheroa

Figure 8: Distribution of toheroa at Bluecliffs Beach, by distance along the beach (from the eastern side) and distance across the beach (from the toe of the dune). The break between the two disjoint strata was at 1.8 km along the beach. Dots indicate the position of sampled quadrats, and circle sizes correspond with the number of toheroa sampled. Large toheroa were $\geq$40 mm shell length and juvenile toheroa were $<$40 mm shell length. Data for large toheroa were based on all sampled quadrats, whereas data for juvenile toheroa were based on sieved transects only.



(a) Large toheroa



(b) Juvenile toheroa

Figure 9: Distribution of toheroa at Orepuki Beach, by distance along the beach (from the eastern side of the first stratum) and distance across the beach (from the toe of the dune). Dots indicate the position of sampled quadrats, and circle sizes correspond with the number of toheroa sampled. Large toheroa were $\geq$40 mm shell length and juvenile toheroa were $<$40 mm shell length. Data for large toheroa were based on all sampled quadrats, while data for juvenile toheroa were based on sieved transects only.

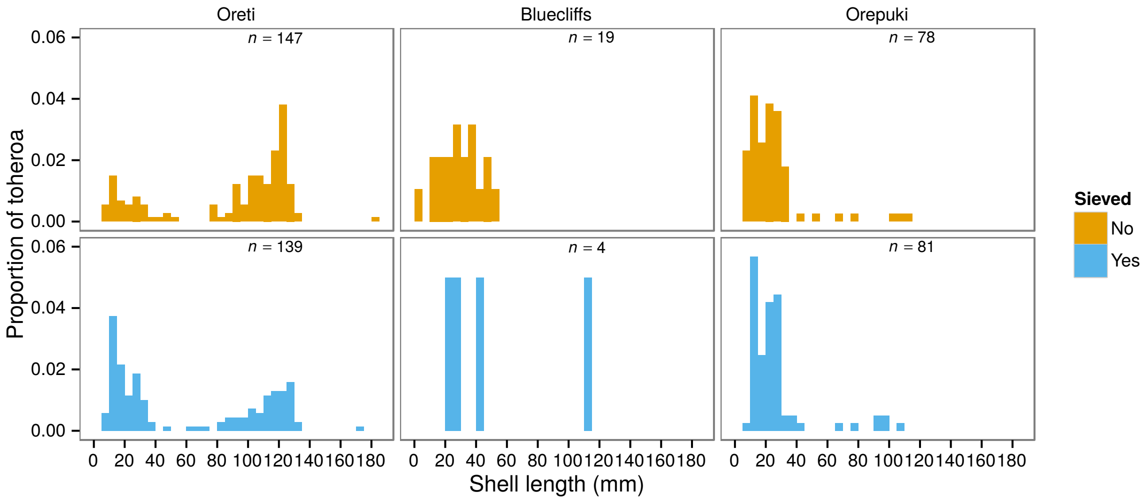


Figure 10: Size-frequency distributions of toheroa at Oreti, Bluecliffs and Orepuki beaches in 2013–14. Data were from non-sieved and sieved transects (sample sizes indicate the number of toheroa measured). (The two records at 170 mm and 180 mm shell length were assumed to be errors.)

3.5 Burrowing ghost shrimp and habitat characteristics

At each beach, one of the sieved transects in each stratum was used to determine the slope of the beach, using field surveying techniques and GPS units. Weather conditions made this determination of beach profiles difficult, and data show that only few of the profiles extended across the entire intertidal area (Figure 11). Nevertheless, the beach profiles show the similarities in the upper intertidal areas at each beach, with discernible differences in the upper beach steepness. Transects at Oreti Beach had a considerably gentler slope than transects at both Bluecliffs and Orepuki beaches. The two transects at Bluecliffs Beach had markedly different profiles, exhibiting distinct differences in the beach slopes between the two disjunct areas of the beach.

Sediment properties were generally similar at the three beaches (see Appendix B). Sediment organic content was low along the transects at all three beaches. Across the sediment samples, organic content ranged from 0.5 to 1.0% at Oreti Beach, from 0.5 to 1.4% at Bluecliffs Beach, and from 0.2 to 1.4% at Orepuki Beach.

Similarly to organic content, there was only a low proportion of fines (silt and clay, grain size <63 µm) in the sediment: it was ≤2.6% at Oreti Beach and ≤1.0% at Bluecliffs Beach, with no sediment in this grain size fraction at Orepuki Beach. At all three beaches, the sediment grain size distribution was dominated by fine sand (grain size >125 µm)(Figure 12). This grain size fraction was particularly high (over 75%) at Orepuki Beach. It was slightly lower at Oreti Beach, where very fine sand (grain size >63 µm) also made up a relatively large proportion (25–50%) of the sediment grain size. The very fine sand fraction was less prevalent (i.e., less than 25%) at Bluecliffs and Orepuki beaches, especially in the two strata at the former beach. Medium sand (grain size >250 µm) made up a small proportion of the grain size on some of the transects at Oreti and Orepuki beaches, increasing to about 25% of the overall grain size at Bluecliffs Beach.

The proportions of coarse sand (grain size >500 µm) and of gravel (>2000 µm) varied considerably across the beaches. At Oreti Beach, both grain size fractions made up a relatively high proportion of the sediment in parts of strata 1 to 3. Sediment in the mid-beach sections of these strata contained a particularly high proportion of gravel (up to 24% in stratum 3) and also coarse sand, whereas most of the other transect points and other strata had usually little or no gravel and coarse sand (less than 1% each) in other parts of the transects. At Bluecliffs Beach, most of stratum 2 contained a high percentage of gravel, with 23 to 96% of the sediment in the high intertidal area consisting of this grain size. Orepuki

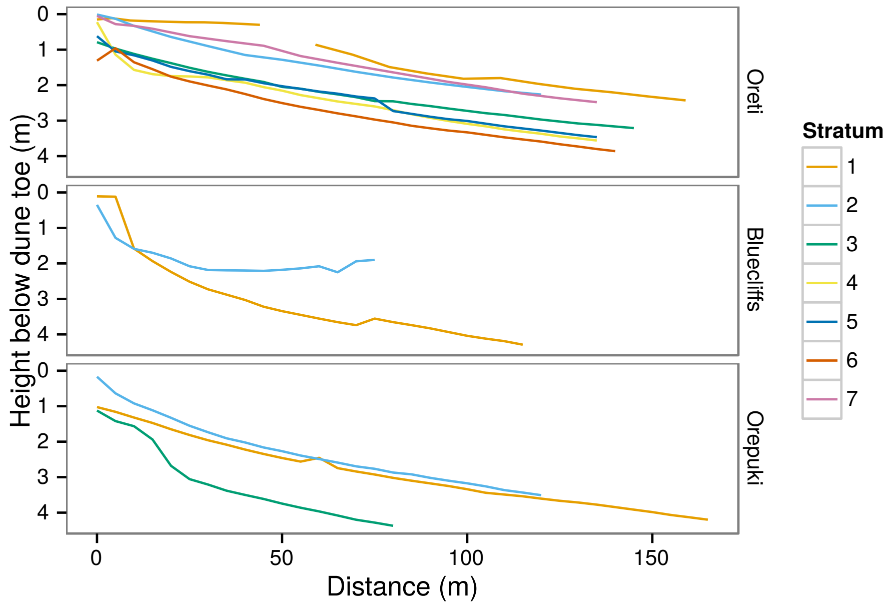


Figure 11: Beach profiles of strata sampled at Oreti, Bluecliffs and Orepuki beaches in the 2013–14 toheroa survey. The heights were not absolute, and so the relative heights of the profiles is not important.

Beach contained a low proportion of coarse sand and gravel, and sediment in these grain size fractions was only evident at some of the quadrat sampling points.

The distribution and abundance of burrowing ghost shrimp were assessed by counting the number of burrow holes at the sediment surface. This proxy measure of ghost shrimp density was calibrated by counting the number of ghost shrimp burrow holes at the surface of nine quadrats (0.5 m by 0.5 m), before excavating and sieving the sediment (0.5 m depth), and counting the number of ghost shrimp retained on 1 mm mesh. The quadrat placement in this exercise involved areas of different ghost shrimp burrow hole density. The resulting ratio between ghost shrimp and burrow openings was 0.5 to 2.3. This range of values is comparable with data from estuarine environments that indicate a ratio of 0.2 to 3.0 ghost shrimp per burrow hole (Berkenbusch & Rowden 1999, 2000). Formal testing in a previous study confirmed the value of this proxy measure (Berkenbusch & Rowden 2007), and it was used in the present study to indicate ghost shrimp density at the beaches surveyed.

