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Toheroa survey of Oreti Beach, 2009, and review of historical surveys

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EXECUTIVE SUMMARY

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This report includes the results of a toheroa survey of Oreti Beach in February 2009, and a review of length frequency, abundance, and distribution from historic surveys of Oreti Beach.

A survey of Oreti Beach toheroa was carried out between 9 and 13 February 2009 using a two phase random stratified transect survey design with 40 transects being sampled (16 sieved and 24 non-sieved). Transect rope lines were run down the beach between high and low water on which 0.5 square metre quadrats spaced at 5 m intervals were excavated to a depth of about 30 cm with a spade. Two transects from each of eight strata were sieved to sample juveniles from which the juvenile population was estimated. The population estimates were about 980 000 adults (100 mm or over), 493 000 sub-adult (40–99 mm), 6 030 000 juveniles (under 40 mm), and 1 192 000 toheroa 80 mm or over. The corresponding coefficients of variation were 11%, 18%, 25%, and 11%. The required survey target c.v. for legal-sized (100 mm or over), toheroa was 20%. Length frequency distribution was bimodal regardless of whether sampled from sieved or non-sieved transects characterised by a juvenile mode (under 40 mm) and an adult mode between 100 and 145 mm, with relatively few toheroa of intermediate size. Toheroa were found in all strata, but adults were not found in stratum 4 near the main entrance, and were most abundant in the southeast end near New River Estuary, i.e., 65% of adults were found in the first 2 km of the beach. Juveniles and sub-adults were more evenly distributed along the entire beach, with a slight southeast bias. Adults occupied a well defined zone mainly from about 100 to 225 m from high water (mean = 169 m). Sub-adult toheroa occupied a similar but slightly shallower distribution, but had a wider range that extends further up the beach toward the dunes (mean = 163 m). Juveniles had the widest vertical distribution from about 25 to 250 m (mean = 77 m), but were most abundant higher on the beach. Of the 2535 quadrats sampled, 99.6% had substrate suitable for toheroa (sand).

Abundance estimates, size, and spatial distribution of toheroa were reviewed from 30 toheroa surveys of Oreti Beach from 1969 to 2005. Numbers of large toheroa (80 mm or over) on Oreti Beach declined after 1985, when the population almost halved in two years from about 2 million to 1 million and then continued to decline over the next 10 years until 1996, when the population was estimated at only 400 000. The population since 1998 appears to be stable or increasing, and the steep trend of declining abundance that began in the mid 1980s has not continued. Indeed the time series historical average (80 mm and over, 1971 to 1990) is 1.7 million, and some estimates from the early 1970s and 1980s were not dissimilar to the 2009 estimate. From an historical perspective the population is reasonably stable, but at a density below the historical average. In general, the size composition of historical surveys was characterised by a variable mode of juvenile toheroa (where juveniles were sampled) and a second strong mode of adult toheroa, with relatively few of intermediate size. This suggests that juvenile mortality is high. Mark-recapture data from the 1970s indicate that those that do survive grow rapidly through the sub-adult size range (40–75 mm) and reach maturity (76 mm) at about 2 y. The strong mode between 100 and 140 mm represents accumulation of multiple cohorts within which growth has slowed substantially compared to the sub-adults. Analysis of historical distributions of toheroa on Oreti Beach indicates that the southeast end of the beach near the New River Estuary mouth is an area where toheroa have consistently been densest. Juvenile surveys indicate the importance of the upper beach for juveniles.

1. INTRODUCTION

Toheroa (*Paphies ventricosa* Gray) is a mesodesmatid bivalve endemic to New Zealand and found intertidally on fine sand dissipative beaches fully exposed to surf (Rapson 1952, Cassie 1955). Toheroa are active burrowers, living up to 20 cm beneath sand where they extend siphons to the surface during periods of submergence to filter feed from the water column and excrete waste. Large toheroa frequently aggregate in dense beds midway between low and high water. The main toheroa populations today are found in Northland (Ninety Mile Beach, Dargaville Beach, and Muriwai Beach), with smaller populations on the Kapiti coast, and in Southland (Oreti Beach, Bluecliffs Beach, and Orepuki), although historically they were more widespread (see Morrison & Parkinson (2001) for a review of the fishery).

Toheroa have been subjected to intensive harvesting since the late 1800s, from both recreational and commercial sectors (Cassie 1955, Stace 1991, McKinnon & Olsen 1994) leading to a gradual decline in populations nationally. Toheroa from Northland were commercially harvested from the late 1800s to about the 1960s, with a peak of 77 t processed and canned in 1940 (Stace 1991). Increasingly restrictive regulations on length of recreational seasons, bag limits, methods, and minimum legal size did not result in a recovery of toheroa populations and by 1989 all fishing was prohibited throughout New Zealand, with the exception of one day open seasons on Oreti Beach in 1990 and 1993, subject to pre-open day population surveys to assess the stocks. The only current legal harvest in Southland is Maori customary take by authorisation from kaitiaki representing the appropriate runanga.

Thirty surveys have been carried out at Oreti Beach (Southland) from 1969 to 2005 providing estimates of toheroa abundance, size composition, and distribution. Estimates of the numbers of toheroa (80 mm or over) on Oreti Beach in 1998, 2002, and 2005 (the three most recent surveys) were about 1 000 000, 700 000, and 715 000 toheroa, respectively, indicating that the population has declined since the 1970s when numbers fluctuated between 1.5 and 2.5 million.

Mark-recapture data for toheroa from Oreti and Bluecliffs Beaches in the 1970s provide the most accurate and informative data available on growth of toheroa (Beentjes & Gilbert 2006b). Previously, the best data were from non-validated shell growth ring interpretation (Cassie 1955) of Oreti Beach toheroa and some modal progression analysis of Northland toheroa (Rapson 1952). The analysis of the mark-recapture data indicates that toheroa in Southland grow very fast initially, attaining a length of about 70 mm within the first year and 100 mm (minimum legal size) within four to five years. This contrasts with the estimates based on shell ring counts by Cassie (1955) where the minimum legal size was not reached until about 10 years. Neither dataset is capable of giving a categorical estimate of maximum age, but both are consistent with a maximum age of about 20 years.

A yield per recruit (YPR) analysis was undertaken in 2006 for Oreti Beach toheroa and included length-weight data collected in 2005 and growth data from the unpublished mark-recapture studies in the 1970s (Beentjes & Gilbert 2006b). The customary harvest from 2001 to 2004 was about 2.5 t greenweight annually. The base case YPR yield estimate was about 14 t, assuming a virgin population size based on the surveys since 1985, considerably more than the 2.5 t of annual customary harvest. Taking a more cautious approach to estimate the YPR using the surveys since 1995, the sustainable yield was 9 t. It was concluded therefore that the harvest at then current levels were well below what would be sustainable.

1.1 Survey area (Oreti Beach)

The Oreti River drains into the New River Estuary about 2 km from the opening to the sea (Figures 1 and 2). Oreti Beach starts on the northwest side of the estuary mouth and faces southwest. The beach conforms to the definition of ‘dissipative’ since it is flat with a wide surf zone (about 250 m), high wave-energy, and the substrate is mainly fine sand (Defeo & McLachlan 2005). The beach is backed by marram covered sand dunes, most extensive in the southeast of the main entrance, which is about 6.5 km northwest of the estuary. The beach is composed of fine sand along its entire length with the exception of a small gravel bank about 6 km northwest of the main entrance. Oreti Beach is about 25 km long extending as far as Riverton. The survey area is located in the first 17 km of beach from the New River Estuary to the Waimatuku Stream, where the main toheroa beds are found. An area known as the Reserve is the section of beach that begins about 2 km inside the estuary mouth and finishes at the junction of the estuary and main Oreti Beach.

This report includes the results of a toheroa survey of Oreti Beach in February 2009, and a review of toheroa length frequency, abundance, and distribution from historic surveys of Oreti Beach.

Overall objective

To determine the distribution of toheroa (*Paphies ventricosum*) beds, and the abundance and size structure of toheroa on Oreti Beach and Bluecliffs Beaches.

Specific objectives

1. To estimate the size structure and absolute abundance of toheroa on Oreti Beach, during February 2009. The target c.v. for the estimate of absolute abundance of legal sized toheroa ($\geq$100 mm shell length) is 20%.

2. To describe changes in the size structure and absolute abundance of toheroa on Oreti Beach by comparing the results from this work with those from previous surveys.

3. To estimate the size structure and absolute abundance of toheroa on Bluecliffs Beach, during February 2009. The target c.v. for the estimate of absolute abundance of legal sized toheroa ($\geq$100 mm shell length) is 20%.

4. To describe changes in the size structure and absolute abundance of toheroa on Bluecliffs Beach by comparing the results from this work with those from previous surveys.

The survey of Bluecliffs Beach (objectives 3–4) is reported by Beentjes (2010).

2. METHODS

2.1 2009 Oreti Beach survey

2.1.1 Survey design

A two phase, stratified random transect design (Francis 1984) was used for the 2009 Oreti Beach toheroa survey, the same method used in the 1998, 2002, and 2005 surveys. The survey area covered a 17 km stretch of beach from near the entrance to the New River Estuary in the southeast to the Waimatuku Steam in the northwest (Figures 1 and 2). These are more or less the same boundaries used in the historical surveys dating back to the 1970s; the area known as the 'Reserve', which runs from the extreme southeast end around into the estuary was not surveyed so as to be consistent with earlier surveys during which the Reserve was not surveyed. Eight strata of various lengths (identical to those used in the 1998, 2002, and 2005 surveys) were marked out using hand-held GPS (non-differential (Figure 2, Appendix 1). The southeast boundary of stratum 1 was 167 m southeast of a trig station (-Z, New River Hundred SD; code - AOFQ) at 46° 29' 35.1" S, 168° 15' 54.1" E (New Zealand Geodetic Datum 1949). Sampling transects were marked out within each stratum using randomly generated distances from the southeast end of each stratum, with a requirement that there be at least 20 m between transects. Initially 60 transects were proposed in the design to be consistent with the 1998, 2002 and 2005 surveys, but the Ministry of Fisheries stipulated that this be reduced to 40. Simulations using data from the three previous surveys indicated that the c.v. of 20% would theoretically be acheivable using only 40 transects.

Thirty-two transects (75%) were allocated to phase 1, and the remaining 8 to phase 2. A minimum of three transects was initially assigned to each stratum to estimate sampling variance. The remainder of phase 1 transects was allocated based on the 2005 survey mean catch of adult toheroa per transect in each stratum, and optimised using the "area mean squared" method of Francis (1984). In this way, transects were assigned iteratively to the stratum in which the expected gain was greatest, where expected gain is given by

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

where for the ith stratum, $mean_i$ is the mean number of toheroa encountered per transect, and A_i is the area of the stratum, and n_i is the number of transects.

Phase 2 transects were allocated using the mean catch rates of adult toheroa per transect from phase 1 of the 2009 survey.

2.1.2 Sampling methods

The survey was timed to coincide with several days of spring tides, allowing the maxiumum possible extent of the intertidal beach to be surveyed at low tide. As in previous surveys, a rope line marked every 5 m along its length was used at each transect, running down the beach from high water (edge of dunes) to low water. Following the rope, from low to high tide or vice versa, quadrats of 0.5 square metres (1.0 x 0.5 m) spaced at 5 m intervals were excavated to a depth of about 30 cm with a spade. This depth is adequate to be confident that all toheroa in the quadrat are encountered. The excavated sand was spread out next to the hole and searched for toheroa. All toheroa found in each quadrat were measured to the nearest 1 mm in length and returned to the substrate. To estimate the distribution, size structure, and abundance of juvenile toheroa (under 40 mm), samples were sieved at two transects in each of the eight strata. It is necessary to sieve sand to accurately sample the very small juveniles that might otherwise be missed. Juvenile transects were arbitrarily selected as the outside transects in each stratum. Transects are allocated randomly within a stratum, so selection of the extreme outer transects to sample juveniles is not likely to introduce any bias. To sample juvenile toheroa, sand from quadrats was shovelled into a trolley lined with fine steel mesh (about 4 mm hole width) and then wheeled down to the water where the action of the surf washed out the sand, leaving behind only debris and toheroa, if present. This technique for sampling juveniles was used on the 2002 and 2005 surveys (Beentjes et al. 2003, Beentjes & Gilbert 2006b), but contrasts with the 1998 survey when sand was fed into nylon mesh bags (stretched mesh size about 6 mm) and dragged to the water (Carbines & Breen 1999). We assume that both sieving methods are equally effective in sampling juveniles.

Substrate type was qualitatively recorded for each quadrat as one of six categories: sand, coarse sand, sand and some gravel/stone, sand and moderate gravel/stone, sand and lots of gravel/stone, and sand and mainly rock.

2.1.3 Population estimates

Equations used to estimate population numbers, variance, c.v., and 95% confidence intervals are taken from Carbines & Breen (1999). The population size of toheroa for four size groups (adult, 100 mm and over; sub-adult, 40–99 mm; and juvenile, under 40 mm; and 80 mm and over) on Oreti Beach was estimated from the mean density of toheroa in each stratum and the area of each stratum. In the *i*th stratum, the estimated number of toheroa N_i is

$$N_i = 10\ mean_i\ A_i$$

where $mean_i$ is the mean number of toheroa encountered per transect, and A_i is the area of the stratum (= length of each stratum and equivalent to the number of transects in a stratum). The possible number of 1 m wide transects in a stratum is essentially the length of the upper beach in the stratum (a small overestimate of the area is caused by the slight curvature of the beach). The factor of 10 scales from the area sampled (0.5 m^2 every 5 m along the transect) to the entire area of a 1 m wide transect.

The estimated variance of the $mean_i$, VC_i, is simply

$$VC_i = var_i$$

where var_i is the variance of the observed numbers for each transect in $stratum_i$

The population estimate on the whole beach (= survey area) is given by

$$N = \Sigma\ N_i$$

where summation is over all strata, and the estimated variance of this estimate is

$$VN = 100\ \Sigma\ (A_i^{\,2}\ VC_i / n_i)$$

Where n_i = number of transects in $stratum_i$ and the factor 100 is introduced in scaling up from the sampled area of the transect to the whole transect.

The c.v. is

$$c.v. = sqrt\ (VN) / N$$

95% confidence intervals around the population estimates were calculated from ± 1.96 (*c.v. N)*

2.1.4 Size and distribution

Toheroa length data were plotted as unscaled length frequency histograms from all transects combined, and from unsieved and sieved transects separately. The spatial distributions of toheroa for all toheroa and the three size groups (adult, sub-adult, and juvenile) were plotted in three dimensional space by quadrat (high water to low water) and transect (distance along the beach).

