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EXECUTIVE SUMMARY

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

A survey of Bluecliffs Beach toheroa was carried out between 9 and 12 March 2009 with 44 transects sampled (16 sieved and 28 non-sieved) using a two phase random transect design. The juvenile population estimate was derived from sieved transects only and adults and sub-adults from all transects. The population estimates were about 34 000 adults (100 mm or over), 14 400 sub-adults (40–99 mm), and 6300 juveniles (under 40 mm). The corresponding coefficients of variation (c.v.) were 57%, 52%, and 83%. The survey target c.v. for adult toheroa was 20%, considerably lower than the c.v. of 57% achieved — the high c.v. was a result of the sparse and aggregated nature of the distribution with only 57 toheroa found on the survey. To achieve a c.v. of 20% would have been cost prohibitive.

Length frequency distribution of toheroa was not well defined because there were only 57 individuals sampled and measured, but there is a clear mode of large toheroa (over 70 mm) with a peak at about 110 mm. There were only 9 juveniles (under 40 mm) and no clear mode is discernible.

Toheroa were found in only four of the eight surveyed strata, and adults (100 mm and over) were found in just two strata. Seventy percent of all toheroa were found in only 2 of the 44 transects indicating that there were only two small but relatively dense adult beds on Bluecliffs Beach. Of the 858 quadrats sampled, 31% had substrate suitable for toheroa (sand or coarse sand), compared to 54% in 2005, indicating that erosion is continuing with further loss of habitat since 2005 and current distribution and abundance is becoming increasingly associated with availability of fine sand.

A total of 42 historical toheroa surveys of Bluecliffs Beach from 1966 to 2005 were reviewed. The results indicate an overall decline in abundance which is steepest over a 10 year period between the mid 1960s and mid 1970s where the population of toheroa (75 mm and over) declined from about 2.2 million to about 500 000. This was followed by a further decline in the late 1980s to about 85 000 by 1990. The most recent surveys from 1997 through to 2009 indicate that the population has not recovered with consistently low numbers of toheroa 100 mm and over (mean number = 92 000, range, 10 000 to 165 000). The estimate for 2005 of 165 000 was the highest since 1984 indicating a partial recovery, but the 2009 estimate of only 34 000 confirms that the population continues to track at historically very low numbers. The area of the beach surveyed was reduced in the mid 1980s because of erosion, which has removed sand and/or prevented access, and I assume that toheroa are not found in any number outside the areas surveyed. Recent surveys by others suggest that this assumption is valid.

In general, the size composition of historical surveys was characterised by a mode of juvenile toheroa (where juveniles were sampled) and a second strong mode of adult toheroa, with relatively few of intermediate size. This indicates that juvenile mortality is high. Mark-recapture analyses indicate that toheroa grow rapidly and reach maturity (76 mm) at about 1 y. The strong adult mode between 100 and 140 mm represents multiple accumulating cohorts. Historically (1966 to 1984), toheroa were distributed along 11 km of the beach from the Grove Burn to the Hump Burn, but were most abundant immediately east and west of the Rowallan Burn. Distribution changed as sand was lost from the beach and gradually the population became confined to a 5 km stretch of beach, with most adults aggregated within 1 km immediately west of the Rowallan Burn.

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. There has been no legal recreational harvest of toheroa from Bluecliffs Beach for nearly 30 years since the one-day open season in 1980. Previous seasons at Bluecliffs Beach were in 1972, 1974, 1978, and 1979 (McKinnon & Olsen 1994), and before this there were more extensive seasons with larger bag limits. The only current legal harvest in Southland is Maori customary take by authorisation from kaitiaki representing the appropriate runanga.

Thirty-two Ministry of Fisheries (and predecessors New Zealand Ministry of Agriculture and Fisheries (MAF) and New Zealand Marine Department) funded surveys have been carried out at Bluecliffs Beach between 1966 and 2005 providing estimates of toheroa abundance, size composition, and distribution. Initially surveys were annual events or sometimes twice a year to assess stocks before and after open season, but after 1982 they were carried out every few years or so until 1990 (Street 1970, 1972, McKinnon & Olsen 1994). There was then an eight year gap until the 1998 survey (Carbines & Breen 1999), followed by seven years until the 2005 survey (Beentjes & Gilbert 2006a). In addition, there was also a series of 10 summer and winter surveys between 1997 and 2001 carried out by NIWA for Meridian Energy Ltd (Beentjes & Carbines 2001).

Numbers of toheroa (75 mm and over) at Bluecliffs beach declined steeply from 2.2 million in 1966 to 500 000 by 1972, and thereafter fluctuated around this level before another steep decline in the mid 1980s. The population has not recovered and numbers have ranged between 10 000 and 165 000 adults (100 mm and over) since then. On the last survey in February 2005 (Beentjes & Gilbert 2006a), the estimate of 165 000 was the highest since 1984 and combined with good recruitment of juveniles (under 40 mm) indicated a partial recovery. To a large extent the declines are strongly correlated with loss of habitat as the beach erodes (Beentjes et al. 2006).

The 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 at Bluecliffs Beach grow faster initially than those at Oreti Beach, attaining a length of about 80 mm within the first year and 100 mm (minimum legal size) within three 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. It is notable that toheroa from Bluecliffs beach attain a greater overall size than those from Oreti Beach, i.e., maximum size at Oreti Beach in 2005 was 136 mm (Beentjes & Gilbert 2006b) compared to 153 mm at Bluecliffs Beach. The adult modes were also larger at Bluecliffs. The mark-recapture analysis is not capable of determining if this difference is a result of faster growth or greater longevity for Bluecliffs toheroa.

A yield per recruit analysis (YPR) was undertaken in 2006 for Bluecliffs Beach toheroa and included length-weight data collected in 2005 and growth data from the unpublished mark-recapture studies in the 1970s from Oreti and Bluecliffs Beaches (Beentjes & Gilbert 2006b). The customary harvest from 2001 to 2004 was about 90 kg greenweight annually. YPR recruit estimates, assuming an average population of 96 000 was about 2.1 t, considerably more than the 90 kg harvested. It therefore appears that the harvest at current levels is well below what would be sustainable. However, the YPR estimate depends on the assumption that no further physical changes will occur and that recruitment and survival will remain at their current levels. Survey evidence from other toheroa populations does not provide support for this assumption.

1.1 Survey area (Bluecliffs Beach)

Bluecliffs Beach faces south to southwest in an embayment in the coastal cliffs at the western end of Te Waewae Bay, Southland (Figures 1 and 2). The Waiau River flows into the middle of Te Waewae Bay. The intertidal zone of Bluecliffs Beach is flat and wide but progressively narrows and steepens toward the west. A narrow vegetated (mostly marram grass) sand dune extends about 4 km west from the Rowallan Burn, before it terminates in a steep cobble bank, although this has eroded rapidly in recent years and in March 2009 had completely disappeared in many places, replaced by cobbles. The main cobble bank begins about 2 km west of the Rowallan Burn between the sand dunes and intertidal zone and becomes wider and steeper toward the west. The beach substrate at low tide is mainly fine or coarse sand, but further up the beach gravel and cobbles are common. The beach conforms to the definition of 'dissipative' since it is generally flat with a wide surf zone (about 150 m), high wave-energy, and the substrate is mainly fine sand (Defeo & McLachlan 2005).