At Oreti Beach, the distribution of ghost shrimp was predominantly in the mid- to low-intertidal zone (Figure 13). Burrow hole densities were high at 8–10 km along the beach, and also in the northern part at 16–18 km from the southern end. There was no evidence of ghost shrimp at Orepuki Beach, with only two quadrats at Bluecliffs Beach containing burrow holes.

The potential influence of sieving and of sediment habitat characteristics (i.e., the presence of gravel in quadrats) and ghost shrimp density (by burrow hole counts) on the number of toheroa was assessed using statistical modelling which aimed to predict the counts in the quadrats as a function of covariates (Table 5). There was no relationship between sieving, gravel, or ghost shrimp burrows and large toheroa, whereas variation in the number of juvenile toheroa was explained by the presence of gravel and by the number of ghost shrimp burrows, and also by sieving versus non-sieving of the sampling quadrats.

From these coefficients it can be estimated that 3.6 (95% CI: 2.21–5.88) times as many juvenile toheroa were counted in sieved quadrats, compared with unsieved quadrats. In quadrats that had gravel recorded, the number of juvenile toheroa was around 0.13 (95% CI: 0.06–0.26) the number found in quadrats without gravel. Ghost shrimp were included in the model as the number of burrow holes, so the impact of ghost shrimp may be estimated by multiplying the number of juveniles by 0.83 (95% CI: 0.69–0.99)

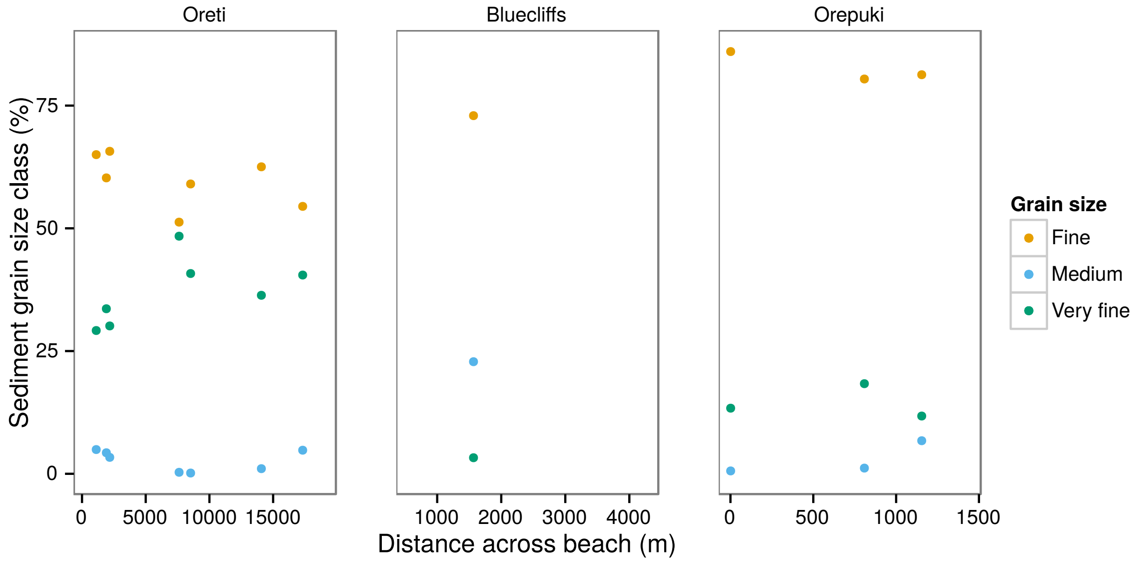
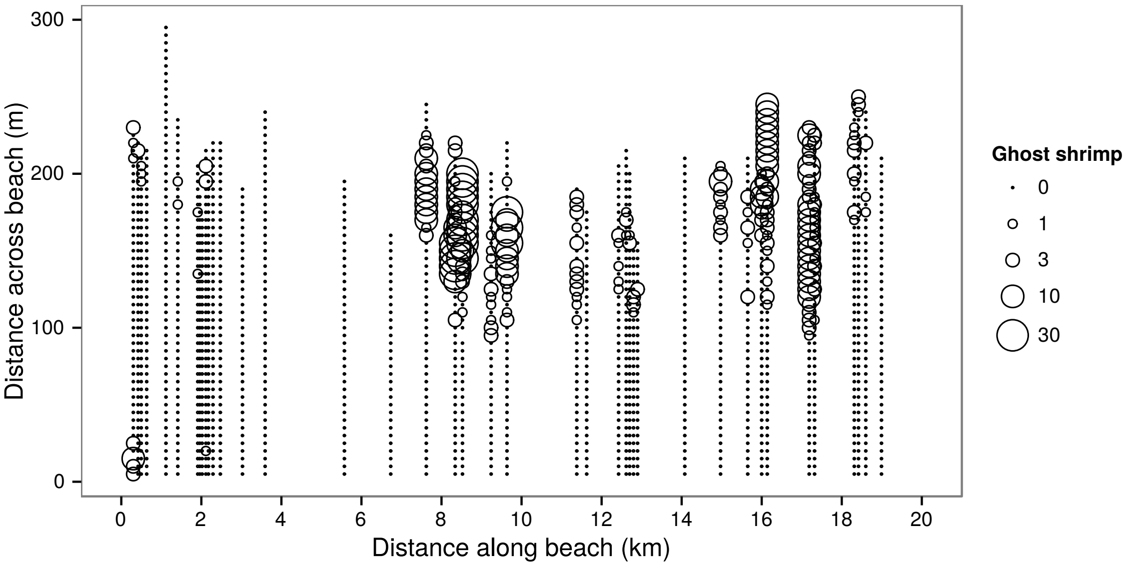


Figure 12: Sediment grain size distribution at Southland beaches surveyed in 2013–14. Grain size is presented as the proportion (%) of the three dominant sediment fractions in samples averaged over transects. The dominant sediment grain size fractions were very fine (>63 µm), fine (>125 µm), and medium (>250 µm) sands. (Note the different scales on the *x*-axes.)

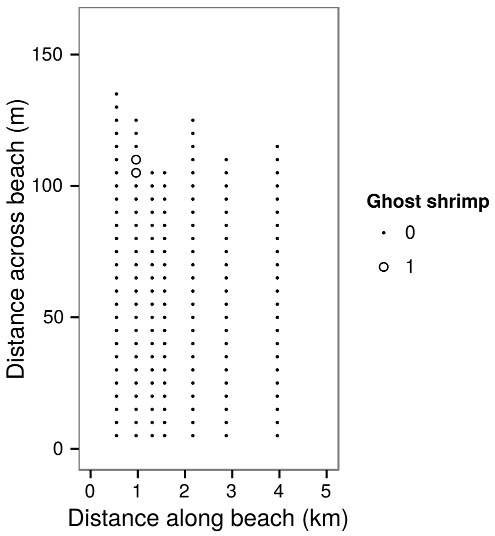
for each burrow hole in the quadrat (e.g, if there were three burrow holes in a quadrat the mean reduction in the juvenile count would be $0.83\times 0.83\times 0.83$).

Application of the GAM resulted in distinct patterns in the distribution and abundance of large and juvenile toheroa at Oreti Beach along and across the extent of the beach (Figure 14). Along the beach, the estimated densities of toheroa in both size classes were high at the southeastern end, close to New River Estuary. Juvenile toheroa in particular showed the highest along-shore density in this area, with smaller peaks between 6 and 8 km along the beach, and also at the northwestern end of the survey area (about 18 km distance from the southeastern end). In contrast, large individuals reached a peak in density at 14–15 km distance from the southeastern end.