2.1.5 Oreti Beach historical toheroa survey data

An analysis of historical toheroa data (abundance, length frequency, and distribution) comprising 29 surveys from 1969 to 2002 was carried out in 2006 (Beentjes & Gilbert 2006b) and the results compared to those of the 2005 survey. Here we update these analyses and compare the results to the 2009 survey. Of these 30 surveys, only the most recent in 1990, 1996, 1998, 2002, and 2005 have been documented (McKinnon & Olsen 1994, Carbines 1997, Carbines & Breen 1999, Beentjes et al. 2003, Beentjes & Gilbert 2006b) and the earlier surveys were converted from hard copy to electronic form in 2002. Necessary assumptions of surveys before 1990 were that transects were sampled and hence numbered from low to high water and that this was consistent among surveys.

Not all surveys were used to plot distributions and length frequencies because, for some, coverage of the beach was considered to be insufficient or unknown.

3. RESULTS

3.1 2009 Oreti Beach survey

Oreti Beach was surveyed from 9 to 13 February 2009 and all 40 transects (32 phase 1 and 8 phase 2) were successfully completed (Table 1). Of the 40 transects, 16 were sieved (2 for each strata). Phase 2 transects were allocated to strata 1, 6, 7, and 8 (*n* = 1, 1, 5, and 1, respectively). A total of 1836 quadrats was excavated with a mean of 46 per transect (range 35–56), equating to a mean transect length (beach width) of 230 m. Low-tide height during the survey ranged from 1.20 to 1.45 m below mean sea level.

3.1.1 Abundance estimates

Mean numbers of toheroa per stratum and population estimates of adult (100 mm and over), sub-adult (40–99 mm), and juvenile toheroa (under 40 mm) are given in Table 2. Population estimates were also calculated for toheroa 80 mm and over to allow comparison with historical estimates. The population estimates were about 980 000 adults, 493 000 sub-adults, 6 030 000 juveniles, and 1 192 000 toheroa 80 mm or over. The corresponding coefficients of variation were 11%, 18%, 25%, and 11% (Table 2). The survey target c.v. for legal-sized (adult) toheroa was 20%.

3.1.2 Length frequency

Length frequency distributions of toheroa were bimodal regardless of whether sampled from sieved or non-sieved transects and were characterised by a juvenile mode (under 40 mm) with a modal peak of 15 mm skewed to the right, and a symmetrical adult mode between 100 and 145 mm, with a modal peak at 120 mm (Figure 3). The juvenile mode is less pronounced in the non-sieved since small toheroa can often go undetected by this method. Conversely, the juvenile mode dominates the distribution from the sieved transects. This clearly demonstrates the value of the sieving technique in adequately sampling juvenile toheroa. The mean size from all transects was 51 mm (range 4–150 mm), from non-sieved transects mean size was 81 mm (range 4–150 mm), and mean size from sieved transects was 35 mm (range 4–134 mm).

3.1.3 Spatial distribution

Toheroa were found in all strata (Table 2), but no toheroa 100 mm or over were found in stratum 4, just southeast of the vehicle entrance (see Figure 2). For large toheroa (80 mm and over, and 100 mm and over), density (mean number per transect) was highest in the southeast end of Oreti Beach in stratum 1; density was also relatively high in Stratum 7 at the northwest end of the beach (Table 2). Juvenile density along the beach was similar to that of adults, but sub-adult density was more even along the entire beach (Table 2). Toheroa distribution and density are shown clearly in the three dimensional bubble plots (distance along the beach *x* distance down the beach *x* toheroa number) (Figure 4). These plots indicate the density and location of the main toheroa beds by size group. For all size groups combined, toheroa are distributed along the entire 17.2 km of beach, but when plotted by size group it is clear that the main bed of adult toheroa is at the southeast end of the beach (Figure 4) with smaller beds between 10 km and 12 km along the beach. This pattern is also shown in a plot of the cumulative numbers of each size group by distance along the beach (Figure 5). Indeed, about 65% of adults are found in the first 2 km of the beach – to some extent this figure will be biased by the allocation of phase 2 stations to those strata with the highest catch rates. Juvenile and sub-adult toheroa also tend to be more abundant in the southeast end of the beach, but their overall distribution is more even along the beach than that of adults.

Vertical distribution (high to low water) of toheroa is also size dependent with adults preferring the position near low water and juveniles near high water (see Figure 4). Adults occupied a well defined area mainly from about 100 to 225 m from high water (mean = 169 m) (Figure 6), although the bed at the southeast end was further down the beach at about 150 and 225 m (see Figure 4). Sub-adult toheroa occupied a similar but slightly shallower distribution, but had a wider range that extends further up the beach toward the dunes (mean = 163 m) (Figure 6). Juveniles had the widest vertical distribution from about 25 to 250 m (mean = 77 m), but were most abundant higher on the beach.

3.1.4 Substrate

Substrate in 99.5% of the 1836 quadrats sampled was categorised as sand (Table 3). Only stratum 7 in the northwest end of the beach had quadrats containing coarse sand. There is a large gravel bank in stratum 7 a few hundred metres long, but this year the first quadrats were placed at the transition of the cobble and sand interface, hence no substrate was recorded with stones or gravel.

3.1.5 Customary harvest

Maori customary take from Oreti Beach is monitored through authorisations issued by kaitiaki. Records include amounts issued and taken and this information is provided quarterly to the Ministry of Fisheries by Waihopai Runaka (Table 4). Customary take from 2006 to 2008 was provided to NIWA by Fisheries Management Areas 3–7 combined (TOH 5) and we assume this includes both Oreti and Bluecliffs Beaches, and possibly Orepuki (southeast end of Te Waewae Bay). Further, most of the records from 2006 to 2008 are probably from Oreti Beach, since the numbers taken from Bluecliffs between 1998 and 2004 were comparatively low (range 100–400 toheroa) (Beentjes & Gilbert 2006a). Annual customary removals from Oreti Beach are variable, ranging from about 2000 to 14 000 individual toheroa.

3.2 Oreti Beach toheroa historic toheroa surveys (time series)

3.2.1 1971 to 1990 survey data

Before 1996, Ministry of Fisheries (and predecessors New Zealand Marine Department, New Zealand Ministry of Agriculture and Fisheries (MAF), and MAF Fisheries) carried out toheroa surveys of Oreti Beach using a systematic sampling design with transects spaced every 330 m along the beach, except the April 1990 juvenile survey where transects were 660 m apart and only the top 50 m of beach was surveyed (Table 5). Unfortunately, apart from 1990, the methods and results from these surveys were not published or documented, sometimes making it difficult to interpret the raw data. The precise locations of transects are unknown, but it is likely that they varied slightly among surveys in the absence of documented benchmarks, without the aid of GPS, and given that transects were located using a vehicle odometer. All surveys started on the northwest side of the New River Estuary mouth (see Figure 2) with the number of transects used ranging from 20 to 78, but most often it was about 54 (Table 5) equating to a distance along the beach of about 17 km (as far as Waimatuku Stream). Three surveys (1968, 1971, and 1976) used over 70 transects and included the beach about 7 km northwest of the Waimatuku Stream. The December 1977 survey used only 9 transects and covered the first 3 km of the southeast end, where the main beds were located (Table 5). Quadrats (1 x 0.5 m^2) were excavated every 5 m along each transect. The cross-sectional width of the beach surveyed (low to high water) was on average about 115 m, with sampling beginning near low water and moving up the beach (quadrat 1 = low water). No details are available of tide heights during the surveys, although McKinnon & Olsen (1994) stated that surveys covered the area from mean low water to mean high water. These surveys targeted larger toheroa and did not sample all the way up to the dunes, but the length of the transects was probably adequate given that large toheroa tend to be nearer low water.

All surveys between 1971 and 1990, with the exception of April 1990, targeted adults because a threshold number of 1 million toheroa of minimum legal size (75 mm and 100 mm from 1980) was required before an open season would be considered in that year (plenary report) (McKinnon & Olsen 1994). The April 1990 dedicated juvenile survey was undertaken using transects spaced every 660 m along the length (every second transect was used) of the beach from mid to high water with excavated sand being carefully examined for the presence of juveniles.

3.2.2 1996–2009 survey data

NIWA conducted the last five Oreti Beach toheroa surveys (1996, 1998, 2002, 2005, and 2009). The 1996 survey was a systematic transect sampling design similar to the historic surveys described above, but from 1998 onward all surveys used a stratified random transect design (see methods above for 2009 survey). The same area along the beach was surveyed, i.e., mouth of New River Estuary to Waimatuku Stream, a distance of about 17 km, although there is some uncertainty as to the precise southeast end benchmark or start point of the 1996 survey. The main points of difference from 1998 onward are that the random stratified surveys covered a greater cross sectional area of the beach (low to high water), all sizes including juveniles were surveyed, and the benchmark and strata boundaries were mapped and subsequently located using GPS. The 1998 to 2009 surveys sampled about 35 to 60 quadrats per transect, and the mean length of transects was about 200 m compared with 115 m for the 1971 to 1990 surveys and just 86 m in 1996. In 1996, low tide at Oreti Beach over the survey duration was documented as 0.4 m above chart datum (mean low water) with a tidal range of 86 m (Carbines 1997). Hence, it is possible that the 1996 survey did not adequately cover the adult beds which may have been partially submerged – the very low population estimates for this survey support this conjecture. The greater vertical coverage of the beach in the last four surveys carried out by NIWA was necessary to ensure that both adults and juveniles were properly sampled. NIWA also introduced methods to properly sample juveniles, i.e., nylon mesh bags in 1998 and in surveys thereafter steel fine-mesh lined trolleys were used to sieve sand and ensure that even the smallest juveniles were counted and measured.

3.2.3 Abundance estimates (1971–2009)

Millar & Olsen (1995) estimated numbers of toheroa 80 mm or over from 22 Oreti Beach surveys between 1971 and 1990 (Figure 7). They restricted their estimates to surveys that they considered provided representative sampling of the beach and stated that estimates include the Reserve area at the southeast end of the beach. It is not clear from examination of the raw data that these surveys included the Reserve, but regardless the difference in numbers would not be significant. Abundance was estimated for the five most recent surveys (1996, 1998, 2002, 2005, and 2009) for adult toheroa (100 mm or over), as per the project objectives, but to allow comparison with earlier estimates of Millar & Olsen (1995), abundance was also estimated for toheroa 80 mm or over (Beentjes et al. 2003, Beentjes & Gilbert 2006b) – estimates from these latter four surveys did not include the Reserve area. The sampling fraction method was used to estimate abundance for all systematic transect surveys, i.e., those before 1998. This method scales the total number by the reciprocal of the fraction of the area surveyed, which is calculated from the distance between transects (Millar & Olsen 1995). For the random stratified transect surveys in 1998, 2002, 2005, and 2009 the mean number of toheroa per transect was scaled up to the area of each stratum. The latter are designed to provide higher precision in estimating abundance of toheroa and consequently transects were concentrated where toheroa beds were most dense. Despite using different survey designs, the estimates from the 1971 to 1996 surveys and 1998 to 2009 surveys are directly comparable.

There were open seasons at Oreti Beach ranging from 5 to 14 days in 1972, 1973, 1974, 1978, 1980, and 1981, with one day seasons in 1990 and 1993 (McKinnon & Olsen 1994). Between 1971 and 1990, the population of toheroa 80 mm or over varied between 1 and 2.4 million toheroa (Figure 7). Estimates from the 1996 survey indicated that the population had declined markedly to about 330 000 toheroa 80 mm or over, the lowest estimate to date, although as mentioned above there is some doubt as to the validity of this estimate. The 1998 survey indicated recovery (assuming 1996 is a valid estimate) to about 1.1 million toheroa 80 mm or over, but by 2002 numbers had declined to 720 000, and were similar in 2005 at 714 000. In the 2009 survey the numbers of 80 mm or over toheroa were 1.2 million, an increase of 67% from the 2005 estimate (see Table 2, Figure 7). The number of toheroa 80 mm or over in 2009 is the highest since 1988 when it was also about 1.3 million, but still less than the peak estimate in 1976 of 2.4 million. The time series historical average (1971 to 1990) is 1.7 million, but the abundance of toheroa is variable among and between years, and some estimates from the early 1970s and 1980s were not dissimilar to the 2009 estimate, and certainly not statistically different.

Estimates for the 100 mm or over toheroa since 1996 mirror those of the 80 mm toheroa, and we would expect the long term trend to be similar (Figure 7).

Estimates of juvenile numbers (under 40 mm) from 1998 to 2009 have steadily declined from a peak of 15.8 million in 1998 to 6 million in 2009 (Figure 8).

3.2.4 Length frequency distributions

1969 to 1996

Length frequency histograms of toheroa on Oreti Beach from 26 historical surveys between 1969 and 1996 (systsematic transects) are shown in Figure 9. All surveys before 1998 targeted adult toheroa, except April 1990, which was a dedicated juvenile survey over a small section of the beach. The difficulty in interpreting survey data from before 1996 is that we know little about the sampling procedures used, particularly, how thoroughly excavated sand was examined for juvenile toheroa. This can introduce bias into the length frequency data if in some years and/or transects more effort was given to searching for juveniles. Additionally, the upper section of the beach, where juveniles are most abundant, was not sampled before 1998. Length frequency distributions from 1969 to 1974 suggest that some attempt was made to sample juveniles (under 40 mm), because they were reasonably well represented. From 1975 to March 1990 the size distributions were remarkably similar and characterised by a strong adult mode between about 100 and 140 mm, with few sub-adults (40–99 mm), and even fewer juveniles. The April 1990 juvenile survey combined with the March 1990 adult survey provides the first indication of the relative number of juveniles compared to larger sizes on Oreti Beach. The 1996 distribution differed from those between 1975 and 1990 in that there were relatively few adults, and this was reflected in the low abundance estimate for the 1996 survey. Surveys from 1998 onward differed from earlier surveys because juveniles were sampled in both adult (non-sieved) and juvenile transects (sieved); however, only toheroa length frequency distributions from sieved transects can be regarded as representative of the whole population structure on Oreti Beach. Thus, in general, the size composition of toheroa on Oreti Beach has been characterised by a mode of juvenile toheroa, the strength of which varies between years, and a second mode of adult toheroa with relatively few of intermediate size. The data are unsuitable for modal progression analyses because only one or two modes are present and no progression of these modes is apparent between years.

1998 to 2009

The length frequency data from the 1998 to 2009 surveys are plotted by method of sampling, i.e., sieved, unsieved, and combined total (Figure 10). Comparing the length distributions among years by method indicates that the size distribution is reasonably constant with the characteristic bimodal shape representing juveniles and adults, but with few of intermediate size. The relative proportions of juvenile toheroa are greater using the sieved quadrat method compared with unsieved (Figure 10). This difference is more apparent when plotted as overlaid density distributions by method for each survey (Figure 11).