Overall objective

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

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 (≥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 (≥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 and review of Oreti Beach (specific objectives 1 and 2) were reported by Beentjes (2010). This report includes the results of a toheroa survey of Bluecliffs Beach in March 2009, and a review of toheroa length frequency, abundance, and distribution from historic surveys at Bluecliffs Beach.

2. METHODS

2.1 2009 Bluecliffs Beach survey

2.1.1 Survey design

The Bluecliffs Beach toheroa survey used a two phase, stratified random transect design (Francis 1984). The survey area covered a 5.07 km stretch of beach from the Grove Burn in the east to about 1 km west of where the access road heads inland (Figures 1 and 2). Eight strata of various lengths (identical to those used in the 1998 and 2005 MFish funded surveys) (Carbines & Breen 1999, Beentjes & Gilbert 2006a) were marked out using hand-held GPS (non-differential). The eastern boundary of stratum 1 was 46°09' 43.2” S and 167°31' 53.0” E. (World Geodetic Data System 1984) (Appendix 1). Sampling transects were marked out within each stratum using randomly generated distances from the east end of each stratum, with a requirement that there be at least 20 m between transects. A total of 44 transects was considered sufficient to meet the target c.v. of 20% since in 1998 a c.v. of 14% was achieved using 40 transects, and in 2005 47 transects were used to achieve a c.v. of 15%.

Thirty-two transects (73%) were allocated to phase 1, and the remaining 12 to phase 2. A minimum of three transects was initially assigned to each stratum to estimate sampling variance. The remainder of phase 1 transects were allocated based on the 2005 survey mean catch of adult toheroa per transect in each strata, 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. 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 2005 survey (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). I 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

The population size of toheroa for three size groups (adult, 100 mm and over; sub-adult, 40–99 mm; and juvenile, under 40 mm) on Bluecliffs Beach was estimated from the mean density of toheroa in each stratum and the area of each stratum**.** In the ith 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

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

The factor 100 is introduced in scaling up from the sampled area of the transect to the whole transect.

The c.v. is

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

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, 100 mm and over; sub-adult, 40–99 mm; and juvenile, under 40 mm) were plotted in three dimensional space by quadrat (high water to low water) and transect (distance along the beach).

2.2 Bluecliffs Beach historical toheroa survey data

I examined historical data from 42 Bluecliffs toheroa surveys between 1966 and 2005 and compared these with the results from the March 2009 survey. Of these 42 surveys only those from 1966 to 1970 (11 surveys) (Street 1970, 1972) and 1990 onward (3 MFish surveys and 10 Meridian Energy Ltd surveys) are documented (McKinnon & Olsen 1994, Carbines & Breen 1999, Beentjes & Carbines 2001, Beentjes & Gilbert 2006a). Raw data in hard copy forms from December 1970 to 1990 surveys were entered onto a database for analysis as part of the 2005 survey objectives. There were no raw data on toheroa available on distribution from transect/quadrat counts from the 1966 to 1970 surveys, and length frequency data were transcribed and hence estimated from the survey report figures. In this report data have been replotted using R graphics and substrate distribution has also been plotted (surveys since and including 1997) as well as distributions of toheroa by size range for 1998 and 2005 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.

1966 to 1990 survey data (Ministry of Fisheries)

From 1966 to 1990 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 Bluecliffs Beach using a systematic sampling design with transects spaced every 321 m along the beach, except the 1990 survey where transects were 330 m apart. Unfortunately, apart from early surveys (1966 to February 1971)(Street 1970, 1972) and 1990 (McKinnon & Olsen 1994), the methods and results from these surveys were not published or documented, sometimes making it difficult to interpret the raw data.

There are two events that have affected standardisation of the survey procedures during this time series. Firstly, from 1966 to 1984 the survey area encompassed an area about 1.6 km east of the Grove Burn west to the Hump Burn (see Figure 2), a distance of about 11 km and 35 transects were used. Erosion of the beach structure and loss of sand about 1985 prevented access to the beach west of the Waikoau River and the area immediately east of the river. Hence from 1985 onward the length of the beach covered by surveys ranged from about 4.5 to 6.1 km. The assumption was that the erosion of the beach in the west of the bay was accompanied by a loss of toheroa. Secondly, in 1987 erosion affected the east end of Bluecliffs Beach, also resulting in a loss of sand substrate and the survey area was further truncated with the most eastern transects starting at the Grove Burn (previously transect #5). From 1990 onward the benchmark for transect #1 was changed to at or near the Grove Burn.

Quadrats (1 m x 0.5 m) were excavated every 5 m down each transect. The cross-sectional width of the beach surveyed (low to high water), based on the number of quadrats excavated, was on average about 110 m. No details of tide heights are available during the surveys, although McKinnon & Olsen (1994) stated that the 1990 survey covered the area from mean low water to mean high water. Necessary assumptions of undocumented surveys before 1990 were that transects were sampled from low to high water and that quadrat numbering was consistent between surveys.

All surveys were adult surveys with no attempt made to actively search for juvenile toheroa. The aim of these surveys was to determine if an open season was sustainable. Hence, surveys were often carried out before and after an open season.

1997 to 2001 survey data (Meridian Energy Ltd)

NIWA conducted a series of 10 surveys for Meridian Energy Ltd from 1997 to 2001 (Beentjes & Carbines 2001). Over each of the five years a summer and winter survey was carried out using a systematic sampling design with the distinction being that during winter surveys, every second transect was sieved. Transects were positioned every 250 m along the beach starting at the Grove Burn and covering 4.5 km of beach, roughly equivalent to transects 5 to 20 of the 1966 to 1980 surveys (Figure 2). The same sampling methodology as described above was used except for the sieving of transects in the winter surveys. For sieved transects, sand was fed into nylon mesh bags (stretched mesh size about 6 mm) and dragged to the water's edge to wash out fine sand leaving behind toheroa, shell debris, and stones. Substrate type was also qualitatively recorded from 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.

1998 to 2009 stratified survey data (Ministry of Fisheries)

There have only been three Ministry of Fisheries funded toheroa surveys of Bluecliffs Beach since 1990, and these were carried out by NIWA in 1998, 2005, and the most recent survey in March 2009 (Carbines & Breen 1999, Beentjes et al. 2003). All three surveys used a random stratified transect design and covered the same general area as the Meridian surveys (i.e., equivalent to transects 5 to 23 of the 1966 to 1980 surveys) although transects were spaced randomly within strata of variable size (Figure 2). The same strata (Appendix 1) and sampling design have been used for all three surveys (see 2009 survey methods).