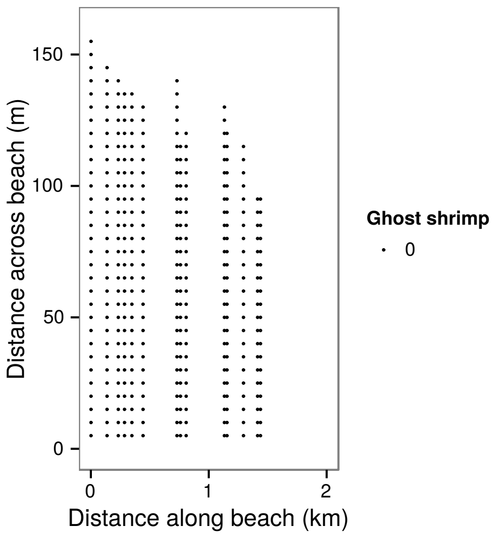
Across the intertidal extent of the beach, juveniles had high estimated densities in the upper intertidal area (about 60 m from the toe of the dune), with a second, larger peak further down the shore (160–170 m from the dune), but well above the low tide mark. Large toheroa had low densities across most of the intertidal extent, with an increase from the mid-intertidal area to the highest density close to the low tide mark.



(a) Oreti

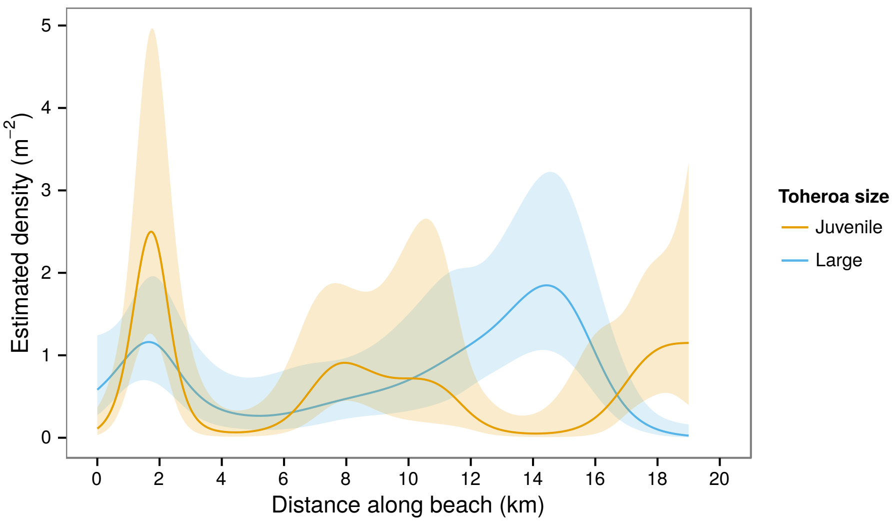


(b) Bluecliffs

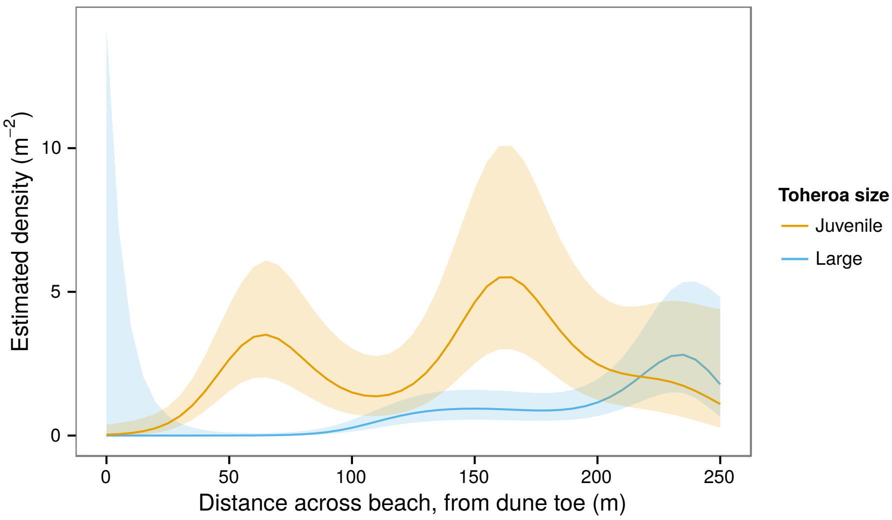


(c) Orepuki

Figure 13: Distribution of ghost shrimp at (a) Oreti, (b) Bluecliffs, and (c) Orepuki beaches. Dots indicate the position of sampling quadrats, and circle sizes correspond with the number of ghost shrimp burrow holes counted in each 0.25-m^2 quadrat. Ghost shrimp counts are shown by distance along the beach (from the eastern side of the first stratum) and distance across the beach (from the toe of the dune).



(a) Along beach



(b) Across beach

Figure 14: Density of toheroa (m^{-2}) at Oreti Beach estimated with a generalized additive model (GAM). The lines mark the mean estimate and the shading indicates the 95% confidence interval for juvenile (<40 mm shell length; red) and large toheroa ($\geq$40 mm shell length; blue). The variation with distance along the beach (from south-east to north-west) is shown in (a), with the predictions made at 200 m distance from the toe of the dune. In (b) the variation with distance across the beach is shown, with the predictions made at 1.8 km distance from the south-eastern end of the sampling region. In both cases, the predictions were made for no gravel, no ghost shrimp, and sieved quadrats. (In (b), the large confidence interval for densities of large toheroa close to zero is owing to the logarithmic values of the large number of zeros affecting the model.)

Table 5: Summary of coefficients of a generalised additive model (GAM) fitted to the quadrat data, for models of large (≥40 mm shell length) and juvenile (<40 mm) toheroa in the quadrat counts. Included are the mean estimate of the coefficients, the standard error (SE), and the *P*-value, with the coefficients being on a log-scale. The mean and 95% confidence interval (CI) of the these coefficients expressed as multiplicative effects are also included. Ghost shrimp was a numeric covariate, while "gravel" and "sieved" were factors (with the coefficients being relative to no-gravel, or not-sieved). The coefficients were interpreted as significantly different from zero if P < 0.05.

Toheroa size	Covariate	Estimate	SE	*P*-value	Multiplicative effect	
					Mean	95% CI
Large	Ghost shrimp	-0.00	0.02	0.8944	1.00	0.95–1.04
	Gravel	0.10	0.24	0.6791	1.11	0.69–1.77
	Sieved	-0.13	0.18	0.4819	0.88	0.61–1.26
Juvenile	Ghost shrimp	-0.19	0.09	0.0439	0.83	0.69–0.99
	Gravel	-2.07	0.37	<0.001	0.13	0.06–0.26
	Sieved	1.28	0.25	<0.001	3.60	2.21–5.88

4. DISCUSSION

Findings from the current surveys confirmed that Oreti Beach continues to support the largest toheroa population in Southland. There were 1 489 000 (95% CI: 1 036 000–1 941 000) large toheroa (shell length ≥40 mm) across the three beaches surveyed in 2013–14, and 1 395 000 (95% CI: 951 000–1 840 000) toheroa of this total were at Oreti Beach. In comparison, the toheroa populations at Bluecliffs and Orepuki beaches were small, with a total of 65 000 (95% CI: 0–150 000) and 28 000 (95% CI: 10 000–46 000) large individuals, respectively. At Oreti Beach, there were an estimated 2 052 000 (95% CI: 755 000–3 348 000) juvenile toheroa (with shell lengths <40 mm). The population at Orepuki Beach was dominated by juveniles, with an estimated 365 000 (95% CI: 211 000–519 000) juveniles. The number of juveniles at Bluecliffs Beach was not estimated.

There have been regular toheroa surveys at Oreti and Bluecliffs beaches since 1969 and 1966. These surveys provide information about the toheroa populations over time, although the methods of some of the earlier surveys were different or are difficult to evaluate (see discussions in Beentjes 2010a, 2010b, Williams et al. 2013a). Only some of the early surveys at Oreti Beach included the reserve area, but the difference in the overall estimates resulting from this inclusion is considered to be small (Beentjes 2010b). Another limitation to temporal comparisons is the lack of sieved transects in the early surveys, as they were focused on the adult population, so that juvenile toheora were not specifically targeted (Millar & Olsen 1995). In more recent surveys, however, juvenile toheroa were systematically included by sieving quadrats on a subset of transects.

Recent surveys at Oreti and Bluecliffs beaches (i.e., since 1998) were based on a stratified random transect design, covered similar areas, and systematically included juveniles by sieving some of the transects (Beentjes 2010b). At Orepuki Beach, the first formal assessment of the toheroa population was in December 2008, as part of a university study (Futter 2011). This study did not use a stratified random design, but sampled within regularly spaced strips along the beach (16 strips of 100 m length each across the intertidal extent), with one transect in each strip. The field sampling methods were similar to those in recent surveys at Oreti and Bluecliffs beaches, but all quadrats were sieved.