3.2.5 Spatial distribution

1975 to 1996

Distribution bubble plots of toheroa (all sizes) from 18 Oreti Beach surveys between 1975 and 1996 from mean low water to mean high water are shown in Figure 12. Between 1975 and 1987, toheroa (adult sizes) were distributed along the entire length of the beach, but were densest in the first few kilometres of the southeast end of the beach, within 50 m of mean low water. Because the first quadrats at low water sometimes had toheroa present, it is likely that there were toheroa present below mean low water in some cases. The number of quadrats with no toheroa in the upper section of the beach is suspicious, given the distributions from the 1998 to 2009 surveys. Further, anecdotal evidence suggests that not all transects were sampled up to mean high water – we speculate that where several consecutive quadrats revealed no toheroa, samplers assumed that there were no toheroa higher up the beach and zeros were allocated to the unsampled quadrats. From 1988 to 1996, the pattern of distribution changed and toheroa were less concentrated in the southeast end of the beach.

1998 to 2009

Distribution bubble plots of toheroa (all sizes) from the last four Oreti Beach surveys between 1998 and 2009 from the dunes to well below mean low water are shown in Figure 13. Although the 1998 to 2009 distributions were to some degree influenced by the random allocation of transects within strata and allocation of phase 2, they indicate that the densest beds were again in the southeast end of the beach, and this is most marked in the last three surveys. Further, bubble plots of the distributions by size (adults, sub-adults, and juveniles) for the last four surveys indicate that adults tend to occupy the zone near low water and juveniles predominate closer to mean high water (Figures 14–16).

4. DISCUSSION

4.1 2009 Oreti Beach survey

This report includes the results of a toheroa survey of Oreti Beach in February 2009, and a review of toheroa length frequency, abundance, and distribution from historic surveys of Oreti Beach.

The 2009 population estimates of adult, sub-adult, and juvenile toheroa were 980 000, 493 000, and 6 030 000, respectively, with a c.v. for adult toheroa of 11%, which is well below the 20% target (see Table 3). Population estimates for adult toheroa (100 mm or over) were 68% greater than those in 2005, sub-adults were 23% greater, but in contrast juveniles were 13% less than in 2005 (see Figure 7). The longest published time series is for toheroa 80 mm and over, and for these the 2009 estimate of 1.2 million individuals was the highest since 1988.

The Oreti Beach toheroa population size structure in 2009 was characterised by the presence of a strong juvenile mode (under 40 mm) comprised of 0+ year class individuals (Redfearn 1974, Beentjes & Gilbert 2006b), and an adult mode. In this regard the 2009 size distribution is typical of this population (see Section 3.2.4). Mark-recapture data from the 1970s indicate that toheroa in this adult mode are about five years and older (Beentjes & Gilbert 2006b). The absence of a distinguishable mode in the sub-adult size range is also a feature of this and previous surveys. It is unlikely that sampling bias has contributed to an underestimate of sub-adult toheroa, especially given that smaller juvenile toheroa (under 40 mm) were sampled reasonably well in non-sieved transects and also that sub-adults were almost always poorly represented on all previous surveys.

The three size groups of toheroa in 2009, to some extent, occupied different zones between high and low water, with juveniles more abundant near high water and adults near low water (see Figure 6). This pattern was also observed in the 2002 and 2005 surveys (Beentjes et al. 2003, Beentjes & Gilbert 2006b). Larger toheroa will therefore, on average, be submerged for longer on each tidal cycle. Further, small toheroa have shorter siphons and therefore are likely to be found closer to the surface than larger toheroa. The implications are that small toheroa are more susceptible to damage from storms, crushing by vehicle/foot traffic, and predation by birds. A recent study on the impacts of vehicle traffic during the Burt Munro Challenge motorcycle race on Oreti Beach in November 2008 has shown that about 50 000 juveniles (under 40 mm) were killed due to crushing on a small section of the beach during the event (Moller et al. 2009).

Adults were concentrated at the southeast end of Oreti Beach, but juveniles and sub-adults were more evenly spread along the entire beach, a pattern similar to the 2002 and 2005 survey distributions (see Figure 4).

Maori customary take from Oreti Beach is monitored, and although sizes are not recorded, most are probably adult toheroa (see Table 4). Based on the 2005 adult toheroa population estimate (582 000) and the maximum recorded customary harvest of about 14 000 toheroa in 2004, the exploitation rate was about 2% of the adult population annually (Beentjes & Gilbert 2006b). Hence assuming a the maximum customary take of 14 000 toheroa per annum, and the current population estimate of 980 000 adults, the exploitation rate would be about 1%. This is very low relative to what the population can sustain since Beentjes & Gilbert (2006) suggested that an exploitation rate of 30% should not severely reduce the population size.

4.2 Oreti Beach historic toheroa surveys (time series)

4.2.1 Abundance estimates

The time series indicates a decline in abundance of toheroa 80 mm or over on Oreti Beach since 1985 when the population almost halved in two years from about 2 to 1 million and then continued to decline over the next 11 years until 1996 when the population was estimated at 400 000 individuals (see Figure 7). The Oreti Beach toheroa population since 1998 appears to be stable or increasing, and the steep trend of declining abundance that began in the mid 1980s has not continued. Indeed the time series historical average (80 mm and over, 1971 to 1990) is 1.7 million, and some estimates from the early 1970s and 1980s were not dissimilar to the 2009 estimate (see Figure 7). It could be argued that from an historical perspective the population is reasonably stable, but tracking at a density below the historical average.

Toheroa populations in Northland are known to be subject to mass mortalities resulting in steep declines in the population biomass within only a year or two, followed by recovery (Morrison & Parkinson 2001). The cause of these mortalities is largely speculative. The toheroa populations in Northland are currently very low compared to their historic numbers (Morrison & Parkinson 2008). Bluecliffs Beach has also experienced a similar decline in the toheroa population over much the same time frame as Oreti Beach (Beentjes & Gilbert 2006a) although this is in part due to erosion of the Bluecliffs Beach (Beentjes et al. 2006, Beentjes 2010). Given that there has been no recreational or commercial harvest of toheroa for over 20 years from most areas, we would have expected a recovery of the populations including those where they were once common, but are now rare. The relatively low current population of toheroa at Oreti Beach may be partly the result of unknown environmental factors that are impacting toheroa populations throughout New Zealand.

Because the historical surveys on Oreti Beach did not target juveniles until the last four surveys, the magnitude of annual recruitment and the extent to which recruitment strength translates into adult numbers cannot be determined. However, it does appear that recruitment is not correlated with abundance in the following survey, although annual surveys would be required to track the survival and mortality of yearly recruits. It does support the often held view that toheroa recruitment and mortality are highly variable.

4.2.2 Spatial distribution

The southeast end of the beach near the New River Estuary mouth is an area where adult toheroa have consistently been most dense (see Figures 12 and 13). From 1988 to 1998 however, this was not the case and the dense beds of adults were no longer a dominant feature in the southeast. Instead there was a more even coverage along the length of the beach. From 1998, when the surveys began to survey the entire beach width, together with all sizes, it became possible to look at the spatial distribution of size groups. In 1998 all size groups were reasonably well distributed along the entire length of the beach (see Figure 14). However, in 2002 there were signs of the reestablishment of the adult beds toward the southeast end near the New River Estuary mouth (see Figure 15). By 2005 this was very marked, to the extent that 90% of adults were found in the first 3 km of the 17 km surveyed area (see Figure 16). In 2009 the southeast adult bed was still present but not as marked as in 2005. In contrast, juvenile and sub-adult distributions from 1998 to 2009 have remained more even along the beach, but with a slight southeast bias. The reasons for the changes in spatial abundance along the beach among surveys are unknown but may be related to local environmental conditions and survivorship. It appears from the four most recent surveys that recruitment is occurring along the entire beach and given that the beach is virtually all fine sand, we might also expect distribution of large toheroa to be even along the beach. Hence, toheroa distribution may be a result of migration along the beach, or toheroa from discrete areas experience enhanced survivorship resulting from more favourable habitat. The southeast end of the beach is currently wide and shallow, the result of a large sand bar formed at the juncture of the beach and the New River Estuary mouth. Toheroa at this end of the beach are exposed to intermittent low salinity periods caused by the freshwater outfall from the estuary and also to nutrient inputs from river, which will enhance plankton growth and thus available food for toheroa. The importance of phytoplankton as a food source for toheroa and also as a key factor controlling distribution has been documented (Rapson 1954, Cassie 1955, Redfearn 1974). The southeast end of Oreti Beach is known by tangata whenua to be an area of high density, and is the preferred location for customary harvest (Jodie Cameron, Waihopai Runaka representative, pers. comm.).

The occupation of distinct tidal zones by size is a feature of Oreti Beach. This intertidal size zonation was also described for toheroa from Bluecliffs Beach in the 1960s (Street 1970) and for toheroa from Northland beaches (Redfearn 1974). The explanation for this spatial pattern may lie in how juveniles recruit to the beach. Spat settlement is known to be a passive process dependent on characteristics of wave action and alongshore currents (Redfearn 1974). The zonation occurs during settlement, when spat washed onto the upper beach experience a protracted period of alternating settlement and dislodgement by wave action (Redfearn 1974). Eventually, most of the spat are washed up just above high water where they are able to settle and successfully burrow into the sand without being displaced. As juveniles grow in size, they burrow deeper, become more physically able to withstand the pounding of waves, and migrate down the beach at about 15 m per month (Redfearn 1974). The largest toheroa are probably less vulnerable to dislodgement and the narrow band (30–40 m) occupied by the adults near low tide suggests that the degree of submergence experienced at this level provides the optimal feeding regime. Small recruited toheroa higher up the beach, however, have significantly less time to feed, and are more susceptible to damage from storms, crushing by vehicle/foot traffic, predation by birds, and desiccation. That some juveniles are found close to low water, however, suggests that recruitment and settlement into the sand can occur even at low water.

4.2.3 Size

The consistency in length frequency distributions over many years of surveys is notable. In general, they are characterised by a variable mode of juvenile toheroa (when juveniles were sampled) and a strong mode of adult toheroa, with relatively few of intermediate size. It has been suggested that toheroa migrate between the littoral and sub-littoral zone, offering an explanation for the large fluctuations in Northland toheroa populations (Cassie 1951, 1955, Waugh & Greenway 1967, Greenway 1969), although there is no evidence to support this theory. By extension, it has also been suggested that sub-adult toheroa inhabit areas of Oreti Beach below low water in the sub-littoral zone, providing an explanation for the consistently low numbers of sub-adult toheroa relative to adults. Underwater observations of the bottom using scuba on Bluecliffs Beach (Street 1970) (dives on three separate occasions in 1967, 1968, and 1970) along different sections of the beach 250 m out from low water, found no signs of toheroa and Street (1970) concluded that toheroa are not present in the sub-littoral zone in any number. The more likely explanation is that mortality of juveniles is high and that relatively few toheroa survive through to the sub-adult size range (40–75 mm). Those that do survive grow rapidly through the sub-adult size range and reach maturity at about 2 y (Beentjes & Gilbert 2006b). The strong mode between 100 and 140 mm represents the accumulation of multiple cohorts (5–20 y), within which growth has slowed substantially compared to the sub-adults, and mortality is low.

Toheroa at Bluecliffs Beach have similar size distributions to those at Oreti Beach (Beentjes & Gilbert 2006a, Beentjes 2010). In contrast, in Northland toheroa do not grow as large as those in Southland (data from 1955 to 2006) and large adult (100 mm or over) toheroa have been largely absent in Northland since the early 1980s (Morrison & Parkinson 2001, Akroyd et al. 2002, Morrison

& Parkinson 2008). Indeed, in the most recent survey of Ninety Mile Beach in 2006 found only one toheroa over 75 mm and none over 100 mm.

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6. REFERENCES

Akroyd, J.M.; Walshe, K.A.R.; Millar, R. B. (2002). Abundance, distribution, and size structure of toheroa (*Paphies ventricosa*) at Ripiro Beach, Dargaville, Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research 36*: 547–553.

Beentjes, M.P. (2010). Toheroa survey of Bluecliffs Beach, 2009, and review of historical surveys. *New Zealand Fisheries Assessment Report 2010/7*. 42 p.

Beentjes, M.P.; Carbines, G.D.; Willsman, A.P. (2006). Effects of beach erosion on abundance and distribution of toheroa (*Paphies ventricosa*) at Bluecliffs Beach, Southland, New Zealand. *New Zealand Journal of Marine and Freshwater Research 40*: 439–453.

Beentjes, M.P.; Gilbert, D.J. (2006a). Bluecliffs Beach 2005 toheroa survey: yield per recruit and review of historical surveys. *New Zealand Fisheries Assessment Report 2006/37*. 48 p.

Beentjes, M.P.; Gilbert, D.J. (2006b). Oreti Beach 2005 toheroa survey: yield per recruit and review of historical surveys. *New Zealand Fisheries Assessment Report 2006/36*. 47 p.

Beentjes, M.P.; Gilbert, D.J.; Carbines, G.D. (2003). Oreti Beach 2002 toheroa survey: yield per recruit and review of historical surveys. *New Zealand Fisheries Assessment Report 2003/9*. 36 p.

Carbines, G.D. (1997). Survey of toheroa at Oreti Beach, June 1996. *NIWA Technical Report 1*. 12 p.

Carbines, G.D.; Breen, P.A. (1999). Toheroa (*Paphies ventricosum*) surveys at Oreti Beach and Bluecliffs Beach in 1998. New Zealand Fisheries Assessment Research Document 99/23. 18 p. (Unpublished report held in NIWA library, Wellington.)

Cassie, R.M. (1951). A molluscan population with an unusual size frequency-distribution. *Nature 167*: 284–285.

Cassie, R.M. (1955). Population studies on the toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata). *Australian Journal of Marine and Freshwater Research 6*: 348–391.

Defeo, O.; McLachlan, A. (2005). Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multiscale analysis. *Marine Ecology Progress Series 295*: 1–20.

Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59–71.

Greenway, J.P.C (1969). Population surveys of toheroa (Mollusca: Eulamellibranchiata) on Northland beaches, 1962–67. *New Zealand Journal of Marine and Freshwater Research 3*: 318–338.

McKinnon, S.L.C.; Olsen, D.L. (1994). Review of the Southland toheroa fishery. *New Zealand Fisheries Management: Regional Series No. 3*. 25 p.

Millar, R. B.; Olsen, D.L. (1995). Abundance of large toheroa (*Paphies ventricosa* Gray) at Oreti Beach, 1971–90, estimated from two-dimensional systematic samples. *New Zealand Journal of Marine and Freshwater Research 29*: 93–99.

Moller, J.S.; Moller, S.I.; Futter, J.M.; Moller, J.A.; Harvey, J.P.; White, H.A.; Stirling, F.F.; Moller, H. (2009). Potential impacts of vehicle traffic on recruitment of toheroa (*Paphies ventricosa*) on Oreti Beach, Southland, New Zealand. *He Kohinga Rangahau* No. 5. 62 pp. University of Otago

Morrison, M.; Parkinson, D. (2001). Distribution and abundance of toheroa (*Paphies ventricosa*) on Ninety Mile Beach, March 2000. *New Zealand Fisheries Assessment Report 2001/20*. 27 p.