2.2.1 Abundance estimates

Street (1972) estimated numbers of toheroa 3 inches (about 75 mm or over — the minimum legal size until 1978, thereafter 100 mm) from 11 Bluecliffs Beach surveys between 1966 and February 1971. Estimates were based on simple scaling of the actual area of beach excavated to the total area of beach surveyed (see Carbines 1997).

$$\text{Population estimate} = (T/A) \times B$$

Where T = number of toheroa sampled, A = area sampled, and B = total area of the beach surveyed

(McKinnon & Olsen (1994) also used the simple scaling method to estimate numbers of toheroa of the legal minimum size for the December 1971 to 1990 surveys. Neither Street (1972) nor McKinnon & Olsen (1974) provided estimates of variance around their population estimates. To estimate variance, population estimates for toheroa 75 mm and over, and 100 mm and over, were recalculated for the December 1971 to 1990 surveys (this report) using the sampling fraction method which scales the total number of toheroa by the reciprocal of the fraction of the area surveyed (Millar & Olsen 1995).

$$\textit{Sampling fraction} = 1 \times \textit{quadrat area}/(\textit{transect width} \times \textit{distance between quadrats})$$

In these surveys transect width = 330 m, quadrat area = 0.5 m^2, and distance between transects = 5 m. Hence the reciprocal of the sampling fraction is 1/0.0003 = 3300. Using this method it is not necessary to know the area of the beach surveyed, just the fraction sampled. The coefficient of variation and 95% confidence intervals were also estimated as follows:

$$c.v. = s.e./mean$$

where *s.e.* is the standard error of the number of toheroa per quadrat, and *mean* is the mean number of toheroa per quadrat.

And 95% confidence intervals around the population estimates were calculated from

$$\pm c.v.\ 1.96\ N$$

where N is the toheroa population estimate.

It was not possible to estimate variance for the 1966 to February 1971 surveys because I do not have the raw data.

Population estimates of adult toheroa for the 10 Meridian Energy surveys from 1997 to 2001 (Beentjes & Carbines 2001) were also calculated from the sampling fraction method, but the variance was estimated using a systematic overlapping sampling variance estimator (Millar & Olsen 1995).

For the random stratified transect surveys in 1998, 2005, and 2009 surveys (this report), a third method was used where the mean number of toheroa per transect was scaled up to the area of each stratum (see Section 2.1.3).

The length of beach surveyed in 1998 and 2005, and also in the Meridian Energy surveys from 1997 to 2001, is almost half that of the surveys from the 1966 to 1984 (see Figure 2), and so for the comparison of abundance estimates to be valid, I assume that toheroa are no longer present in areas outside the present survey area.

3. RESULTS

3.1 2009 Bluecliffs Beach survey

Bluecliffs Beach was surveyed from 9 to 12 March 2009 and 44 transects (32 phase 1 and 12 phase 2) were successfully completed (Table 1). Of the 44 transects, 16 were sieved (2 per strata). Phase 2 transects were allocated to strata 1 (n = 6), 6 (n = 5), and 7 (n = 1). The number of quadrats per transect ranged from 9 to 32, with a mean of 19.5 equating to a mean transect length (beach width) of 97 m. Low tide height throughout the survey ranged from 1.36 to 1.07 m below mean sea level.

3.1.1 Abundance estimates

Mean numbers of toheroa per stratum and population estimates of adults (100 mm or over), sub-adult (40–99 mm), and juvenile toheroa (under 40 mm) are given in Table 2. The population estimates were about 34 000 adults, 14 400 sub-adults, and 6300 juveniles. The corresponding coefficients of variation (c.v.) were 57%, 52%, and 83% (Table 2). The survey target c.v. for adult toheroa was 20%.

3.1.2 Length frequency

Length frequency distribution of toheroa on the March 2009 survey are not well defined because there were only 57 individuals caught and measured, but there is a clear mode of large toheroa (over 70 mm) with a peak at about 110 mm (Figure 3) There were only 9 juveniles (under 40 mm) and no clear modes are discernible. Of the 9 juveniles, 6 were sampled from unsieved and 3 from sieved transects. There were no toheroa of intermediate size sampled.

3.1.3 Spatial distribution

Toheroa were sparse and highly aggregated in the March 2009 survey with 53 of the 57 toheroa (93%) found in just 2 strata (1 and 6) and of these 37 toheroa (70%) were found in only 2 of the 44 transects. Hence, only two small but relatively dense adult beds were encountered on the survey (Table 2). All 13 sub-adults were found in strata 1, but the 9 juveniles were spread along the beach among strata 1, 5, 6, and 7. Three dimensional distribution bubble plots show the spatial distribution along and down the beach (Figure 4). This distribution is also shown in a plot of the cumulative numbers of each size group by distance along the beach (Figure 5) and show a punctuated trend reflecting the small numbers and aggregated nature of the distribution. Vertical distribution of toheroa by size is shown in Figure 6 — the few data do not indicate a difference in vertical distribution by size.

3.1.4 Substrate

The substrate in 31% of the 858 quadrats sampled was sand or coarse sand (substrate types 1 and 2) and was most prevalent in strata 1, 5, 6 and 7, and least in strata 2, 3, 4 and 8 (Table 3). Correspondingly, gravel and stones (substrate types 3 to 7) were encountered in 69% of quadrats.

3.1.5 Customary harvest

Maori customary take from Bluecliffs Beach is monitored through authorisations issued by kaitiaki. Records include amounts issued and taken and this information is provided to the Ministry of Fisheries by Oraka-Aparima Runaka quarterly (Table 4). Removals have ranged between about 90 and 402 toheroa each year from 1998 to 2004. Customary take records from 2006 to 2008 were provided to NIWA by Fisheries Management Areas 3–7 combined (TOH 5) and I 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). It is not possible to estimate customary take in recent times from Bluecliffs without accessing the individual authorisations, hence I have not updated the table.

3.2 Bluecliffs Beach historic toheroa surveys (time series)

3.2.1 Abundance estimates

Despite the use of three different methods to estimate population numbers in the 43 year time series, and the reduction in the size of the survey area (Table 5), the estimates of toheroa numbers reflect the population status on Bluecliffs Beach (Figure 7). Essentially there are two time series, one for toheroa 75 mm and over (1966 to 1990), and another for toheroa 100 mm and over (1971 to 2009); the overlap indicates that differences are slight and trends are mirrored. The results show an overall decline which is steepest over a 10 year period between the mid 1960s and mid 1970s where the population of toheroa 75 mm and over declined from about 2.2 million to about 500 000. This was followed by a further decline in the late 1980s to about 85 000 by 1990. The most recent surveys from 1997 through to 2009 indicate that the population has not recovered with consistently low numbers of toheroa 100 mm and over (mean number = 92 000, range =10 000 to 165 000). The estimate for 2005 of 165 000 was the highest since 1987 indicating a partial recovery, but the 2009 estimate of only 34 000 confirms that the population continues to track at historically very low numbers.