The survey methods in the present study were consistent with these previous surveys, allowing direct comparisons across these population assessments. The exception was quadrat size, which was half the surface area in the current survey (i.e., 0.5 m by 0.5 m). Nevertheless, this quadrat size has been used in recent toheroa surveys in Northland (Williams et al. 2013a). Using a smaller quadrat size reduced the sampling effort, and preliminary analyses prior to sampling indicated that this change still allowed

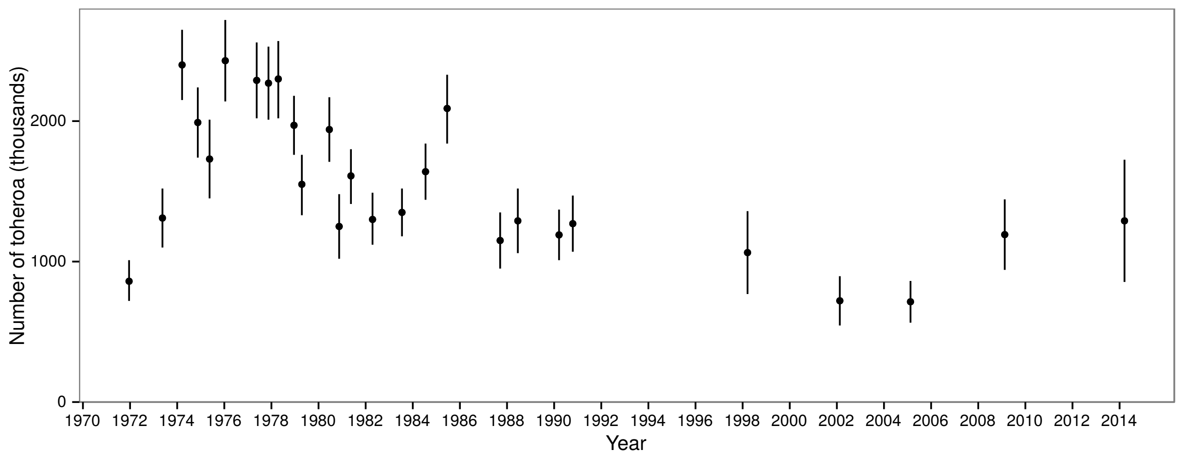


Figure 15: Number of toheroa ≥80 mm shell length at Oreti Beach over time. Historical data include values from surveys before 1992 (Millar & Olsen 1995) and between 1998 and 2009 (Carbines & Breen 1999, Beentjes et al. 2003, Beentjes & Gilbert 2006b, Beentjes 2010b). The latter surveys did not include the reserve area (stratum 1 in the 2013–14 survey). Data from a survey in 1996 (Carbines 1997) were omitted, as the survey transects were truncated and did not cover the entire tidal range of toheroa. Uncertainties in the 1998 survey were not available from the original report (Carbines & Breen 1999), and were constructed using the same coefficient of variation as the estimate of the number of toheroa over 100 mm shell length.

the target CV of 20% or less to be met for the abundance estimate of large toheroa (≥ 40 mm). This target CV value was achieved at Oreti Beach, and for the estimate of total large toheroa abundance at all three beaches. The statistical analysis showed that there was no significant difference in the number of toheroa ≥40 mm shell length recorded in sieved or unsieved quadrats. This finding supports the use of the manual sorting method for counting toheroa in the quadrats.

4.1 Toheroa at Oreti Beach

At Oreti Beach, the preceding toheroa survey was in 2009, with other recent population assessments in 1998, 2002, and 2005 (see Beentjes 2010b). A comparison between the current study and those recent surveys showed that the population size of large toheroa (e.g., ≥40 mm shell length) has remained relatively stable, although it was slightly smaller in 2013–14 than in 2009. There were 365 000 (95% CI: 205 000–525 000) individuals at 40–99 mm shell length and 890 000 (95% CI: 539 000–1 240 000) individuals ≥100 mm shell length in 2013–14, compared with 493 000 (95% CI: 324 000–662 000) and 980 000 (95% CI: 760 000–1 200 000) in these size classes in 2009 (when considering the same area sampled, i.e., excluding stratum 1 from the current study).

Over the entire data series from the early 1970s onwards, large toheroa (≥80 mm shell length) showed considerable fluctuation in population size, with high abundances in the 1970s and 1980s, followed by a marked decrease in subsequent surveys in the late 1980s and 1990s (Figure 15). Particularly low estimates from a survey in 1996 (300 000 toheroa at >100 mm shell length, including the reserve area; Carbines 1997) were not included in this temporal comparison as the field sampling in this earlier survey had truncated transects. The transects in this survey were about 86 m in length, with an average of 17.5 quadrats per transect (Carbines 1997). In comparison, the mean transect length in subsequent surveys was 200 m, resulting in 35 to 60 quadrats per transect (Beentjes 2010b). In the 2013–14 survey, the transect length ranged from 182 to 229 m, with 36 to 45 sampling quadrats per transect.

Beentjes (2010b) highlights the potential limitation of the truncated transects in the 1996 survey, and suggests that the low estimates may have been due to the inadequate sampling of adult toheroa, as their beds are generally in the lower intertidal area of the beach. For this reason, we omitted the 1996 survey data from the time series. This omission means that the estimated population size of large toheroa appears to have remained relatively constant from 1987 onwards, following the considerable decline in the preceding period.

In contrast to large toheroa, the estimated number of juveniles (less than 40 mm shell length) showed a marked decline in 2013–14. The number of individuals in this size class dropped from 6 030 000 (95% CI: 3 056 000–9 005 000) toheroa in 2009 to 2 052 000 (95% CI: 755 000–3 348 000) toheroa in 2013–14. This reduction in juvenile numbers continued the decreasing trend in the population of juveniles that has been evident at Oreti Beach since 1998, when their population size was over 15 million individuals (see Beentjes 2010b). Although toheroa recruitment can be highly variable across years, including high juvenile mortality in some populations such as documented at Bluecliffs Beach (Beentjes 2010a), the population assessments over the past 16 years show that the number of juveniles has consistently decreased at Oreti Beach.

The comparatively low number of juvenile toheroa in 2013–14 was also reflected in the size-frequency distributions, as this size class no longer dominated the population as it did in the previous surveys (i.e., since 1998). Although the population was bimodal, large individuals represented a stronger cohort than juveniles in 2013–14. If the lower number of juveniles persists, then it will lead to lower recruitment into the adult population. This study did not consider the demography of toheroa, and further research is necessary to understand the impact of the decline in juvenile toheroa on the Oreti Beach population.

Although the reasons for the decline in juvenile toheroa are unknown, the present study indicated a possible link between their observed decrease and the presence of gravel. The occurrence of gravel has not been previously reported at Oreti Beach; the preceding survey in 2009 documented sand in 99.5% of all quadrats, with coarse sand in the remaining small number of quadrats (Beentjes 2010b). The current study recorded gravel (sediment grain sizes over 2 mm) in the sediment analysis and also in a number of quadrats during field sampling. Records from the field sampling were qualitative only, based on the presence of gravel or pebbles. In addition to gravel being visible at the surface, some of the quadrats also contained a layer of gravel and pebbles below the surface, or interspersed through the sand. In the statistical analysis of toheroa counts from the quadrats at Oreti Beach, a negative association was found between the presence of gravel and juvenile abundance. As toheroa have a preference for fine sand substrate (Cassie 1955, Williams et al. 2013b), this finding suggests that the decline in juvenile toheroa at Oreti Beach since 2009 is related to an increase in gravel and pebbles at the beach. The decline of toheroa at Bluecliffs Beach was attributed to habitat loss, with beach erosion reducing the area of suitable toheroa habitat and causing a change from sandy sediment to gravel (Beentjes 2010a).