Morrison, M.; Parkinson, D. (2008). Distribution and abundance of toheroa (*Paphies ventricosa*) on Ninety Mile Beach, 2006. *New Zealand Fisheries Assessment Report 2008/26*. 27 p.

Rapson, A.M. (1952). The toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata), development and growth. *Australian Journal of Marine and Freshwater Research 3*: 170–198.

Rapson, A.M. (1954). Feeding and control of toheroa (*Amphidesma ventricosum* Gray) (Eulamelibranchiata) populations in New Zealand. *Australian Journal of Marine and Freshwater Research 5*: 486–512.

Redfearn, P (1974). Biology and distribution of toheroa, *Paphies* (*Mesodesma*) *ventricosa* (Gray). *Fisheries Research Bulletin 11*. 49 p.

Stace, G. (1991). The elusive toheroa. *New Zealand Geographic 9:* 18–34.

Street, R.J. (1970). Studies on toheroa at Te Waewae Bay, Southland. *Fisheries Technical Report 70*. 22 p.

Waugh, G.D.; Greenway, J.P. (1967). Further evidence for the existence of sub-littoral populations of toheroa, (*Amphidesma ventricosa* Gray), off the west coast of New Zealand. *New Zealand Journal of Marine and Freshwater Research 1*: 407–411.

Table 1: Strata length and numbers of transects used in the toheroa survey at Oreti Beach in February 2009.

		Transects		
Stratum	Length (m)	Phase 1	Phase 2	Total
1	900	6	1	7
2	1 000	7		7
3	3 500	4		4
4	1 100	3		3
5	1 000	3		3
6	2 700	3	1	4
7	2 800	3	5	8
8	4 247	3	1	4
Total	17 247	32	8	40

Table 2: Population estimates of toheroa at Oreti Beach in February 2009. c.v., coefficient of variation; CI, confidence intervals.

Adult (≥ 100 mm)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	23.9	116.81	214 714	13 516 531
2	10.0	54.00	100 000	7 714 286
3	3.0	3.33	105 000	10 208 333
4	0.0	0.00	0	0
5	3.0	13.00	30 000	4 333 333
6	3.8	17.58	101 250	32 045 625
7	9.6	21.41	269 500	20 982 500
8	3.8	8.25	159 263	37 201 331
Total			979 727	126 001 939
		c.v.	11.5%	
		95% CI	± 220 011	

Sub-adult (40–99 mm)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	4.4	7.62	39857	881 633
2	3.6	3.29	35714	469 388
3	1.5	0.33	52500	1 020 833
4	3.3	16.33	36667	6 587 778
5	5.3	9.33	53333	3 111 111
6	3.0	2.00	81000	3 645 000
7	2.4	4.84	66500	4 742 500
8	3.0	12.00	127410	54 111 027
Total			492 981	74 569 270
		c.v.	17.5%	
		95% CI	± 169 253	

Table 2 – *continued*

Juvenile (< 40 mm) (sieved transects)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	75.5	0.50	679 500	202 500
2	59.5	112.50	595 000	56 250 000
3	19.0	2.00	665 000	12 250 000
4	19.5	264.50	214 500	160 022 500
5	24.5	0.50	245 000	250 000
6	21.0	50.00	567 000	182 250 000
7	24.5	760.50	686 000	2 981 160 000
8	56.0	2178.00	2 378 320	19 642 302 801
Total			6 030 320	23 034 687 801
		c.v.	25.2%	
		95% CI	± 2 974 728	

≥ 80 mm

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	26.0	115.67	234 000	13 384 286
2	11.4	51.62	114 286	7 374 150
3	3.8	4.92	131 250	15 057 292
4	1.3	2.33	14 667	941 111
5	5.3	5.33	53 333	1 777 778
6	5.0	29.33	135 000	53 460 000
7	10.6	18.27	297 500	17 902 500
8	5.0	12.00	212 350	54 111 027
Total			1 192 386	164 008 143
		c.v.	10.7%	
		95% CI	± 251 009	

Table 3: Summary of substrate types in quadrats sampled in each strata on Oreti Beach in 2005. 1, sand; 2, coarse sand; 3, sand and some gravel/stone; 4, sand and moderate gravel/stone; 5, sand and lots of gravel/stone; 6, sand and mainly rock.

	Substrate type					
Strata	1	2	3	4	5	6
1	347					
2	343					
3	204					
4	149					
5	145					
6	155					
7	311	9				
8	173					
Total quadrats	1 827	9	0	0	0	0
Percent	99.5	0.5	0	0	0	0

Table 4: Estimated customary take of toheroa from Oreti Beach for calendar years 1998–2004 and from TOH 5 for 2006 to 2008. Data are from customary authorisation permits provided quarterly to the Ministry of Fisheries. 2006 includes data from three quarters of the year and 2008 from two quarters of the year. – no data available; TOH 5, Fisheries Management Areas 3–7.

Year	Numbers	
	Oreti Beach	TOH 5
1998	2 167	
1999	2 429	
2000	8 703	
2001	6 623	
2002	11 681	
2003	14 206	
2004	13 610	
2005	–	–
2006	–	2 506
2007	–	11 183
2008	–	8 890

Table 5: Toheroa surveys of Oreti Beach, including the 2009 survey. For systematic surveys before 1998, transects were numbered from 1 (southeast near the New River Estuary) to a maximum of 78 (8 km northwest of Waimatuku Stream), and were 330 m apart. The 1998 to 2009 random transect surveys cover the equivalent area of systematic survey transects 1 to 52 , i.e., from new River Estuary to Waimatuku stream.

Survey number	Survey date	Survey design	Transects surveyed	Distance between transects (m)	Target size	Organisation	Reference
1	Jun-1969	Systematic transects	7–77	330	Adults	MFish	Undocumented
2	May–Jun-1971	Systematic transects	7–78	330	Adults	MFish	Undocumented
3	Oct–Jan-1971	Systematic transects	1–42	330	Adults	MFish	Undocumented
4	Jun-1972	Systematic transects	1–20	330	Adults	MFish	Undocumented
5	May-1973	Systematic transects	1–70	330	Adults	MFish	Undocumented
6	Nov-1974	Systematic transects	1–44	330	Adults	MFish	Undocumented
7	May-1975	Systematic transects	1–53	330	Adults	MFish	Undocumented
8	May–June-1976	Systematic transects	1–77	330	Adults	MFish	Undocumented
9	May-1977	Systematic transects	1–53	330	Adults	MFish	Undocumented
10	Nov-1977	Systematic transects	1–53	330	Adults	MFish	Undocumented
11	Dec-1977	Systematic transects	1–9	330	Adults	MFish	Undocumented
12	Mar–Apr-1978	Systematic transects	1–55	330	Adults	MFish	Undocumented
13	Nov–Dec-1978	Systematic transects	1–55	330	Adults	MFish	Undocumented
14	Apr–May-1979	Systematic transects	1–55	330	Adults	MFish	Undocumented
15	Apr–Jun-1980	Systematic transects	1–56	330	Adults	MFish	Undocumented
16	Nov-1980	Systematic transects	1–55	330	Adults	MFish	Undocumented
17	Mar–May-1981	Systematic transects	1–54	330	Adults	MFish	Undocumented
18	Mar–Apr-1982	Systematic transects	1–57	330	Adults	MFish	Undocumented
19	Mar/Jun–Jul-1983	Systematic transects	1–52	330	Adults	MFish	Undocumented
20	Jun–Jul-1984	Systematic transects	1–53	330	Adults	MFish	Undocumented
21	Jun-1985	Systematic transects	1–55	330	Adults	MFish	Undocumented
22	Sep-1987	Systematic transects	1–54	330	Adults	MFish	Undocumented
23	Jun-1988	Systematic transects	1–44	330	Adults	MFish	Undocumented
24	Mar-1990	Systematic transects	1–43	330	Adults	MFish	McKinnon & Olsen 1994
25	Apr-1990	Systematic transects	§1–45	660	Juveniles	MFish	McKinnon & Olsen 1994
26	Oct-1990	Systematic transects	1–44	330	Adults	MFish	McKinnon & Olsen 1994
27	Jun-1996	Systematic transects	1–49	350	Adults	NIWA	Carbines 1997

Table 5 – ***continued***

Survey number	Survey date	Survey design	Transects surveyed	Distance between transects (m)	Target size	Organisation	Reference
28	Mar–Apr-1998	Random stratified transects	1–59	Variable	All sizes	NIWA	Carbines & Breen 1999
29	Feb-2002	Random stratified transects	1–60	Variable	All sizes	NIWA	Beentjes et al. 2003
30	Feb-2005	Random stratified transects	1–60	Variable	All sizes	NIWA	Beentjes & Gilbert 2006b
31	Feb-2009	Random stratified transects	1–40	Variable	All sizes	NIWA	This report

§ The April 1990 survey was a juvenile survey which sampled every second transect (1, 3, 5, 7 etc.) 660 m apart, on the top 50 m of the beach.

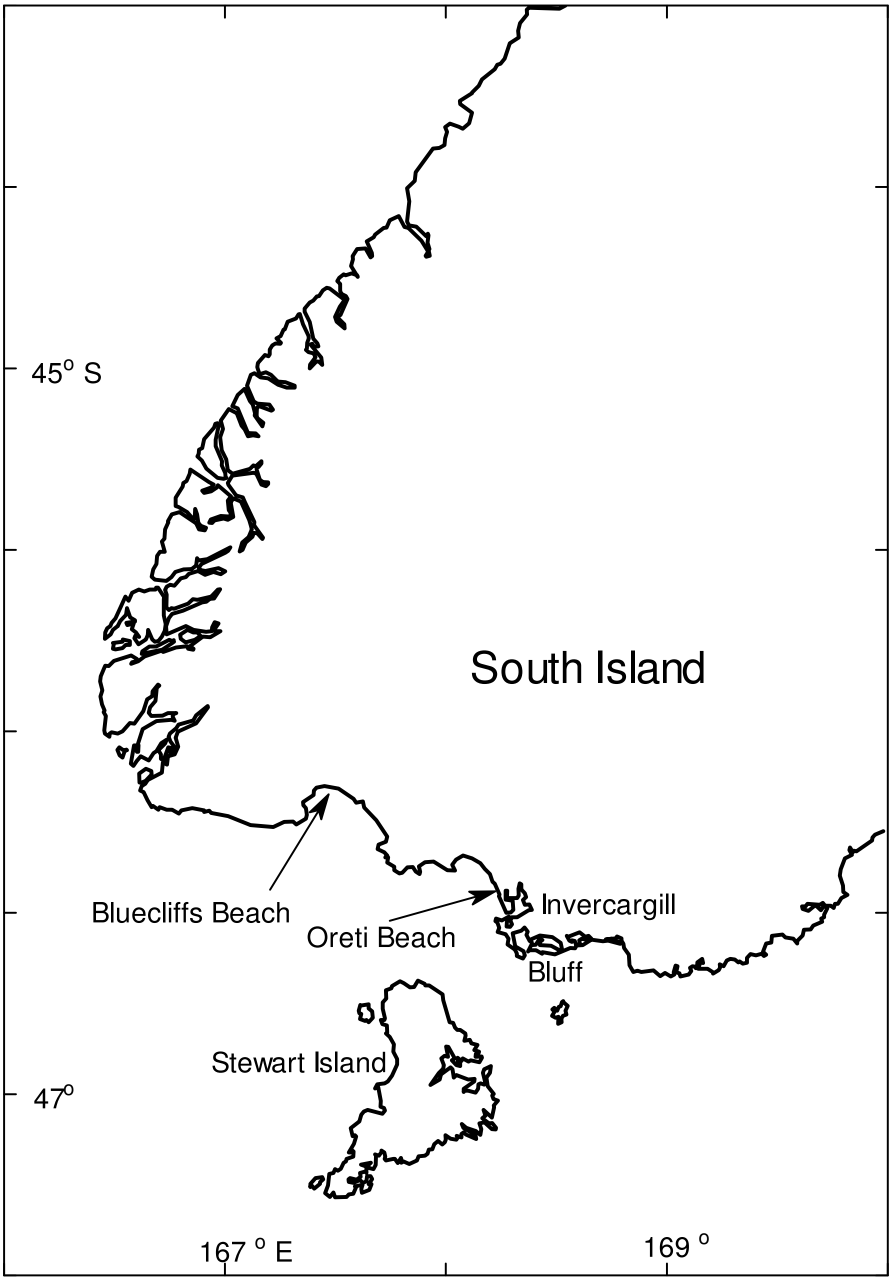

Figure 1: Map of Southland showing the toheroa survey areas at Oreti Beach and also Bluecliffs Beach.

Figure 2: Map of Oreti Beach showing strata used in the survey. Map reproduced by permission of Land Information New Zealand.

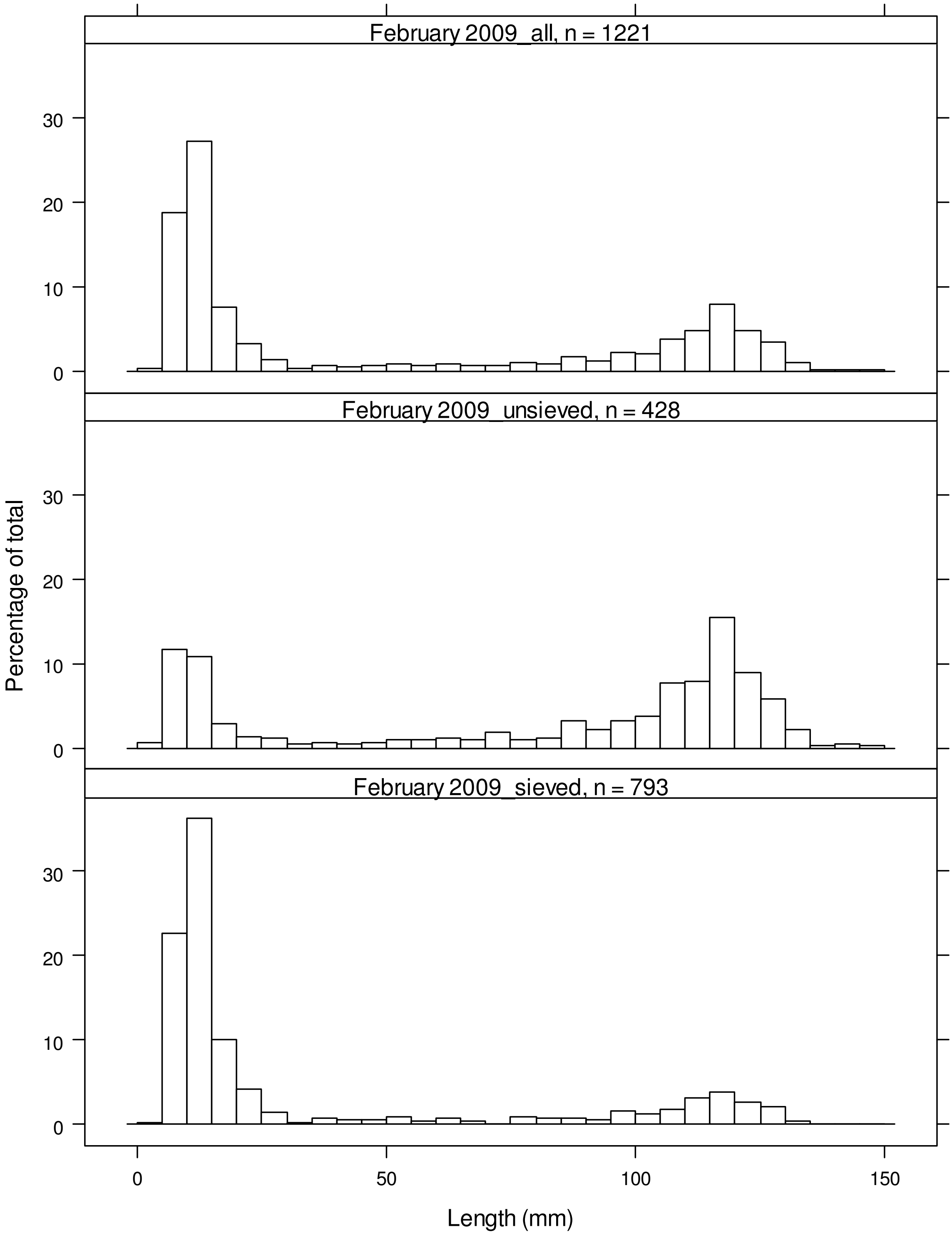

Figure 3: Length frequency distribution of sampled toheroa on Oreti Beach in February 2009 from all transects (40), non-sieved transects (24), and sieved transects (16). n, number of toheroa.