Juvenile toheroa (less than 40 mm) were sampled in only eight surveys between 1997 and 2009 (Table 5). Numbers ranged from 25 000 to 180 000 (mean = 100 000) for the 1997 to 2001 surveys, but in

2005 they increased more than 8-fold to 805 000 (Figure 7). In contrast, there were just 6000 in 2009, the lowest estimate to date.

3.2.2 Length frequency

Length frequency histograms of toheroa on Bluecliffs Beach from historical Ministry of Fisheries systematic surveys between 1966 to 1990 are shown in Figure 8. With the exception of the last three surveys the size distributions are remarkably similar throughout the time series from 1966 to 1990, characterised by a strong adult mode between about 100 and 140 mm, with few sub-adults (40–99 mm), and with the occasional juvenile mode from 10 to 40 mm. All surveys targeted adult toheroa, although length frequency distributions for some years suggest that some attempt was made to sample juveniles (under 40 mm), as they were represented (e.g., see November 1969).

The Meridian Energy surveys from 1997 to 2001 often showed little pattern in the size distributions because of the low numbers of individuals sampled, although adult and juvenile modes were sometimes discernible (Figure 9). Winter surveys, which included juvenile sieved transects, did not have strong juvenile modes, again probably because total numbers of toheroa were small.

The length distributions from the three most recent Ministry of Fisheries surveys using a stratified random transect design are shown in Figure 10. The 1998 survey is unusual in that it has three modes of similar strength representing juveniles, sub-adults, and adults. The 2005 survey has the characteristic distribution of the historic surveys, but includes a strong juvenile mode, most prominent in the sieved data. The 2009 distribution has been described in Section 3.1.2, and is not well defined, but indicates of an underlying distribution typical of historic surveys.

3.2.3 Spatial distribution

Distribution plots of toheroa (all sizes) on Bluecliffs Beach from Ministry of Fisheries systematic surveys between December 1971 and 1990 are shown in Figure 11. The distribution of toheroa shown in these plots presumably includes the area of the beach from low tide to the top of the beach, but this information was often missing and cannot always be assumed in adult toheroa surveys. Because the first quadrats at low water often had toheroa present, it is likely that there were toheroa present below mean low water. In more recent surveys from 1997 onward, quadrats were excavated in the direction of low water until no toheroa are found, ensuring that the area either side of the toheroa bed had been thoroughly sampled.

Between 1971 and 1984 toheroa were distributed along the entire length of Bluecliffs Beach from east of the Grove Burn to northwest of the Waikoau River as far as the Hump Burn, a distance of about 11 km that included 35 transects (see Figure 2). Toheroa were densest, however, in the southeast end of the beach between the Grove Burn and where the access road heads inland (i.e., between transects 6 and 20) (Figure 11). Density was also highest about 80–100 m from the top of the beach towards low water. The number of quadrats with no toheroa in the upper section of the beach is suspicious, given the distributions from the post 1997 surveys. Further, anecdotal evidence suggests that not all transects were sampled up to the top of the beach – I 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.

A reduction in the size of the survey area in both 1985 and 1987 (Table 5), as erosion removed sand and/or prevented access to the west, resulted in a massive decline in numbers (see Figure 7) and a contraction in the distribution of toheroa.

From 1997 to 2001 (Meridian Energy surveys) there were few toheroa near the Grove Burn and highest densities were consistently located in a 1 km stretch of beach northwest of and adjacent to the Rowallan Burn (Figure 12). Further, substrate type plotted on the quadrat sites indicates that much of the beach was uninhabitable to toheroa and distribution was strongly associated with habitat, i.e., toheroa were predominantly confined to areas of the beach with fine sand (Figure 12).

The 1998 and 2005 MFish surveys also showed the area to the northwest of the Rowallen Burn to be the favoured location and where the substrate was mainly fine sand (Figure 13). Further, examination of the distributions by size indicates no real pattern in 1998 (Figure 14), but in 2005 adults were found nearer low water than other sizes (Figure 15).

Comparison of the number of toheroa within transect groups in 1966, 1978, and 1984 (before the survey area was reduced) suggests that the distribution had been moving gradually eastward since the 1970s (Figure 16). It also shows that the highest densities over this period were consistently in transects 6 to 10, between the Grove Burn and Rowallan Burn (see Figure 2). Thus, there has been a substantial shift in density from the east to the west side of the Rowallan Burn over the past 40 years.

4. DISCUSSION

4.1 2009 Bluecliffs beach survey

The 2009 population estimates of adult, sub-adult, and juvenile toheroa were about 34 900, 14 400, and 6300, respectively, with a c.v. for adult toheroa of 57%, well above the 20% target. The high c.v. is a result of the low population numbers aggregated into small beds, and future surveys should consider a pre-survey of the beds and re-stratification, ensuring that the main beds are included in smaller well defined strata where the likelihood of encountering the beds is high. The population estimates for adult toheroa was 80% less than in the last survey in 2005 and juvenile numbers have declined by 99% (see Figure 7). The 2009 survey shows that the Bluecliffs Beach toheroa population remains very low with no indications of recovery. The exceptional numbers of juveniles recorded in 2005 (0.8 million) was an encouraging sign for the population, but this did not translate into an increase in the number of adults by 2009, indicating that juvenile mortality in the interim was high.

The Bluecliffs Beach toheroa population size structure in 2009 was characterised by the presence of a juvenile mode (under 40 mm) comprised of 0+ year class individuals (Redfearn 1974), and an adult mode (75–145 mm), although neither mode was well defined because of the low numbers sampled. Despite the poorly defined modes the size distribution is generally typical of this population. Mark-recapture data from the 1970s indicates that toheroa in the adult mode are about three years and older (Beentjes & Gilbert 2006a). The relative absence of toheroa in the intermediate size range (sub-adult) between juvenile and adults is also a feature of this and previous surveys.

The distribution of adult toheroa in 2009 was notable by the sparse and aggregated nature of the distribution, and also the virtual disappearance of the large bed just west of the Rowallan Burn, present in 2005.

There was no indication that toheroa of different sizes occupied defined height zones between high and low water in 2009 (see Figure 6), but low sample numbers probably obscure this distribution which is typical of Bluecliffs and Oreti Beaches (Beentjes & Gilbert 2006a, 2006b) with juveniles more abundant near high water and adults near low water (see Figure 6).

The substrate in 31% of the quadrats sampled was sand or coarse sand compared to 54% in 2005, an indication that the beach has sustained further erosion in recent years (see Figure 13). For toheroa this means that less than a third of the surveyed area at Bluecliffs Beach is suitable habitat. Further, the sand dunes have continued to recede, exposing underlying stones to the extent that the access road, which runs behind the dunes and parallel with the beach, is washed away in places and has now been abandoned by the local district council.