Another factor that appeared to be negatively associated with juvenile toheroa at Oreti Beach was the density of burrowing ghost shrimp within each quadrat. Through their burrowing and feeding activities, burrowing ghost shrimp cause constant sediment disturbance (bioturbation), which in turn may have adverse effects on associated species, such as small-sized bivalves (i.e., toheroa spat and juveniles). Although this negative impact has been documented in sheltered coastal environments (Berkenbusch et al. 2000), it is uncertain whether bioturbation by ghost shrimp is sufficiently significant given the overall physical disturbance at an unstable, highly-dynamic environment such as Oreti Beach. Another potential negative repercussion associated with burrowing ghost shrimp could be competition for food, as both ghost shrimp and toheroa feed on phytoplankton (Rapson 1954, Devine 1966); however, the observed negative association was only just significant, and further research would be needed to elucidate the interactions between toheroa and ghost shrimp.

Apart from habitat characteristics at the beach, adverse effects on toheroa populations may also arise from vehicles. Vehicle traffic on beaches can cause physical damage and injury to intertidal toheroa, i.e., when large numbers of vehicles are driven in the mid- to high-tide area where juvenile and adult toheroa are abundant (Williams et al. 2013b). The main vehicle entrance at Oreti Beach was about 7.8 km from the southeastern end of the 2013–14 survey area, at the border of strata 4 and 5. Toheroa were present in this area, but the highest densities of large and juvenile toheroa were at a distance from the main beach entrance (see Figure 7). It is unclear whether the lower density near the entrance is related to increased take near the vehicle entrance, vehicle traffic, or coincidental.

4.2 Toheroa at Bluecliffs Beach

Historically, Bluecliffs Beach supported a substantial toheroa population, with population estimates of 2.2 million toheroa over 75 mm shell length in the late 1960s (see Beentjes 2010a). Since then, toheroa numbers have consistently declined, initially to low levels in the 1970s, with some fluctuation across surveys. The population declined further to low estimates (<250 000 large toheroa) in 1985, and has remained small since then.

Recent population surveys that used comparable methods to the present study were conducted in 1998, 2005, and 2009 (see Beentjes 2010a). The sampling area in these recent population assessments has generally been based on the area around Rowallan Burn, with the survey extent including about 1.5 km east and 3.5 km west of Rowallan Burn, respectively. These surveys show that the toheroa population underwent a significant reduction in its distribution and abundance in recent years, coinciding with drastic habitat changes at the beach. The latter included erosion of the beach, continued receding of the sand dunes, and exposure of stones, resulting in the substantial loss of suitable toheroa habitat (Beentjes et al. 2006). The 2009 survey at Bluecliffs Beach reported an 80% decrease in the population of toheroa ≥100 mm shell length, and a 99% decrease in juveniles (<40 mm shell length) compared with the previous survey in 2005 (Beentjes 2010a). The corresponding population estimates were 34 900 toheroa ≥100 mm shell length and 6300 juveniles in 2009; there were 14 400 toheroa at 40–99 mm shell length.

In view of the continuous habitat loss and the significant reduction observed in the toheroa population, the sampling effort at Bluecliffs Beach was reduced in 2013–14. It was focused on two disjunct strata, including the area immediately west of Rowallan Burn and the western bay to ascertain whether toheroa still persisted at this beach. The former area was identified as still containing relatively high concentrations of toheroa in the preceding survey, while the western bay had been identified as providing suitable habitat, with adult toheroa recently observed in this area. Early toheroa surveys included the western bay (e.g., Street 1972), and field sampling in the present study confirmed that the toheroa population at Bluecliffs Beach extended into this area.

Data from both the survey strata at Bluecliffs Beach combined resulted in an estimated 8 000 (95% CI: 0–25 000) toheroa ≥100 mm shell length in the 2013–14 survey. Although toheroa are persisting, the decline in toheroa at Bluecliffs Beach has continued.

4.3 Toheroa at Orepuki Beach

The small population of toheroa at Orepuki Beach is considered to have become established following the transplantation of toheroa in the 1950s (Futter & Moller 2009). The first formal assessment of this population was conducted in December 2008 (Futter 2011). This survey consisted of 16 transects along the extent of the survey area (1.6 km), with a single transect within each of these 100 m strips. The resulting population estimate was a total of 381 553 toheroa, including 238 333 juveniles (≤39 mm shell length), 83 873 individuals at 40–99 mm shell length, and 58 585 individuals ≥100 mm shell length.

The 2013–14 survey confirmed the dominance of juveniles, however, there was a substantial decrease in the number of large toheroa at Orepuki Beach. There were 28 000 individuals at shell lengths ≥40 mm, and 8 000 individuals at shell lengths ≥100 mm. As a consequence, the population consisted largely of juveniles, with 194 000 toheroa in this size class in 2013–14.

The loss of large adults over the 6-year period between the two surveys is substantial, and the underlying causes are unknown. Although there was a mortality event at Orepuki Beach in July 2009, affecting an estimated 10–15% of the population (Robertson & Stevens 2012), this die-back does not explain the magnitude of the decline in large toheroa detected in the current survey.

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APPENDIX A: Transect information

Table A-1: Sampling information of the 2013–14 toheroa survey in Southland, including Oreti, Bluecliffs, and Orepuki beaches. Presented are the stratum and transect numbers, whether transects included sieved quadrats, the percentage of quadrats that contained gravel, and the transect starting points at the toe of the dune (in decimal degrees, World Geodetic System 1984).

Survey site	Stratum	Phase	Transect	Sieved	Gravel (%)	Longitude	Latitude
Oreti	1	1	1	No	0	168.2708	-46.4994
Oreti	1	1	2	No	2	168.2695	-46.4988
Oreti	1	1	3	Yes	0	168.2674	-46.4976
Oreti	1	1	4	Yes	0	168.2632	-46.4941
Oreti	2	1	1	No	32	168.2610	-46.4919
Oreti	2	1	2	Yes	80	168.2586	-46.4878
Oreti	2	1	3	No	59	168.2584	-46.4873
Oreti	2	1	4	Yes	82	168.2582	-46.4868
Oreti	2	1	5	No	63	168.2579	-46.4860
Oreti	3	1	1	Yes	77	168.2577	-46.4854
Oreti	3	1	2	Yes	55	168.2572	-46.4844
Oreti	3	1	3	No	45	168.2565	-46.4828
Oreti	3	1	4	No	13	168.2542	-46.4781
Oreti	4	1	1	No	25	168.2508	-46.4739
Oreti	4	1	2	Yes	3	168.2404	-46.4579
Oreti	4	1	3	No	0	168.2349	-46.4482
Oreti	4	1	4	Yes	0	168.2319	-46.4402
Oreti	5	1	1	Yes	0	168.2288	-46.4340
Oreti	5	1	2	Yes	0	168.2280	-46.4324
Oreti	5	1	3	No	0	168.2244	-46.4264
Oreti	5	1	4	No	0	168.2220	-46.4232
Oreti	5	1	5	No	0	168.2114	-46.4097
Oreti	6	1	1	Yes	0	168.2047	-46.4014
Oreti	6	1	2	No	5	168.2039	-46.3996
Oreti	6	1	3	No	12	168.2033	-46.3991
Oreti	6	1	4	No	74	168.2018	-46.3976
Oreti	6	1	5	Yes	0	168.1933	-46.3891
Oreti	7	1	1	No	100	168.1801	-46.3778
Oreti	7	1	2	No	100	168.1768	-46.3758
Oreti	7	1	3	No	63	168.1755	-46.3750
Oreti	7	1	4	Yes	0	168.1651	-46.3670
Oreti	7	1	5	Yes	71	168.1558	-46.3612
Oreti	7	1	6	No	8	168.1530	-46.3597
Oreti	1	2	4	No	0	168.2687	-46.4985
Oreti	6	2	1	No	0	168.2099	-46.4076
Oreti	6	2	4	No	0	168.2026	-46.3983
Oreti	7	2	2	No	0	168.1859	-46.3828
Oreti	7	2	6	No	0	168.1663	-46.3679
Oreti	7	2	7	No	0	168.1548	-46.3607
Oreti	7	2	8	No	0	168.1492	-46.3575
Bluecliffs	1	1	1	Yes	48	167.5330	-46.1624
Bluecliffs	1	1	2	No	52	167.5281	-46.1609
Bluecliffs	1	1	3	No	62	167.5241	-46.1596