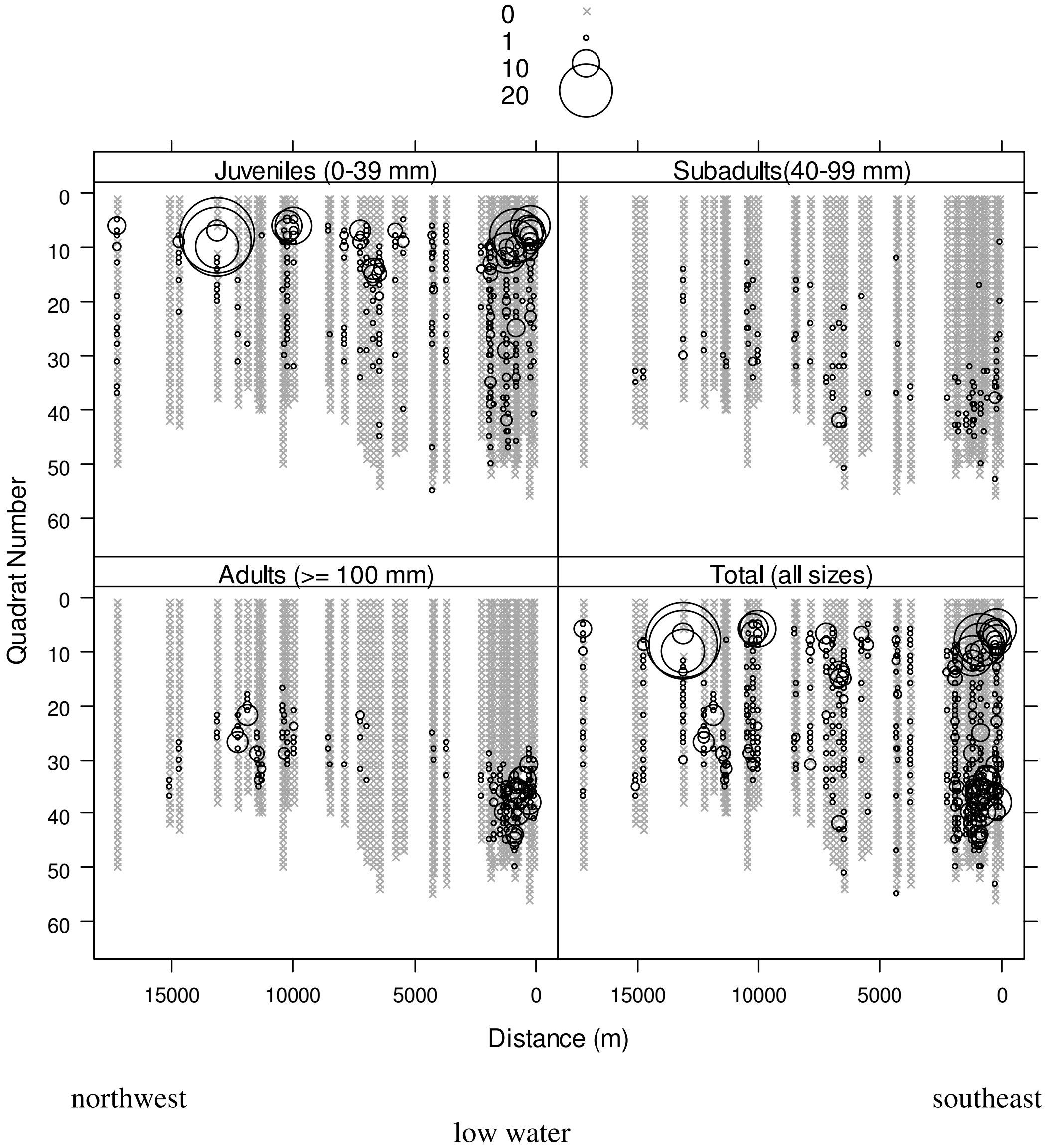

Figure 4: Distribution bubble plots of toheroa on Oreti Beach from the February 2009 survey. Distributions are shown for all toheroa (n = 1221), adults (n = 365), sub-adults (n = 131), and juveniles (n = 725). The bubbles are proportional to the number of toheroa found at each quadrat. The maximum number was 29 toheroa per quadrat. The survey used a random stratified transect design, targeting all sizes. Grey crosses indicate where samples were taken, but no toheroa were recorded.

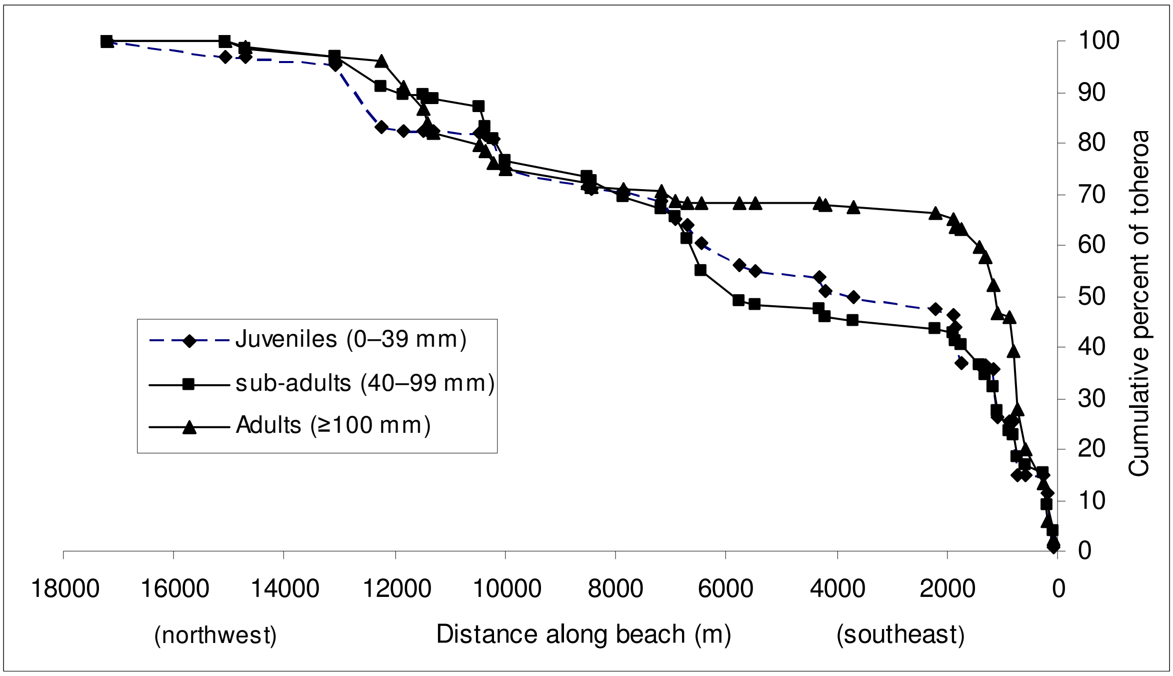

Figure 5: Cumulative distribution of toheroa along Oreti Beach in February 2009 for the three size groups. Distance is from the southeast boundary of stratum 1 near the New River Estuary end of Oreti Beach

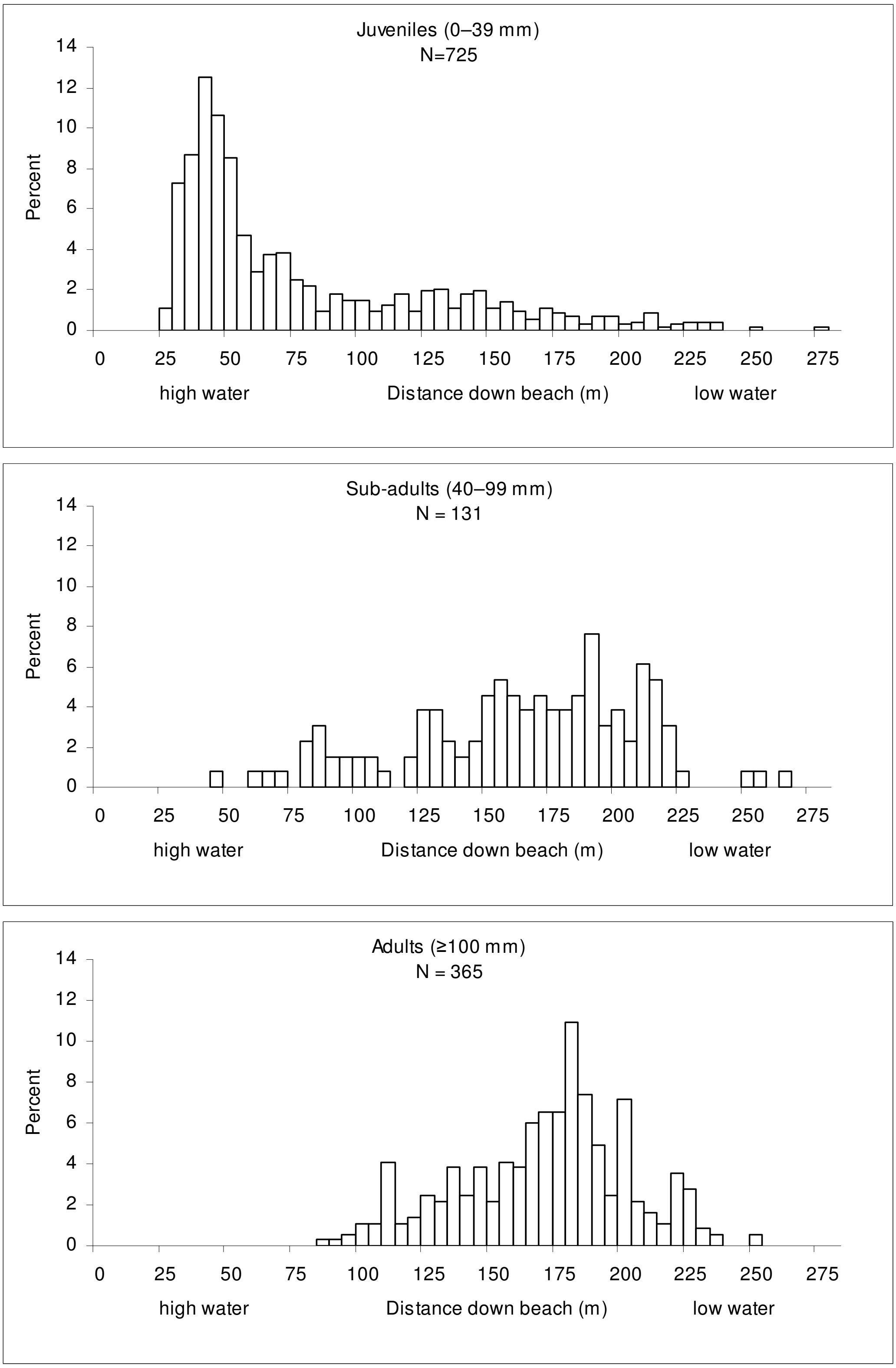

Figure 6: Proportion of toheroa population versus distance down the beach for adults, subadults, and juvenile toheroa on the Oreti Beach survey in February 2009.

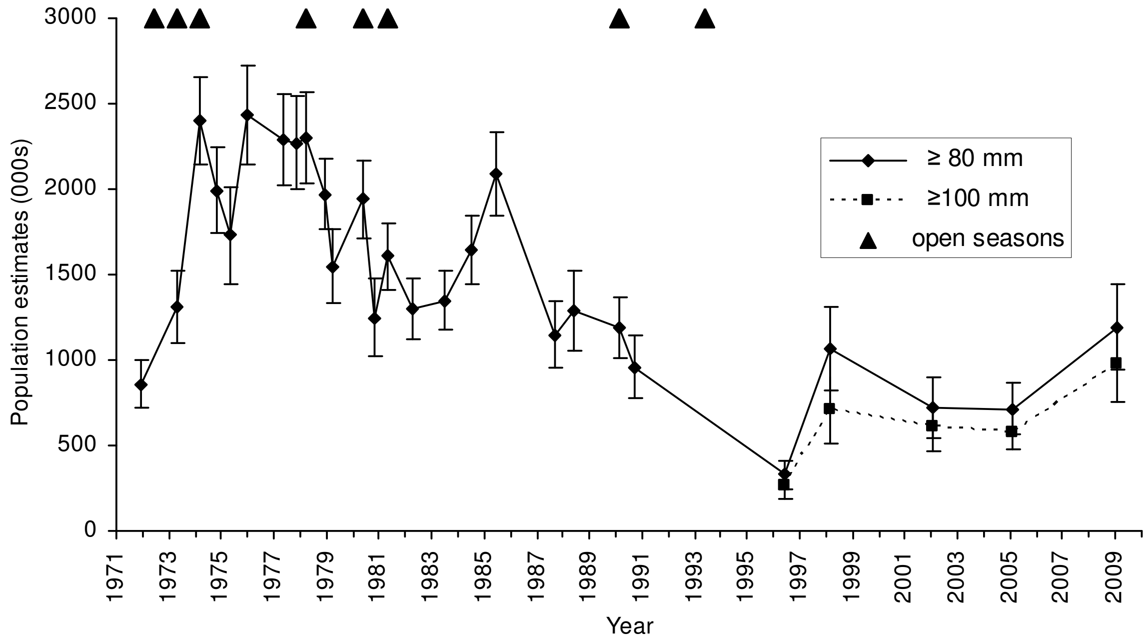

Figure 7: Oreti Beach population number estimates and 95% confidence intervals for toheroa ≥80 mm, and ≥100 mm . Estimates of toheroa ≥80 mm before1996 are from Millar & Olsen (1995). Thereafter, estimates for toheroa ≥80 mm and ≥100 mm are from Beentjes et al. (2003), Beentjes & Gilbert (2006b) and this report. Years with "open seasons " are also shown (1972 to 1981 seasons ranged from 5 to 14 days, and 1990 and 1993 were one day).