Maori customary take from Bluecliffs 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 (165 000), and the maximum recorded customary harvest of about 400 toheroa in 2004, the exploitation rate was estimated at about 0.2% of the adult population annually. Based on the 2009 survey and assuming a similar customary take of 400 per year, the current exploitation rate is about 1%. This is very low relative to what the population can sustain since Beentjes & Gilbert (2006a) suggested that an exploitation rate of 30% should not severely reduce the population size; however, the continual erosion and loss of habitat from the beach suggests that any level of harvest may not be sustainable.

4.2 Historic time series

4.2.1 Abundance

The time series indicates a dramatic decline in abundance of adult toheroa on Bluecliffs Beach between 1966 and 1972 when the population declined by 77% from about 2.2 to 0.5 million (75 mm and over) and then continued to decline gradually over the next 15 years until 1987 when the adult population was estimated at only 19 800, or 0.9% of the 1966 population (see Figure 7). The trend for toheroa 100 mm and over is essentially the same but the numbers are slightly less. Population estimates have remained very low since 1987 ranging from 10 000 to 165 000 (100 mm and over) with the 2009 estimate the third lowest on record. There are no signs of recovery of this population and it may be at serious risk of total collapse.

Management measures were taken to address declining numbers of toheroa as early as 1932 (McKinnon & Olsen 1994), and therefore it is likely the population was considerably larger before 1966. 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. Oreti Beach has also experienced a decline in the toheroa population, although a lesser one, over much the same time frame, but now appears to be recovering to the levels of the mid 1980s (Beentjes 2010). Unlike Oreti Beach, however, Bluecliffs Beach is eroding with ongoing loss of sand, exposing rocks and gravel, changing the beach profile, and resulting in the loss of sand dunes (Beentjes et al. 2006). This has resulted in a progressive reduction in the available habitat for toheroa. Not only has the distribution of toheroa contracted, but of the current survey area, only 31% of the substrate is now suitable for toheroa (see Table 3). The causes of the erosion are unknown, but may be linked to the reduced outflow and therefore sediment load from the Waiau River into Te Waewae Bay when water from Lake Manapouri was diverted through West Arm Power station to Deep Cove in 1969.

Estimates of the toheroa population from Bluecliffs Beach from 1985 onward are based on a length of beach about half that of earlier surveys. If there were still toheroa present at the western end of Bluecliffs Beach (west of the Waikoau River), or in areas that are no longer included in the survey, then abundance will have been underestimated relative to past estimates. The assumption is that toheroa are no longer present in any number outside the survey area. Continual erosion of the beach at the eastern end makes it unlikely that there are any toheroa east of the Grove Burn. The small bay at the western end of Bluecliffs Beach is fully covered in fine sand and appears to be suitable habitat for toheroa; however, a survey in 2008 found only three floating juveniles and no adults (Futter & Moller 2009). Hence my assumption that there are no toheroa on Bluecliffs Beach outside the survey area seems reasonable. Futter & Moller (2009) also surveyed Orepuki, a fine sand beach at the eastern end of Te Waewae Bay. A population of nearly 60 000 adults was estimated to be present in 2008, almost double the 2009 population at Bluecliffs Beach. Given the quality of the habitat at Orepuki and the absence of any observable sign of beach erosion, this may be the only significant toheroa population that survives within Te Waewae Bay in the long term.

Because the historical surveys on Bluecliffs Beach did not target juveniles until 1997, the magnitude of annual recruitment and the extent to which recruitment strength translates into adult numbers cannot be determined. However, the exceptional juvenile recruitment of 2005 (see Figure 7) did not result in good recruitment into adult sizes classes indicating that mortality of juveniles between 2005 and 2009 was high.

4.2.2 Size

The consistency in length frequency distributions over many years of surveys is notable. Only toheroa length frequency distributions derived from sieved transects can be regarded as representative of the entire population size structure on Bluecliffs Beach or elsewhere as other surveys tend to underestimate the juvenile proportion of length frequency distributions. In general, they are characterised by a strong mode of juvenile toheroa (when juveniles were sampled) and a mode of adult toheroa, with relatively few of intermediate size. It is possible that sub-adult toheroa inhabit areas of Bluecliffs Beach below low water in the sub-littoral zone, providing an explanation for the consistently low numbers of sub-adult toheroa relative to adults and also the large seasonal variations in numbers during the Meridian Energy surveys. The concept that toheroa migrate between the littoral and sub-littoral zones, where they would fall outside the survey area, has been suggested by a number of workers to explain large fluctuations in Northland toheroa populations (Cassie 1951, 1955, Waugh & Greenway 1967, Greenway 1969), although there is no evidence to support this theory. In contrast, 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 it was concluded that toheroa are not present in the sub-littoral zone in any number. The more likely explanation for the low numbers of sub-adults is that mortality of juveniles is high and that relatively few toheroa survive through to the sub-adult size range. Based on the growth curve constructed using the mark-recapture data, those that do survive grow rapidly and reach maturity at about 1 y. The strong mode between 110 and 145 mm represents the accumulation of multiple cohorts (3–20 y), within which growth has slowed substantially compared to the sub-adults, and mortality is low. There are, however, large seasonal variations.

Toheroa at Bluecliffs Beach have similar size distributions to those at Oreti Beach (Beentjes et al. 2003, Beentjes & Gilbert 2006b). In contrast, size structure of populations of toheroa in Northland differ from those in Southland with sub-adult toheroa being well represented, but large adult (100 mm or over) toheroa largely absent (Morrison & Parkinson 2001, Akroyd et al. 2002, Morrison & Parkinson 2008). The smaller maximum sizes and lower numbers of large toheroa in Northland suggest either a higher natural mortality rate, a slower growth rate, or high levels of illegal fishing.

4.2.3 Spatial distribution

Analysis of historical distributions of toheroa on Bluecliffs Beach indicate that the adult distribution has changed dramatically from the 1960s through to the present. Historically, toheroa were distributed along the entire 11 km of the beach, but in more recent times have been largely aggregated into a 1 km section just west of the Rowallan Burn. Movement between the east and west of the Rowallan Burn is not possible unless toheroa migrate along the sub-littoral zone. The toheroa beds close to the Rowallan Burn are exposed to periods of low salinity and nutrients from the freshwater outfall, probably enhancing plankton growth and thus available food to toheroa. Historically, large beds were also near the Grove Burn (east of the Rowallan Burn), highlighting the importance of freshwater for toheroa distribution on Bluecliffs Beach. Similarly, the densest adult beds are close to the mouth of the Oreti River (Beentjes & Gilbert 2006b, Beentjes 2010).

In 2009 there were only two small beds found and the main bed west of the Rowallan Burn was absent. The spatial distribution strongly associated with substrate type and the loss of sand between 2005 and 2009 has probably resulted in a decline in numbers and aggregated beds.

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Table 1: Strata and transects used in the toheroa survey at Bluecliffs Beach in March 2009.