Continued on next page

Table A-1 – *Continued from previous page*

Survey site	Stratum	Phase	Transect	Sieved	Gravel (%)	Longitude	Latitude
Bluecliffs	1	1	4	Yes	14	167.5211	-46.1585
Bluecliffs	2	1	1	No	32	167.4355	-46.1493
Bluecliffs	2	1	2	No	27	167.4264	-46.1493
Bluecliffs	2	1	3	No	13	167.4125	-46.1501
Bluecliffs	2	1	4	No	16	167.4086	-46.1507
Orepuki	1	1	1	Yes	0	167.7302	-46.2977
Orepuki	1	1	2	No	0	167.7305	-46.2965
Orepuki	1	1	3	Yes	0	167.7308	-46.2952
Orepuki	2	1	1	No	0	167.7310	-46.2946
Orepuki	2	1	2	Yes	0	167.7312	-46.2938
Orepuki	2	1	3	No	0	167.7321	-46.2911
Orepuki	2	1	4	Yes	0	167.7322	-46.2906
Orepuki	3	1	1	No	15	167.7326	-46.2877
Orepuki	3	1	2	Yes	17	167.7326	-46.2875
Orepuki	3	1	3	No	0	167.7327	-46.2863
Orepuki	3	1	4	Yes	11	167.7326	-46.2850
Orepuki	1	2	5	No	0	167.7307	-46.2956
Orepuki	2	2	5	No	0	167.7320	-46.2913
Orepuki	3	2	7	No	0	167.7326	-46.2852

APPENDIX B: Sediment sampling

Table B-2: Sediment organic content and grain size distributions at Southland beaches included in the 2013–14 toheroa survey. The sampling points were every 10 m along the transects from the toe of the dune to the low tide mark. Sediments grain size fractions are defined as fines (silt and clay; <63 µm), very fine sand (VFS; >63 µm), fine sand (FS; >125 µm), medium sand (MS; >250 µm), coarse sand (CS; >500 µm), and gravel (>2000 µm). Empty cells indicate missing data.

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Oreti	1	1	4	1	0.5	0.0	38.6	61.0	0.1	0.0	0.0
Oreti	1	1	4	2	0.7	0.0	35.7	63.4	0.6	0.0	0.0
Oreti	1	1	4	3	0.7	0.0	31.9	67.4	0.5	0.0	0.0
Oreti	1	1	4	4	0.7	0.0	27.4	72.0	0.3	0.0	0.0
Oreti	1	1	4	5	0.7	0.0	32.1	66.5	1.1	0.0	0.0
Oreti	1	1	4	6	0.5	0.0	29.8	66.9	3.1	0.0	0.0
Oreti	1	1	4	7	0.7	0.0	21.2	74.0	4.4	0.1	0.0
Oreti	1	1	4	8	0.6	0.0	24.2	68.9	6.3	0.2	0.0
Oreti	1	1	4	9		0.8	26.1	59.8	9.4	3.1	0.5
Oreti	1	1	4	10		0.0	33.1	46.4	8.8	4.1	7.4
Oreti	1	1	4	11	0.7	0.6	32.0	47.6	9.2	5.1	5.2
Oreti	1	1	4	12	0.6	0.0	25.5	50.9	10.0	3.5	9.8
Oreti	1	1	4	13	0.6	0.1	27.5	59.8	4.3	0.7	7.4
Oreti	1	1	4	14	0.6	0.0	30.0	67.3	2.1	0.1	0.2
Oreti	1	1	4	15	0.7	0.0	23.2	60.5	14.0	1.6	0.4
Oreti	1	1	4	16	0.7	0.0	20.8	75.6	3.0	0.2	0.0
Oreti	1	1	4	17	0.7	0.0	21.7	68.0	8.6	0.9	0.5
Oreti	1	1	4	18	0.6	0.0	30.9	66.8	1.7	0.1	0.1
Oreti	1	1	4	19	0.7	0.0	25.9	64.0	9.3	0.5	0.0
Oreti	1	1	4	20	0.6	0.0	23.0	72.5	4.1	0.1	0.0
Oreti	1	1	4	21	0.8	0.0	12.9	69.2	10.8	0.5	6.2
Oreti	1	1	4	22	0.8	0.6	32.7	59.5	6.0	0.8	0.0
Oreti	1	1	4	23	0.7	0.0	26.4	71.2	1.9	0.2	0.0
Oreti	1	1	4	24	0.8	0.9	35.8	61.6	1.3	0.1	0.0

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Table B-2 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Oreti	1	1	4	25	0.9	0.0	23.5	71.1	4.6	0.5	0.0
Oreti	1	1	4	26	0.7	0.0	37.6	59.4	2.6	0.1	0.0
Oreti	1	1	4	27		0.0	24.8	69.6	5.0	0.3	0.0
Oreti	1	1	4	28		0.0	28.1	49.2	2.6	0.2	19.7
Oreti	1	1	4	29	0.8	0.0	42.9	53.2	2.9	0.4	0.2
Oreti	2	1	2	1	0.6	0.0	28.7	70.1	1.1	0.1	0.0
Oreti	2	1	2	2	0.5	0.0	38.5	60.9	0.5	0.0	0.0
Oreti	2	1	2	3	0.5	0.0	34.6	64.5	0.9	0.0	0.0
Oreti	2	1	2	4	0.7	0.0	36.4	62.2	1.3	0.1	0.0
Oreti	2	1	2	5	0.6	0.1	29.9	68.0	1.9	0.2	0.0
Oreti	2	1	2	6	0.6	0.0	30.1	66.2	1.7	0.2	1.7
Oreti	2	1	2	7	0.5	0.0	25.0	49.9	7.3	1.0	16.8
Oreti	2	1	2	8	0.6	0.1	27.6	59.9	4.3	0.7	7.4
Oreti	2	1	2	9	0.5	0.0	25.6	51.1	10.1	3.5	9.8
Oreti	2	1	2	10	0.6	0.6	32.1	47.8	9.2	5.2	5.2
Oreti	2	1	2	11	0.8	0.0	33.2	46.5	8.8	4.1	7.4
Oreti	2	1	2	12	0.7	0.8	26.2	59.9	9.5	3.2	0.5
Oreti	2	1	2	13	0.7	0.0	32.2	54.8	7.6	4.4	0.9
Oreti	2	1	2	14	0.8	0.1	31.3	55.6	4.8	4.3	3.9
Oreti	2	1	2	15	0.7	0.0	32.7	59.9	5.0	1.9	0.5
Oreti	2	1	2	16	0.7	0.0	41.9	53.5	2.2	1.1	1.2
Oreti	2	1	2	17	0.8	0.0	34.5	60.5	2.9	1.7	0.4
Oreti	2	1	2	18	0.8	0.0	37.8	58.4	0.9	1.1	1.9
Oreti	2	1	2	19	0.7	0.0	35.6	57.9	2.9	2.5	1.2
Oreti	2	1	2	20	0.7	0.0	35.3	61.4	1.9	1.0	0.5
Oreti	2	1	2	21	0.6	0.2	37.4	61.6	0.5	0.2	0.1
Oreti	3	1	1	1	0.8	0.0	40.6	59.3	0.1	0.0	0.0

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Table B-2 – *Continued from previous page*

Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Oreti	3	1	1	2	0.6	0.0	34.5	64.7	0.7	0.0	0.0
Oreti	3	1	1	3	0.8	0.0	24.7	74.7	0.6	0.0	0.0
Oreti	3	1	1	4	0.7	0.0	38.9	60.5	0.5	0.1	0.0
Oreti	3	1	1	5	0.6	0.2	27.1	71.6	1.1	0.1	0.0
Oreti	3	1	1	6		0.0	27.9	69.0	2.9	0.2	0.0
Oreti	3	1	1	7	0.7	0.0	26.3	71.9	1.7	0.1	0.0
Oreti	3	1	1	8	0.7	0.0	31.4	66.2	2.3	0.2	0.0
Oreti	3	1	1	9	0.6	0.0	32.4	64.9	2.5	0.2	0.0
Oreti	3	1	1	10	0.7	0.0	31.0	64.5	4.0	0.5	0.0
Oreti	3	1	1	11	0.7	0.0	22.0	45.6	7.7	1.4	23.3
Oreti	3	1	1	12	0.7	0.0	30.0	49.0	7.3	2.8	10.9
Oreti	3	1	1	13	0.7	0.0	27.0	54.8	5.6	1.5	11.1
Oreti	3	1	1	14	0.6	0.0	23.8	69.8	5.0	1.3	0.0
Oreti	3	1	1	15	0.7	0.0	18.2	52.1	4.1	1.3	24.3
Oreti	3	1	1	16	0.9	0.0	27.9	60.5	7.7	3.4	0.4
Oreti	3	1	1	17	0.7	0.0	27.0	64.1	6.9	2.1	0.0
Oreti	3	1	1	18	0.8	0.0	41.4	57.2	1.1	0.2	0.0
Oreti	3	1	1	19	0.8	0.0	34.4	62.8	2.4	0.4	0.0
Oreti	3	1	1	20	0.6	0.0	30.5	67.7	1.8	0.1	0.0
Oreti	3	1	1	21	0.9	0.0	35.7	62.0	1.4	0.9	0.0
Oreti	3	1	1	22	0.8	0.0	10.1	88.4	1.0	0.3	0.1
Oreti	4	1	4	1	0.5	0.0	46.9	52.9	0.1	0.0	0.0
Oreti	4	1	4	2	0.6	0.0	42.8	57.0	0.1	0.1	0.0
Oreti	4	1	4	3	0.6	0.0	41.5	58.3	0.1	0.0	0.0
Oreti	4	1	4	4	0.7	0.0	49.2	50.7	0.1	0.0	0.0
Oreti	4	1	4	5	0.8	0.0	37.1	62.8	0.1	0.0	0.0
Oreti	4	1	4	6	1.0	0.0	38.2	61.7	0.0	0.0	0.0

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Table B-2 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Oreti	4	1	4	7	0.9	0.0	53.9	46.1	0.0	0.0	0.0
Oreti	4	1	4	8	0.9	0.1	47.2	52.7	0.1	0.0	0.0
Oreti	4	1	4	9	0.8	0.0	49.4	50.4	0.1	0.0	0.0
Oreti	4	1	4	10	0.8	0.0	50.6	49.3	0.1	0.0	0.0
Oreti	4	1	4	11	0.8	0.0	45.1	54.6	0.2	0.0	0.0
Oreti	4	1	4	12	1.0	0.0	47.6	52.1	0.4	0.0	0.0
Oreti	4	1	4	13	0.9	0.0	48.0	51.8	0.2	0.0	0.0
Oreti	4	1	4	14	0.7	0.0	53.0	46.7	0.3	0.0	0.0
Oreti	4	1	4	15	0.9	0.0	51.5	48.3	0.2	0.0	0.0
Oreti	4	1	4	16	0.8	0.0	43.0	56.6	0.4	0.0	0.0
Oreti	4	1	4	17	0.9	0.0	47.8	51.7	0.4	0.0	0.0
Oreti	4	1	4	18	1.0	0.0	46.1	53.3	0.5	0.0	0.0
Oreti	4	1	4	19	0.9	0.0	61.5	37.9	0.6	0.0	0.0
Oreti	4	1	4	20	0.9	0.0	45.2	53.1	1.6	0.1	0.0
Oreti	4	1	4	21	1.0	0.0	62.1	37.2	0.4	0.3	0.0
Oreti	4	1	4	22	0.9	0.0	41.6	58.4	0.0	0.0	0.0
Oreti	4	1	4	23	0.8	0.0	46.1	53.3	0.5	0.0	0.0
Oreti	4	1	4	24	0.9	0.0	62.9	31.5	0.7	0.0	4.9
Oreti	5	1	2	1	0.7	0.0	45.3	54.6	0.1	0.0	0.0
Oreti	5	1	2	2	0.9	0.0	42.5	57.5	0.0	0.0	0.0
Oreti	5	1	2	3	1.0	0.0	46.4	53.4	0.2	0.0	0.0
Oreti	5	1	2	4	0.7	1.0	32.5	66.3	0.1	0.0	0.0
Oreti	5	1	2	5	0.7	0.8	42.5	56.6	0.1	0.0	0.0
Oreti	5	1	2	6	0.7	0.0	48.6	51.3	0.1	0.0	0.0
Oreti	5	1	2	7	0.9	0.0	51.5	48.3	0.1	0.0	0.0
Oreti	5	1	2	8	0.7	2.6	51.0	46.3	0.1	0.0	0.0
Oreti	5	1	2	9	0.7	0.0	39.2	60.5	0.3	0.1	0.0

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Table B-2 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Oreti	5	1	2	10	0.8	0.0	42.9	56.9	0.2	0.0	0.0
Oreti	5	1	2	11	0.7	0.0	40.3	59.5	0.1	0.0	0.0
Oreti	5	1	2	12	1.0	0.0	55.7	44.2	0.1	0.0	0.0
Oreti	5	1	2	13	0.8	0.0	35.5	64.2	0.3	0.0	0.0
Oreti	5	1	2	14	0.7	0.0	32.2	67.5	0.2	0.0	0.0
Oreti	5	1	2	15	0.7	0.0	31.6	68.2	0.3	0.0	0.0
Oreti	5	1	2	16	0.9	0.0	35.4	64.4	0.1	0.0	0.0
Oreti	5	1	2	17	0.9	0.0	29.3	70.3	0.4	0.0	0.0
Oreti	5	1	2	18	0.8	0.0	39.3	60.5	0.2	0.0	0.0
Oreti	5	1	2	19	1.0	0.0	40.3	59.5	0.1	0.0	0.0
Oreti	5	1	2	20	0.9	0.0	31.7	68.2	0.1	0.0	0.0
Oreti	6	1	5	1	0.7	0.0	35.9	63.9	0.2	0.0	0.0
Oreti	6	1	5	2	0.7	0.0	41.5	58.1	0.4	0.0	0.0
Oreti	6	1	5	3	0.8	0.0	44.2	55.6	0.1	0.0	0.0
Oreti	6	1	5	4	0.5	0.0	41.4	58.4	0.2	0.0	0.0
Oreti	6	1	5	5	0.6	0.0	45.0	54.7	0.2	0.1	0.0
Oreti	6	1	5	6	0.9	0.0	33.3	66.1	0.5	0.1	0.0
Oreti	6	1	5	7	0.8	0.0	47.6	52.1	0.3	0.0	0.0
Oreti	6	1	5	8	0.8	0.0	28.1	70.5	1.3	0.0	0.0
Oreti	6	1	5	9	0.6	0.0	35.6	63.6	0.8	0.0	0.0
Oreti	6	1	5	10	0.7	0.0	26.7	72.0	1.3	0.0	0.0
Oreti	6	1	5	11	0.7	0.0	38.2	61.3	0.5	0.0	0.0
Oreti	6	1	5	12	0.5	0.0	28.3	68.3	3.4	0.1	0.0
Oreti	6	1	5	13	0.6	0.0	29.7	67.4	2.9	0.1	0.0
Oreti	6	1	5	14	0.7	0.1	35.5	61.7	2.6	0.2	0.0
Oreti	6	1	5	15	0.9	0.0	37.9	59.5	2.5	0.1	0.0
Oreti	6	1	5	16	0.8	0.0	28.1	69.3	2.4	0.2	0.0

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Table B-2 – *Continued from previous page*

Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Oreti	6	1	5	17	0.5	0.0	33.3	66.2	0.4	0.0	0.0
Oreti	6	1	5	18	0.8	0.0	36.9	62.6	0.5	0.0	0.0
Oreti	6	1	5	19	0.5	0.0	32.3	67.0	0.6	0.0	0.0
Oreti	6	1	5	20	0.9	0.0	38.2	61.1	0.7	0.1	0.0
Oreti	6	1	5	21	0.8	0.0	46.0	53.6	0.3	0.1	0.0
Oreti	7	1	4	1	0.7	0.1	46.6	53.1	0.2	0.0	0.0
Oreti	7	1	4	2	0.8	0.0	45.6	53.2	1.2	0.0	0.0
Oreti	7	1	4	3	0.8	0.0	52.0	47.2	0.8	0.0	0.0
Oreti	7	1	4	4	0.8	0.1	41.1	58.4	0.3	0.0	0.0
Oreti	7	1	4	5	0.9	0.2	39.6	59.8	0.4	0.0	0.0
Oreti	7	1	4	6	0.8	0.0	42.3	56.3	1.4	0.0	0.0
Oreti	7	1	4	7	0.9	0.0	44.2	55.0	0.7	0.0	0.0
Oreti	7	1	4	8	0.9	0.0	40.8	56.7	2.5	0.0	0.0
Oreti	7	1	4	9	1.0	0.0	40.0	54.6	5.4	0.0	0.0
Oreti	7	1	4	10	0.8	0.0	35.5	61.4	3.0	0.1	0.0
Oreti	7	1	4	11	1.0	0.0	32.1	62.2	2.6	0.1	3.1
Oreti	7	1	4	12	0.8	0.0	38.8	59.7	1.5	0.0	0.0
Oreti	7	1	4	13	0.9	0.0	39.5	58.8	1.7	0.0	0.0
Oreti	7	1	4	14	0.8	0.0	42.8	55.3	1.9	0.1	0.0
Oreti	7	1	4	15	0.9	0.0	36.5	61.0	2.4	0.1	0.0
Oreti	7	1	4	16	1.0	0.0	28.7	64.5	6.8	0.0	0.0
Oreti	7	1	4	17	0.9	0.1	36.7	59.7	0.1	3.4	0.0
Oreti	7	1	4	18	0.9	0.0	35.8	61.5	2.7	0.1	0.0
Oreti	7	1	4	19	0.8	0.0	52.2	45.0	2.5	0.3	0.0
Oreti	7	1	4	20	0.9	0.0	57.8	41.2	0.9	0.1	0.0
Oreti	7	1	4	21	0.9	0.0	37.5	61.1	1.3	0.1	0.0
Oreti	7	1	4	22	0.9	0.7	31.9	62.0	4.7	0.7	0.0

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Table B-2 – *Continued from previous page*

Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Sediment grain size fraction (%)					
						Fines	VFS	FS	MS	CS	Gravel
Oreti	7	1	4	23	0.9	0.0	31.4	2.7	65.6	0.4	0.0
Bluecliffs	1	1	4	1	0.7						
Bluecliffs	1	1	4	2	0.5	0.0	2.7	60.0	37.3	0.0	0.0
Bluecliffs	1	1	4	3	0.6	0.0	3.9	61.7	28.8	1.9	3.8
Bluecliffs	1	1	4	4	0.6	0.0	2.6	74.7	21.5	0.8	0.4
Bluecliffs	1	1	4	5	0.6	0.0	1.4	58.1	38.6	1.9	0.0
Bluecliffs	1	1	4	6	0.7	0.0	3.2	73.4	22.0	0.9	0.5
Bluecliffs	1	1	4	7	0.6	0.1	3.6	76.0	15.2	0.2	4.8
Bluecliffs	1	1	4	8	0.7	0.0	3.7	77.6	15.9	2.8	0.0
Bluecliffs	1	1	4	9		0.0	3.9	81.3	14.7	0.2	0.0
Bluecliffs	1	1	4	10	0.8	0.0	4.3	81.0	14.6	0.1	0.0
Bluecliffs	1	1	4	11	0.8	0.0	3.0	78.8	17.6	0.5	0.0
Bluecliffs	2	1	2	1	0.9	1.0	0.2	2.1	0.4	0.0	96.2
Bluecliffs	2	1	2	2	0.9	0.0	1.2	32.0	36.8	7.0	23.0
Bluecliffs	2	1	2	3	0.9	0.0	0.9	18.9	5.8	0.4	73.9
Bluecliffs	2	1	2	4	0.6	0.0	3.3	38.9	6.3	0.5	51.0
Bluecliffs	2	1	2	5	0.9	0.0	4.9	72.0	13.8	0.4	8.9
Bluecliffs	2	1	2	6	0.9	0.0	5.4	75.6	17.9	0.4	0.6
Bluecliffs	2	1	2	7	1.0	0.0	6.6	58.8	24.5	1.7	8.4
Bluecliffs	2	1	2	8	1.4	0.0	7.3	60.7	31.5	0.5	0.0
Bluecliffs	2	1	2	9	0.5	0.2	8.1	66.7	19.9	1.4	3.7
Bluecliffs	2	1	2	10	1.3	0.0	8.2	74.5	16.1	1.2	0.0
Orepuki	1	1	1	1	0.5	0.0	22.3	76.6	1.0	0.1	0.0
Orepuki	1	1	1	2	0.6	0.0	23.1	76.9	0.0	0.0	0.0
Orepuki	1	1	1	3	0.6	0.0	16.8	83.1	0.1	0.0	0.0
Orepuki	1	1	1	4	0.6	0.0	14.2	85.7	0.1	0.0	0.0
Orepuki	1	1	1	5	0.6	0.0	14.4	85.4	0.1	0.1	0.0

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Table B-2 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Orepuki	1	1	1	6	0.6	0.0	12.6	87.3	0.1	0.0	0.0
Orepuki	1	1	1	7	0.6	0.0	11.3	88.5	0.2	0.0	0.0
Orepuki	1	1	1	8	0.5	0.0	12.0	87.8	0.2	0.0	0.0
Orepuki	1	1	1	9	0.6	0.0	11.1	88.4	0.5	0.0	0.0
Orepuki	1	1	1	10	0.6	0.0	11.3	88.2	0.5	0.0	0.0
Orepuki	1	1	1	11	1.4	0.0	9.7	89.9	0.4	0.0	0.0
Orepuki	1	1	1	12	0.6	0.0	9.3	89.8	0.9	0.0	0.0
Orepuki	1	1	1	13	0.5	0.0	11.6	87.3	1.0	0.0	0.0
Orepuki	1	1	1	14	0.6	0.0	7.9	90.4	1.6	0.1	0.0
Orepuki	1	1	1	15	0.5	0.0	11.2	86.3	2.3	0.1	0.0
Orepuki	1	1	1	16	0.6	0.0	15.0	84.3	0.5	0.1	0.0
Orepuki	2	1	4	1	0.4	0.0	42.9	56.2	0.2	0.1	0.5
Orepuki	2	1	4	2	0.3	0.0	40.0	59.8	0.1	0.0	0.0
Orepuki	2	1	4	3	0.4	0.0	28.7	71.0	0.3	0.0	0.0
Orepuki	2	1	4	4	0.5	0.0	28.6	71.0	0.2	0.2	0.0
Orepuki	2	1	4	5	0.5	0.0	9.5	89.2	1.3	0.0	0.0
Orepuki	2	1	4	6	0.6	0.0	17.4	82.0	0.6	0.0	0.0
Orepuki	2	1	4	7	0.5	0.0	12.2	86.3	1.5	0.0	0.0
Orepuki	2	1	4	8	0.6	0.0	8.2	90.3	1.4	0.0	0.0
Orepuki	2	1	4	9	0.6	0.0	9.5	89.5	0.9	0.1	0.0
Orepuki	2	1	4	10	0.7	0.0	10.0	89.2	0.7	0.1	0.0
Orepuki	2	1	4	11	0.6	0.0	5.1	91.9	2.9	0.1	0.0
Orepuki	2	1	4	12	0.5	0.0	8.0	88.2	3.7	0.1	0.0
Orepuki	3	1	2	1	0.3	0.0	7.8	64.0	28.0	0.2	0.1
Orepuki	3	1	2	2	0.3	0.0	13.3	65.0	20.2	1.5	0.0
Orepuki	3	1	2	3	0.4	0.0	17.0	63.1	19.7	0.2	0.0
Orepuki	3	1	2	4	0.6	0.0	13.6	82.4	3.8	0.2	0.0

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Table B-2 – *Continued from previous page*

						Sediment grain size fraction (%)					
Survey site	Stratum	Phase	Transect	Sample	Organic content (%)	Fines	VFS	FS	MS	CS	Gravel
Orepuki	3	1	2	5	1.2	0.0	16.4	81.5	2.0	0.0	0.0
Orepuki	3	1	2	6	0.5	0.0	16.9	81.4	1.6	0.0	0.0
Orepuki	3	1	2	7	0.5	0.0	14.7	84.6	0.7	0.0	0.0
Orepuki	3	1	2	8	0.6	0.0	10.0	89.3	0.8	0.0	0.0
Orepuki	3	1	2	9	0.5	0.0	11.1	87.8	1.0	0.1	0.0
Orepuki	3	1	2	10	0.6	0.0	7.9	90.6	1.4	0.1	0.0
Orepuki	3	1	2	11	0.5	0.0	4.9	94.4	0.7	0.0	0.0
Orepuki	3	1	2	12	0.6	0.0	7.5	91.3	1.0	0.1	0.0