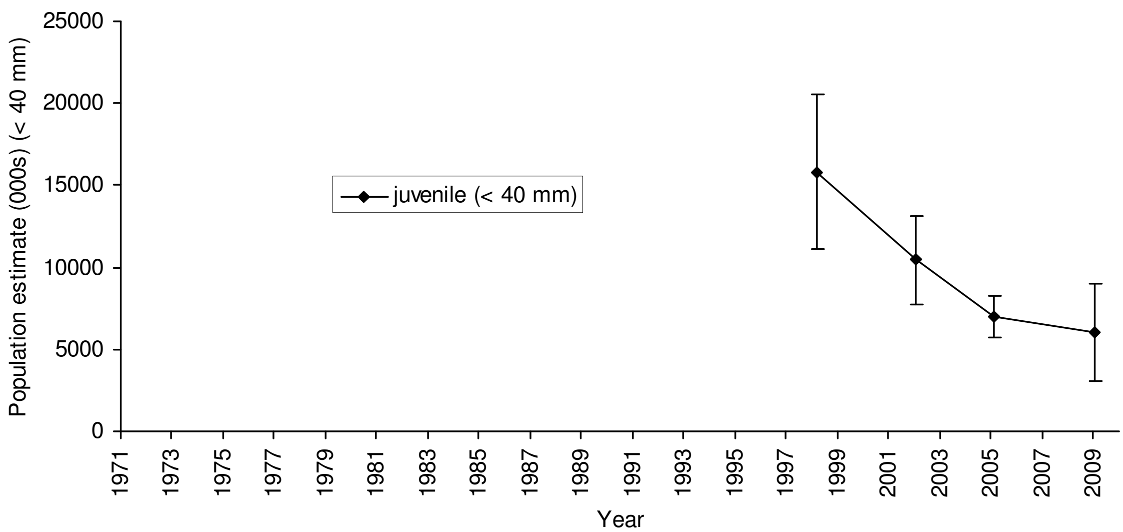

Figure 8: Oreti Beach population number estimates and 95% confidence intervals for juvenile toheroa (<40 mm) (1998–2009). Estimates from Carbines & Breen (1999), Beentjes et al. (2003), Beentjes & Gilbert (2006b), and this report.

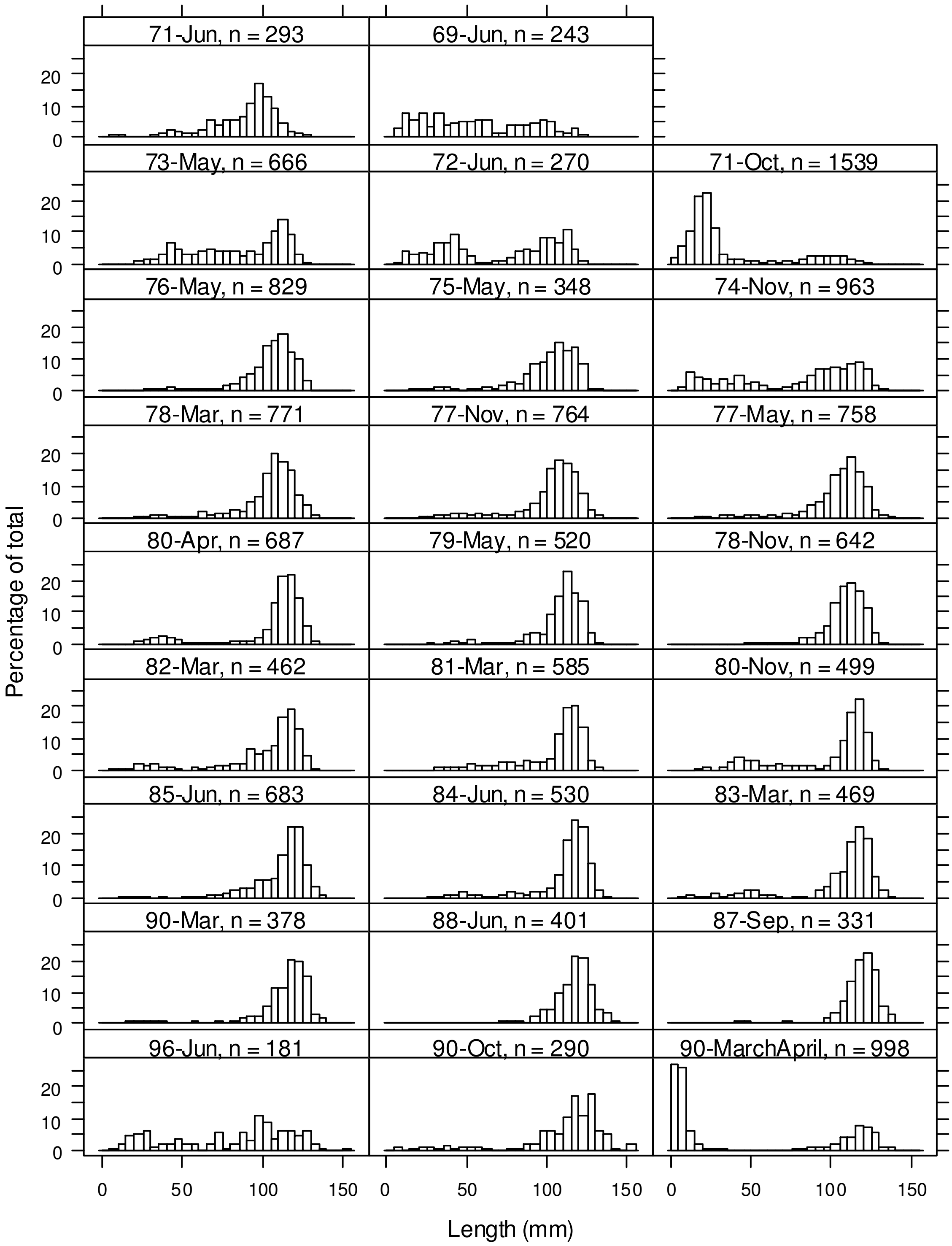

Figure 9: Length frequency distributions of toheroa on Oreti Beach from surveys between 1969 and 1996 using systematic transect surveys. There were all adult surveys except March-April 1990, when all sizes including juveniles were targeted. n, number of individuals measured.

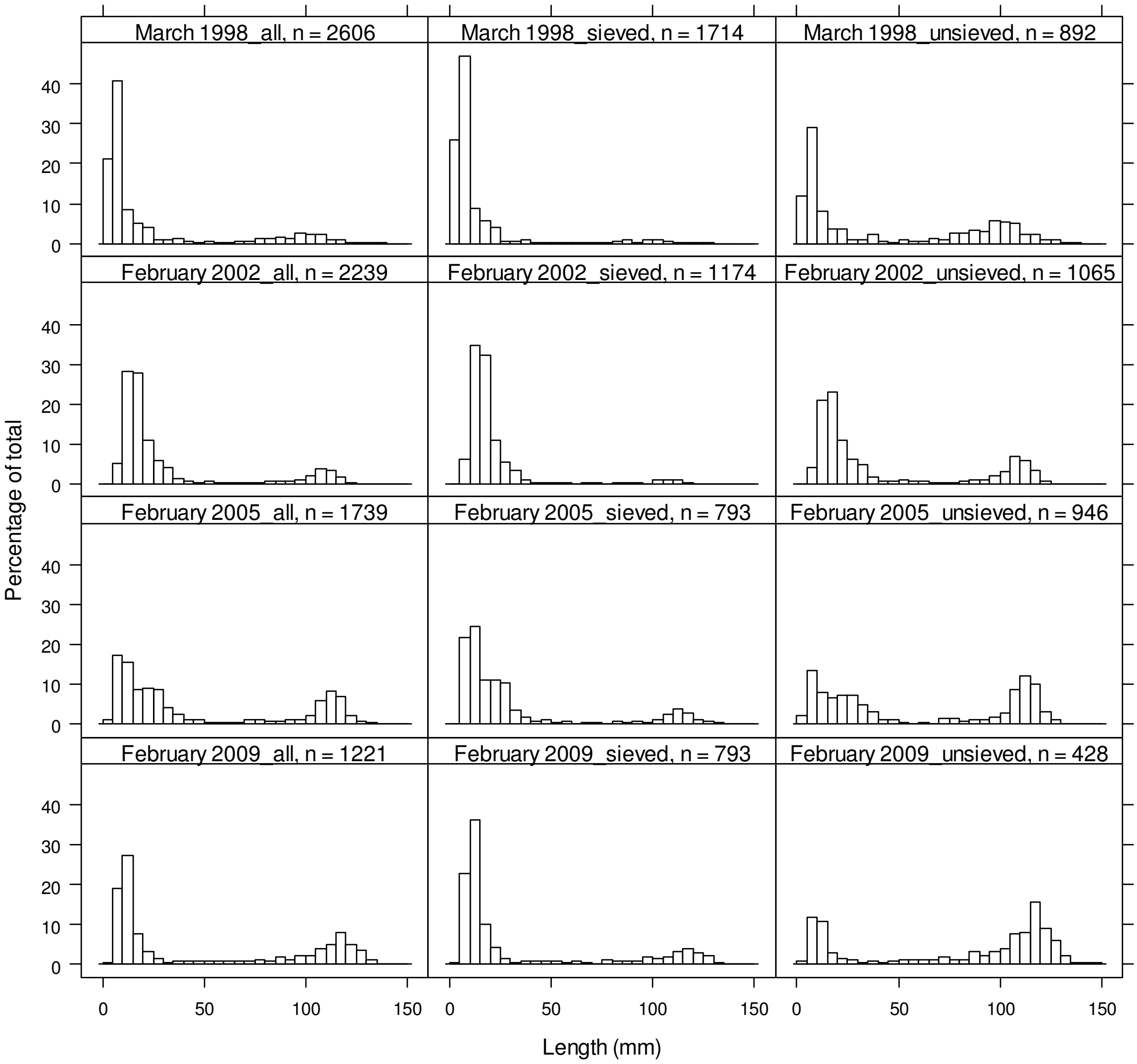

Figure 10: Length frequency distributions of toheroa on Oreti Beach from surveys between 1998 and 2009 using random stratified transect surveys partitioned by method of sampling. All, all transects; sieved, sieved transects; unsieved, unsieved transects.

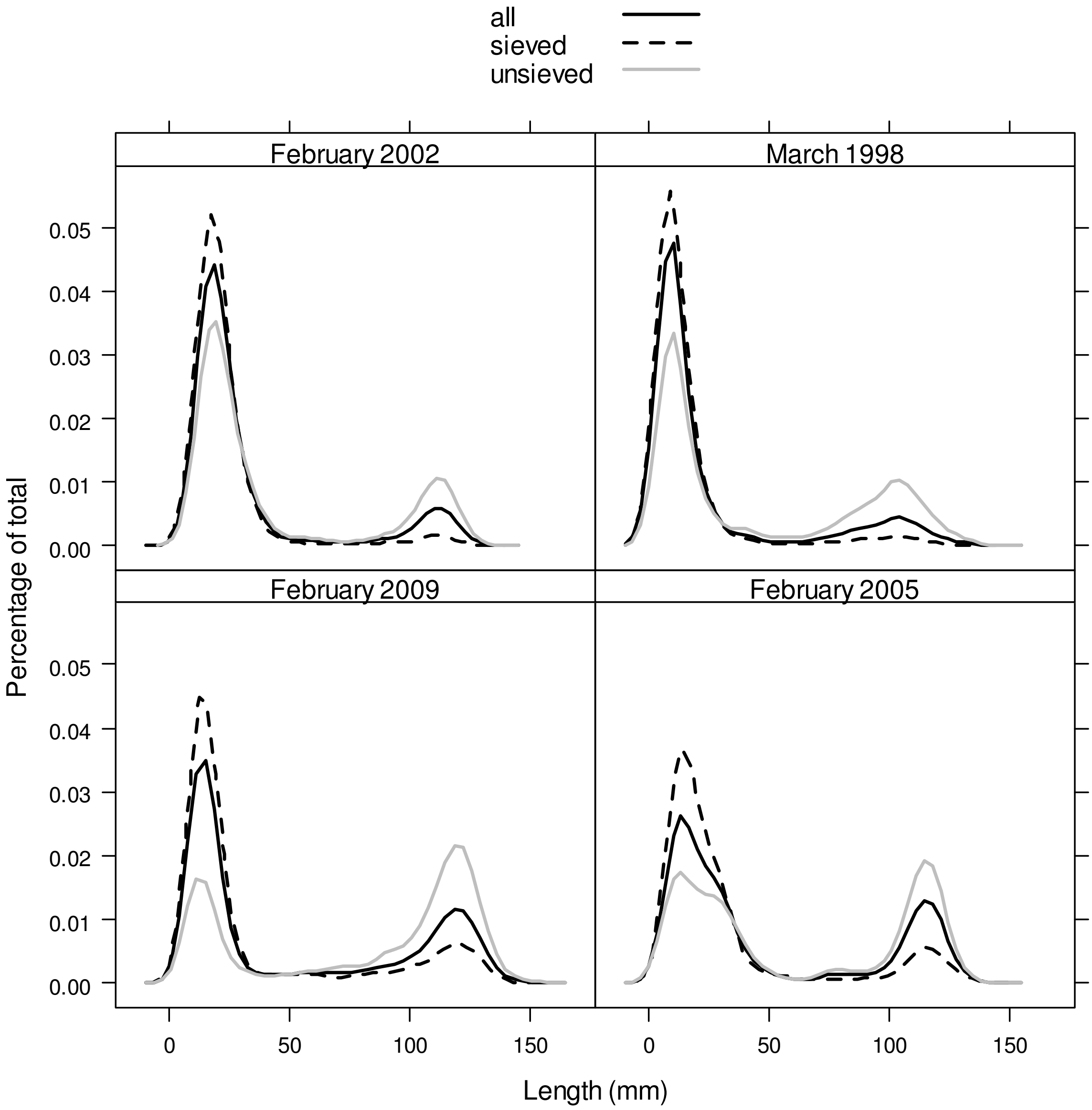

Figure 11: Length frequency density distributions of toheroa on Oreti Beach from surveys between 1998 and 2009 by method of sampling. All four surveys used a random stratified transect design. All, all transects; sieved, sieved transects; unsieved, unsieved transects.