		Transects		
Stratum	Length (m)	Phase 1	Phase 2	Total
1	998	3	6	9
2	503	3		3
3	507	5		5
4	254	5		5
5	253	5		5
6	758	5	5	10
7	510	3	1	4
8	1 289	3		3
Total	5 072	32	12	44

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

Adult (≥ 100 mm)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	2.33	23.75	23 287	2 628 344
2	0.00	0.00	0.0	0.0
3	0.00	0.00	0.0	0.0
4	0.00	0.00	0.0	0.0
5	0.00	0.00	0.0	0.0
6	1.40	19.60	10 612	1 126 145
7	0.00	0.00	0.0	0.0
8	0.00	0.00	0.0	0.0
Total			33 898	3 754 489
	c.v.		57.2%	
	95% CI		± 37 978	

Sub-adult (40–99 mm)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	1.44	5.028	14 416	5 56 410
2	0.00	0.000	0.0	0.0
3	0.00	0.000	0.0	0.0
4	0.00	0.000	0.0	0.0
5	0.00	0.000	0.0	0.0
6	0.00	0.000	0.0	0.0
7	0.00	0.000	0.0	0.0
8	0.00	0.000	0.0	0.0
Total			14 416	5 56 409
	c.v.		51.7%	
	95% CI		± 14 620	

Juvenile (< 40 mm) (sieved transects)

Stratum	Mean number per transect	Variance	Population estimate	Area squared variance
1	0.00	0.000	0.0	0.0
2	0.00	0.000	0.0	0.0
3	0.00	0.000	0.0	0.0
4	0.00	0.000	0.0	0.0
5	0.50	0.500	1265.0	16 002
6	0.00	0.000	0.0	0.0
7	1.00	2.000	5100.0	260 100
8	0.00	0.000	0.0	0.0
Total			6 365	276 102
	c.v.		82.6%	
	95% CI		± 10 299	

Table 3: Summary of substrate types in quadrats sampled in each stratum on Bluecliffs Beach in March 2009. 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; 7 rocks.

	Percent substrate type							
Strata	1	2	3	4	5	6	7	Total quadrats
1	14	35	30	30	29	16	4	196
2	1	3	8	28	16	8	13	87
3	2	10	8	6	14	21	0	71
4	0	12	13	9	15	4	8	73
5	19	17	11	12	6	12	5	104
6	46	10	26	14	20	16	9	208
7	15	4	4	2	0	11	34	76
8	3	9	0	0	1	12	27	43
Total quadrats	195	69	178	101	163	75	77	858
Percent of beach	23	8	21	12	19	9	9	

Table 4: Estimated customary take of toheroa from Bluecliffs Beach for calendar years 1998–2004. Data are from customary authorisation permits provided quarterly to the Ministry of Fisheries.

Year	Numbers
1998	90
1999	263
2000	150
2001	307
2002	229
2003	402
2004	189

Table 5: Toheroa surveys of Bluecliffs Beach, including the 2009 survey. Transect 1 begins at east end.

Survey number	Survey date	Survey design	Transects	Dist. between transects (m)	Coverage: Dist. (km)	Coverage: Physical area	Reference	Funder	Target size
1	May-1966	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
2	Dec-1966	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
3	Apr-1967	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
4	Nov-1967	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
5	Mar-1968	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
6	Dec-1968	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
7	Mar-1969	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
8	Nov-1969	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
9	Mar-1970	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1970	MAF	adult
10	Oct-1970	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1972	MAF	adult
11	Feb-1971	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	Street 1972	MAF	adult
12	Dec-1971	Systematic	1–34	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
13	May-1972	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
14	Jun-1973	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
15	Mar-1974	Systematic	5–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
16	Oct-1974	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
17	May-1975	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
18	Jul-1976	Systematic	4–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
19	Jun-1977	Systematic	1–26	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
20	May-1978	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
21	Oct-1978	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
22	Apr-1979	Systematic	1–36	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
23	Mar-1980	Systematic	1–35	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
24	Nov-1980	Systematic	10–14	321	11	Rowallan Burn to 1..3 km west	undocumented	MAF	adult
25	May-1981	Systematic	1–36	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
26	Jun-1982	Systematic	1–36	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
27	Feb-1984	Systematic	1–36	321	11	1.6 km east of Grove Burn to HumpBurn	undocumented	MAF	adult
28	Jun-1985	Systematic	1–19	321	6.1	1.6 km east of Grove Burn to east of Waikoau*	undocumented	MAF	adult
29	Sep-1987	Systematic	5–19	321	6.1	T#5 @Grove Burn	undocumented	MAF	adult
30	Mar-1990	Systematic	1–16	330	5.3	T#1 @Grove Burn**	McKinnon & Olsen 1994	MAF	adult
31	Mar-1997	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 1997a	Meridian	adult
32	Jul-1997	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 1997b	Meridian	adult and juv.
33	Jan-1998	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 1999	Meridian	adult

Table 5 – *continued*

Survey number	Survey date	Survey design	Transects	Dist. between transects (m)	Coverage Dist. (km)	Physical area	Reference	Funder	Target size
34	Jan-1998	Random stratified	1–40	Variable	5.07	T#1 @Grove Burn	Carbines & Breen 1999	MFish	adult and juv.
35	Aug-1998	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 1999	Meridian	adult and juv.
36	Feb-1999	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 2000a	Meridian	adult
37	Aug-1999	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 2000a	Meridian	adult and juv.
38	Jan-2000	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 2000b	Meridian	adult
39	Jul-2000	Systematic	1–19	250	4.5	T#1 @Grove Burn	Carbines 2000b	Meridian	adult and juv.
40	Feb-2001	Systematic	1–19	250	4.5	T#1 @Grove Burn	Beentjes & Carbines 2001	Meridian	adult
41	Aug-2001	Systematic	1–19	250	4.5	T#1 @Grove Burn	Beentjes & Carbines 2001	Meridian	adult and juv.
42	Feb-2005	Random stratified	1–47	Variable	5.07	T#1 @Grove Burn	Beentjes & Gilbert 2006a	MFish	adult and juv.
43	Mar-2009	Random stratified	1–44	Variable	5.07	T#1 @Grove Burn	This report	MFish	adult and juv.

* West of T19 now stones and western transects can no longer be surveyed
**Transect numbering changed on this survey and surveys thereafter

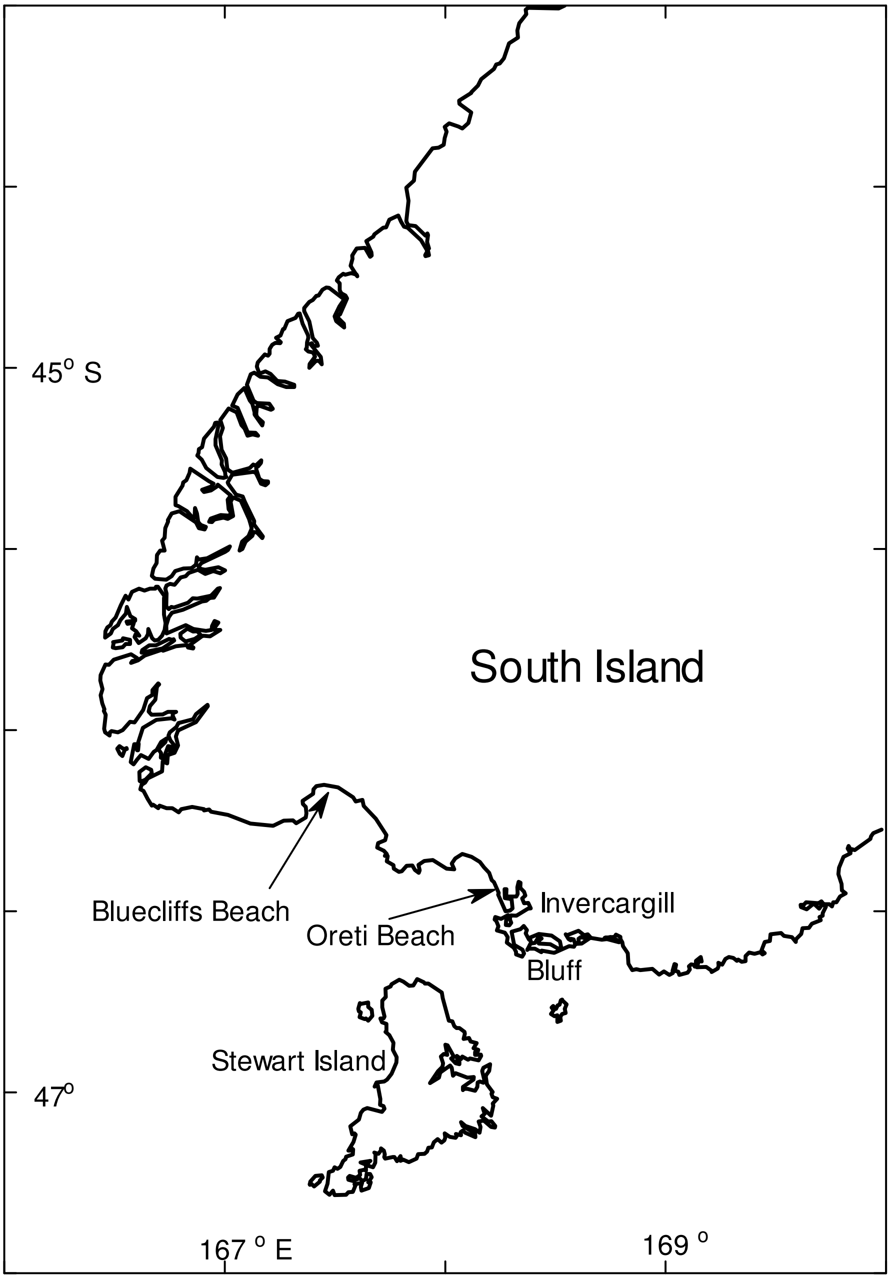


Figure 1: Map of Southland showing the toheroa survey locations at Bluecliffs Beach and Oreti Beach.

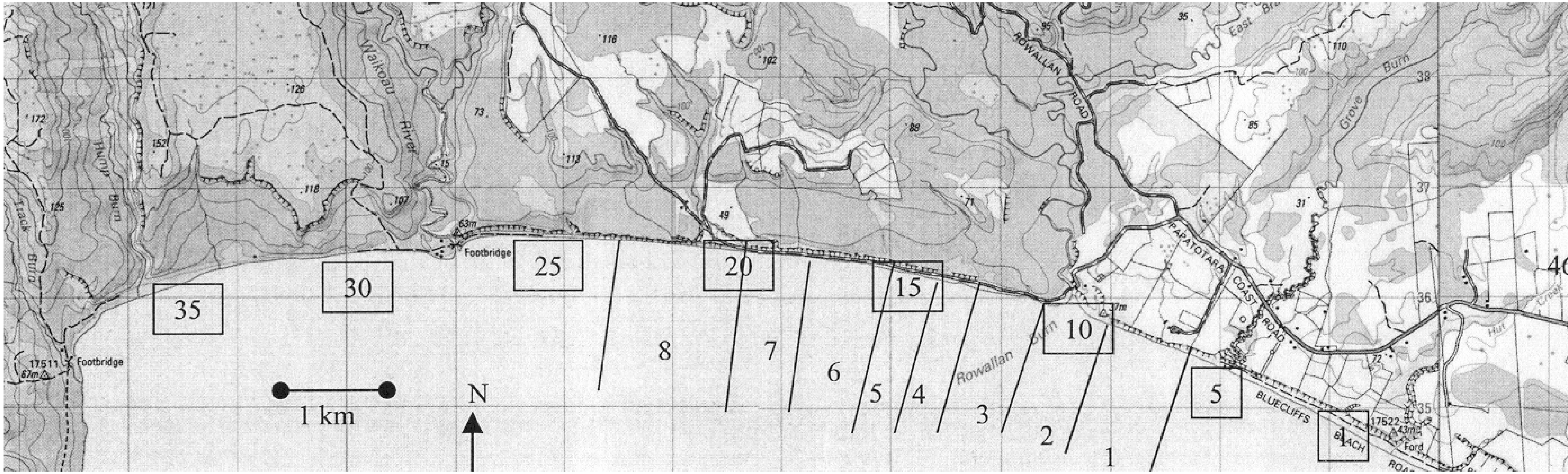


Figure 2: Map of Bluecliffs Beach (within Te Waewae Bay). The eight strata used for the 1998, 2005, and 2009 random stratified transect surveys are shown as well as the transect locations (1–35, bordered) for the historic systematic transect surveys. Map reproduced by permission of Land Information New Zealand.