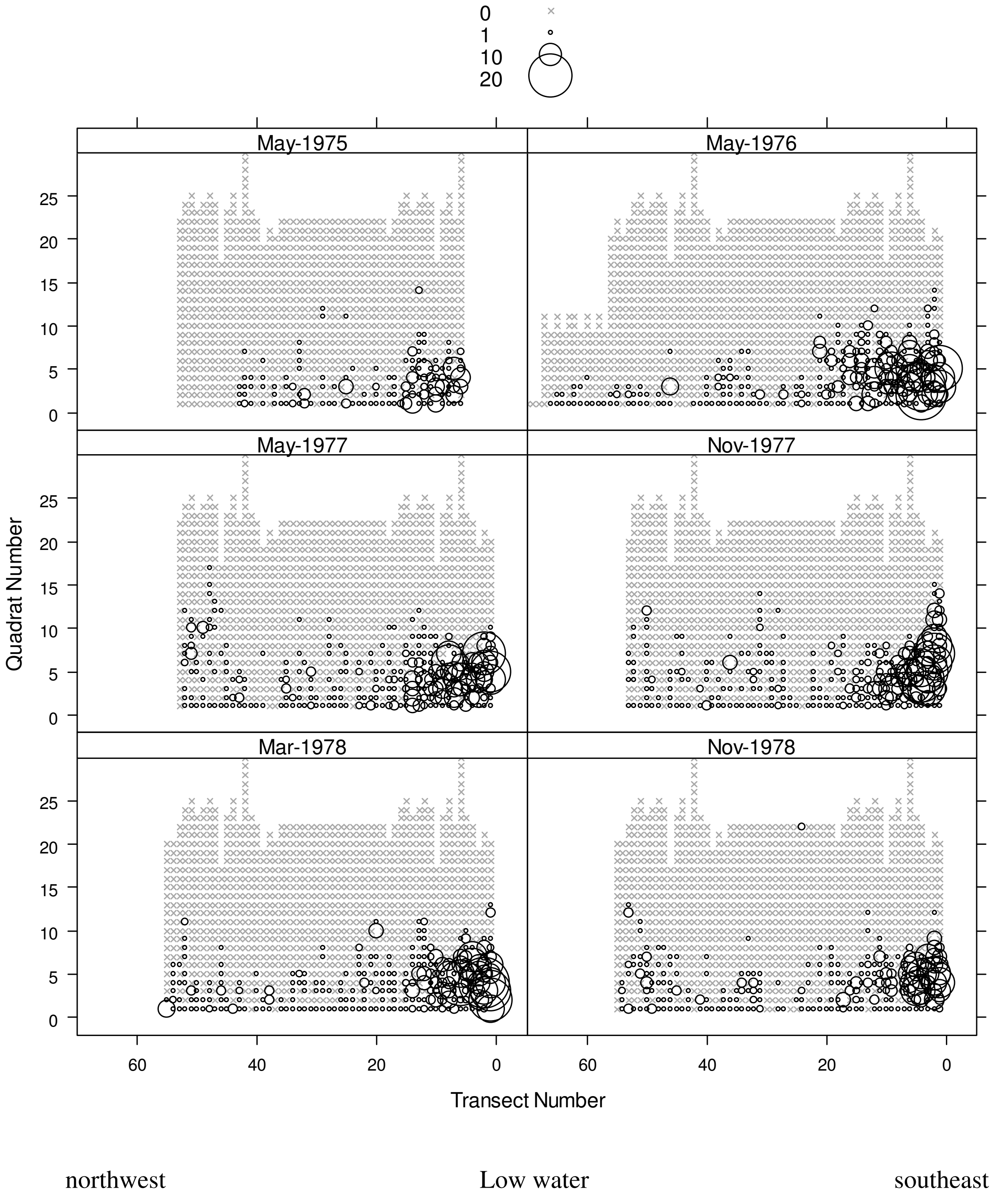

Figure 12: Distribution bubble plots of toheroa (all sizes) on Oreti Beach from surveys carried out between 1975 and 1996. All surveys used systematic transects along the beach targeting adults. Maximum toheroa per quadrat was 24. Grey crosses indicate where samples were taken, but no toheroa were recorded.

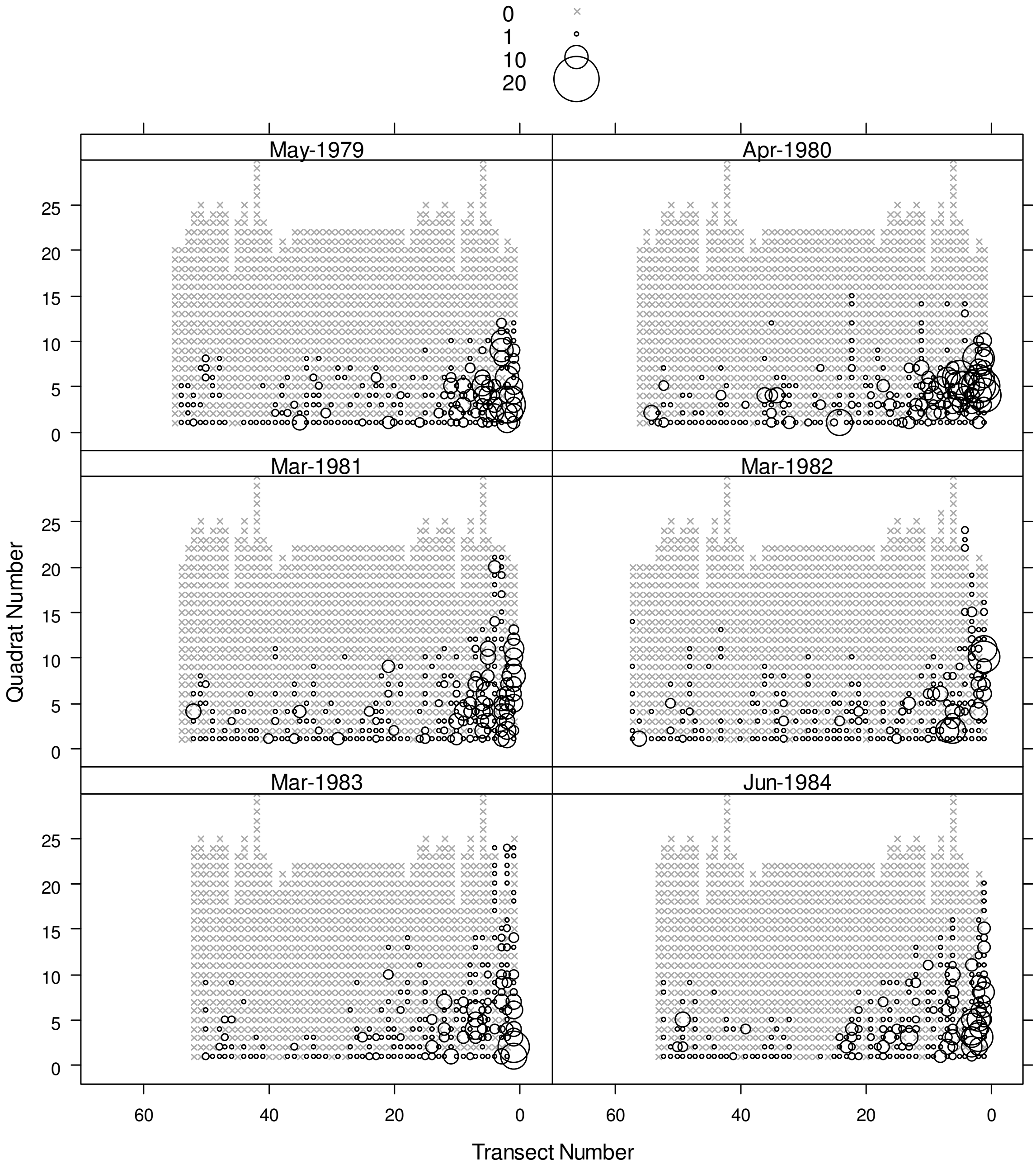

Figure 12 – ***continued***

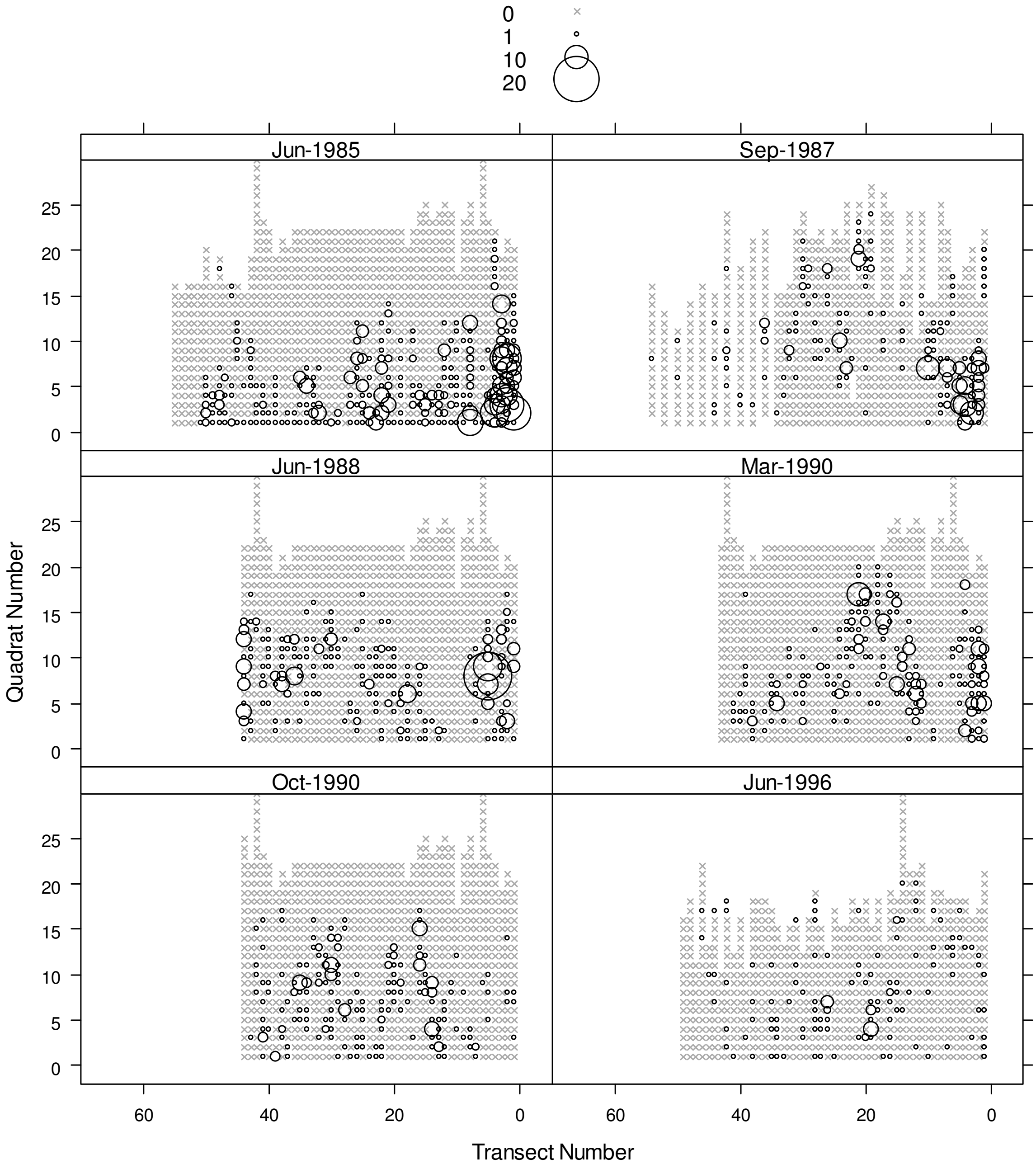

Figure 12 – ***continued***

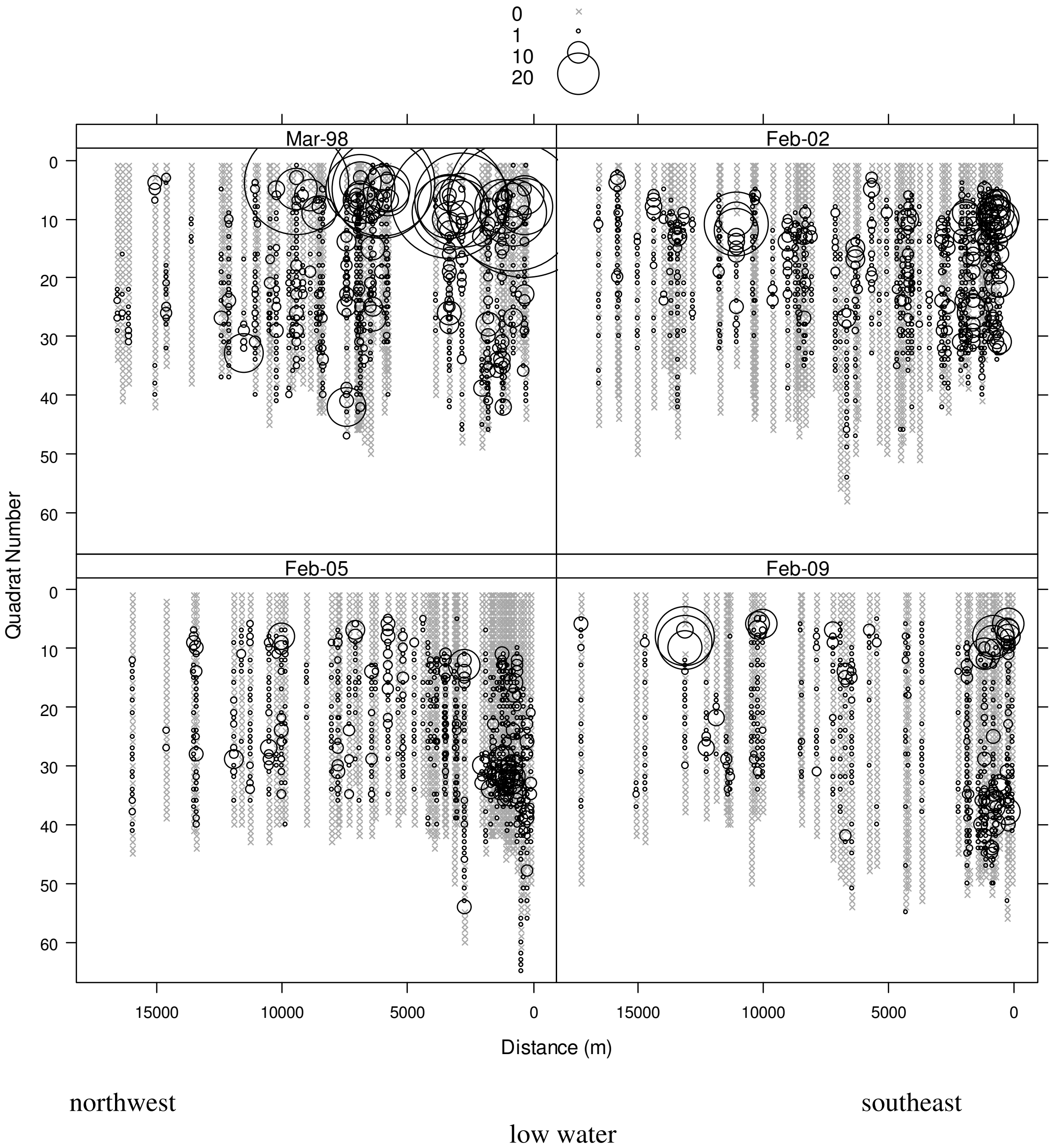

Figure 13: Distribution bubble plots of toheroa (all sizes) on Oreti Beach from the 1998, 2002, 2005, and 2009 surveys. Total number of toheroa and maximum number per quadrat were as follows (1998, n = 2606, max = 76; 2002, n = 2239, max = 31; 2005, n = 1739, max = 15; 2009, n=1221, max = 29). These surveys used a random stratified transect design, targeting all sizes. Grey crosses indicate where samples were taken, but no toheroa were recorded.

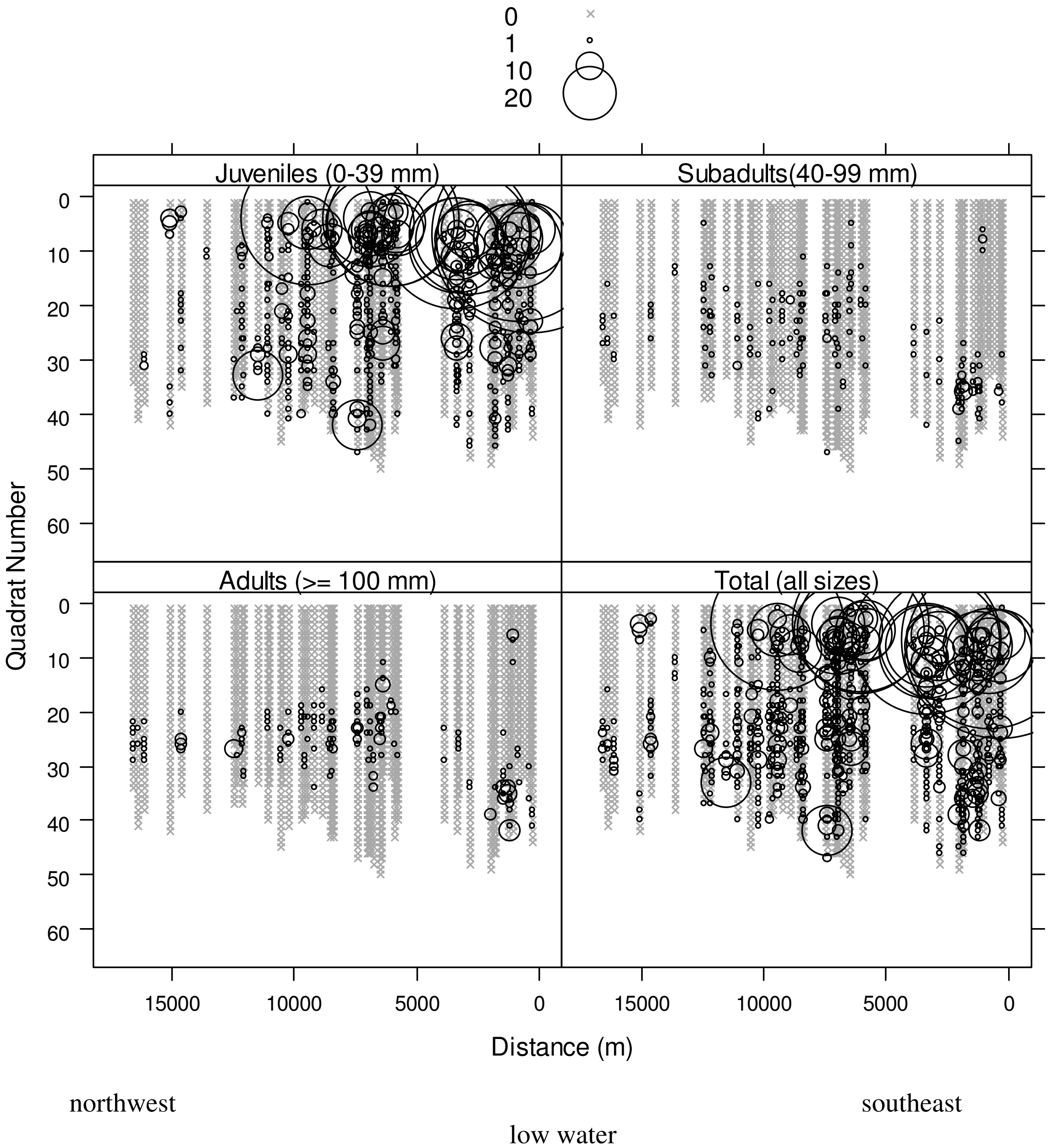

Figure 14: Distribution plots of toheroa on Oreti Beach from the March 1998 survey. Distributions are shown for all toheroa (n = 2606), adults (n = 256), subadults (n = 234), and juveniles (n = 2116). The bubbles are proportional to the number of toheroa found at each quadrat. The maximum number was 76 toheroa per quadrat. Grey crosses indicate where samples were taken, but no toheroa were recorded. The survey used a random stratified transect design, targeting all sizes.

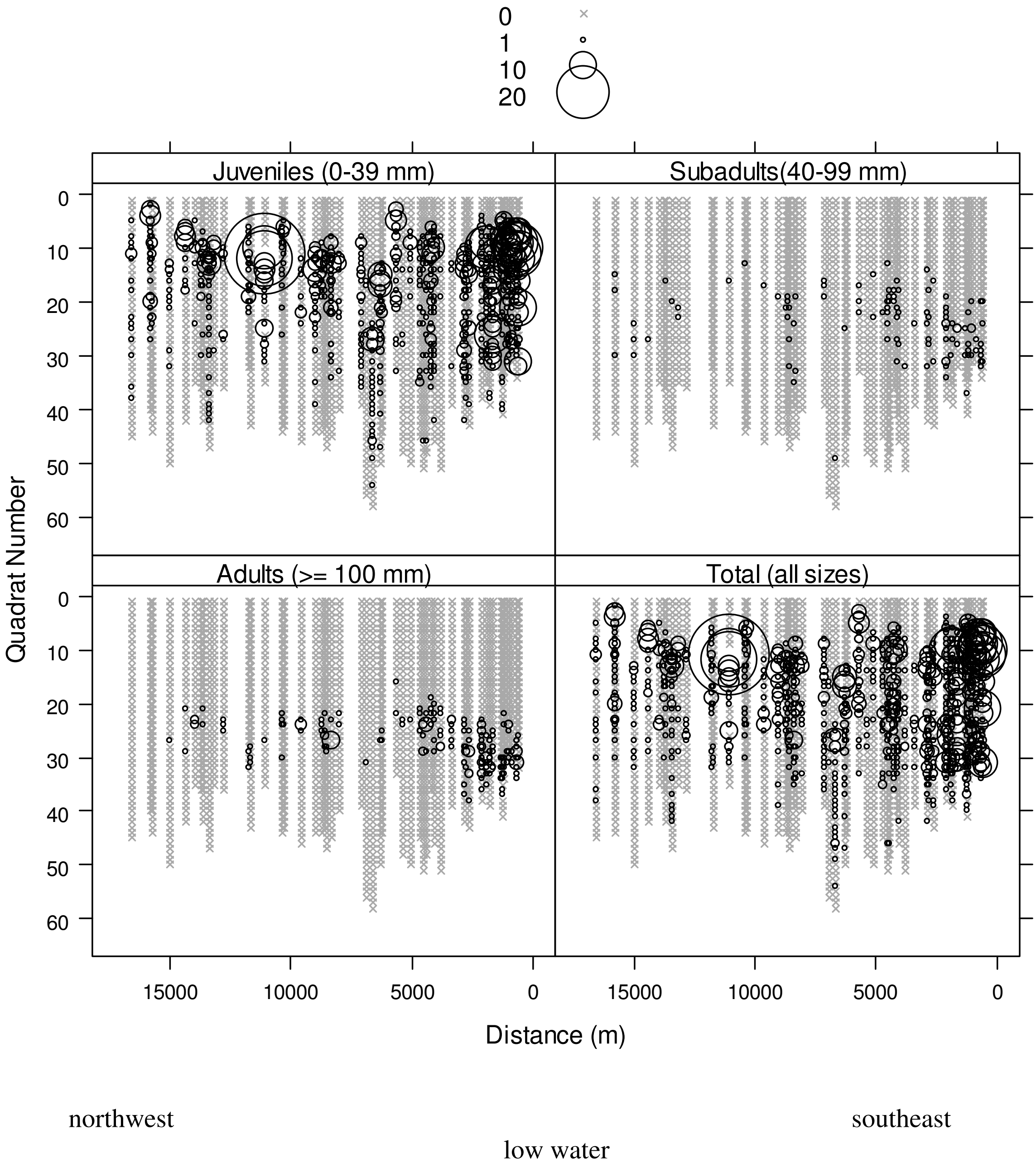

Figure 15: Distribution plots of toheroa on Oreti Beach from the February 2002 survey. Distributions are shown for all toheroa (n = 2239), adults (n = 259), subadults (n = 121), and juveniles (n = 1859). The bubbles are proportional to the number of toheroa found at each quadrat. The maximum number was 31 toheroa per quadrat. Grey crosses indicate where samples were taken, but no toheroa were recorded. The survey used a random stratified transect design, targeting all sizes.

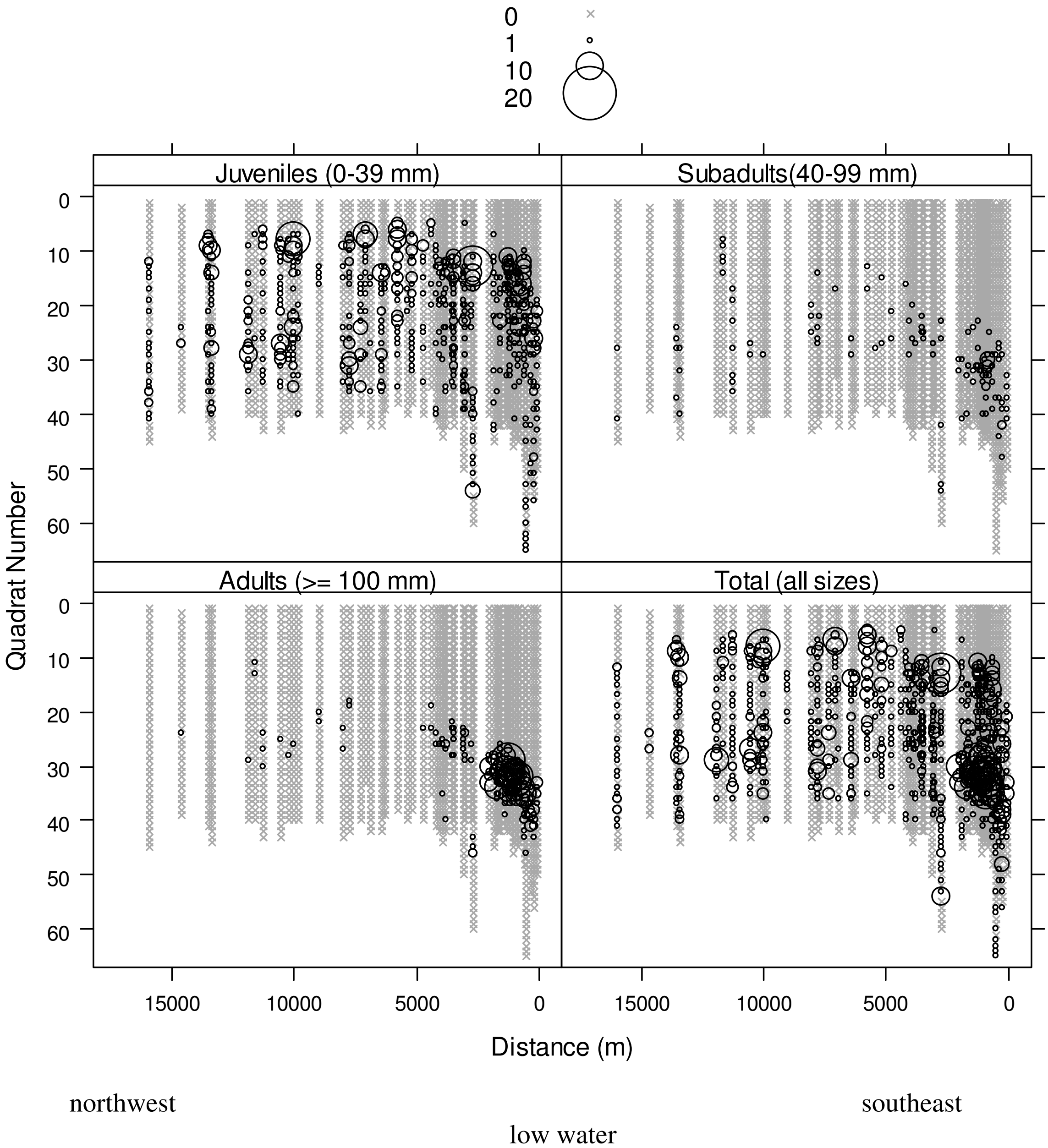

Figure 16: Distribution plots of toheroa on Oreti Beach from the February 2005 survey. Distributions are shown for all toheroa (n = 1739), adults (n = 459), subadults (n = 142), and juveniles (n = 1138). The bubbles are proportional to the number of toheroa found at each quadrat. The maximum number was 15 toheroa per quadrat. Grey crosses indicate where samples were taken, but no toheroa were recorded. The survey used a random stratified transect design, targeting all sizes.

Appendix 1. Coordinates (Geodetic Datum 1949) of the southeast strata boundaries used in the Oreti Beach February 2009 toheroa survey.

Stratum	Latitude	Longitude
1	46° 29' 35.185"	168° 15' 42.731"
2	46° 29' 8.991"	168° 15' 28.364"
3	46° 28' 38.089"	168° 15' 13.367"
4	46° 26' 54.154"	168° 14' 6.000"
5	46° 26' 19.528"	168° 13' 54.649"
6	46° 25' 49.120"	168° 13' 37.264"
7	46° 24' 31.838"	168° 12' 38.65"
8	46° 23' 16.130"	168° 11' 30.605"