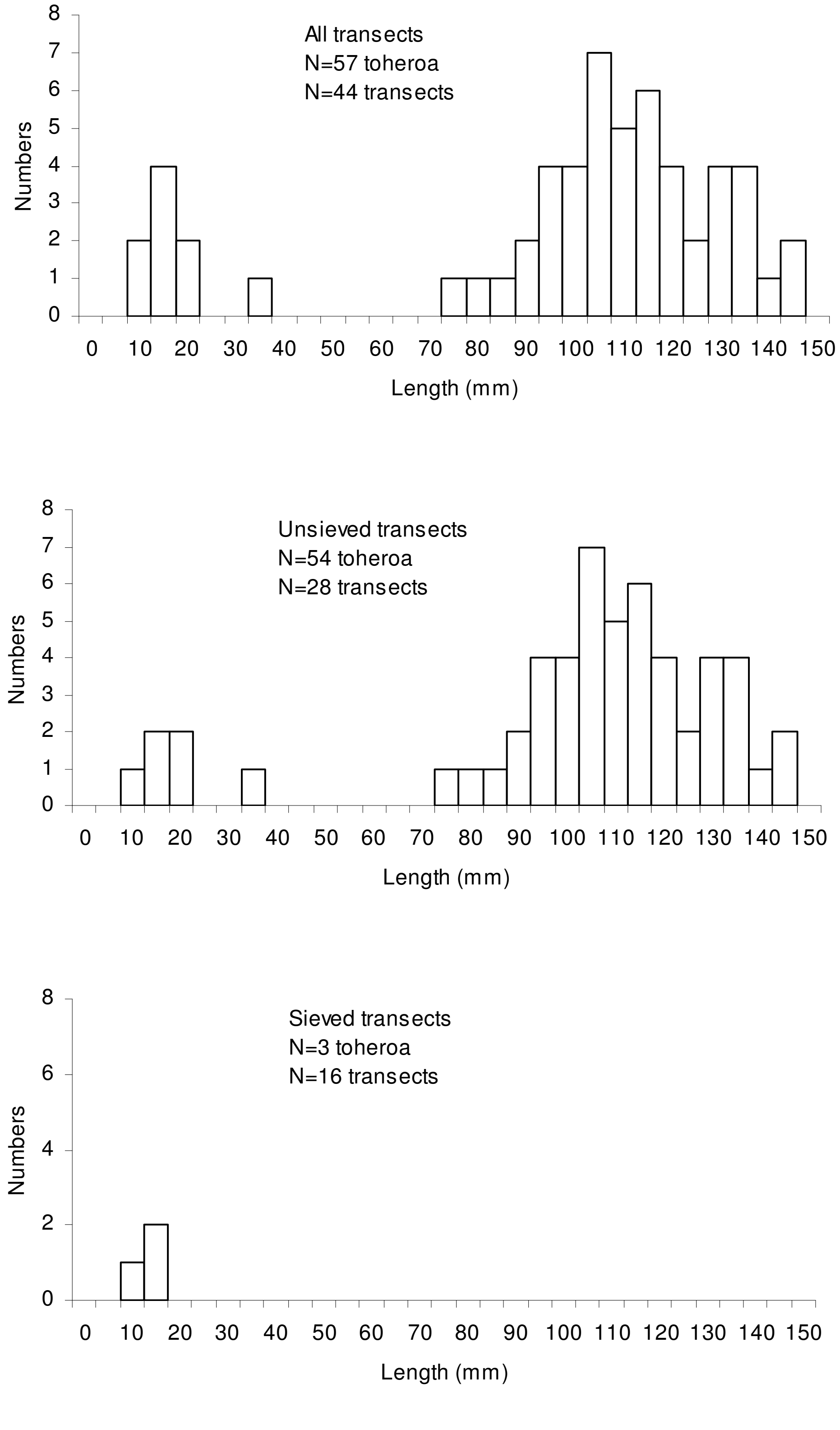


Figure 3: Length frequency distribution of sampled toheroa on Bluecliffs Beach in March 2009 from all, non-sieved, and sieved transects. Scale: 5 = 1–5 mm, 10=6–10 mm) etc.

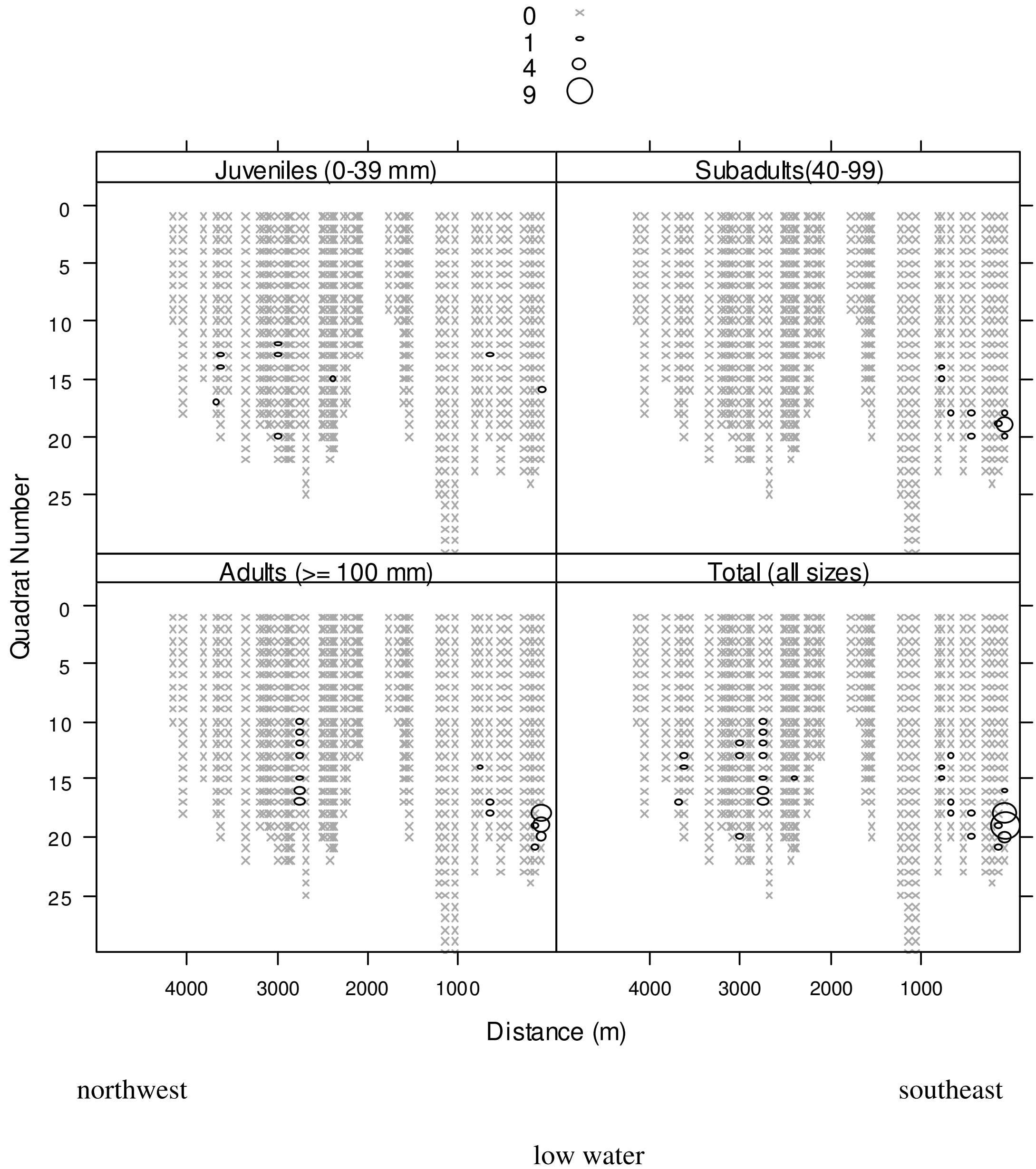


Figure 4: Distribution bubble plots of toheroa on Bluecliffs Beach from the March 2009 survey. Distributions are shown for all toheroa (n = 57), adults (N = 35), sub-adults (N = 13), and juveniles (N = 9). The bubbles are proportional to the number of toheroa found at each quadrat. The maximum number was 10 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, and covered an area of the beach overlapping with historical transects 5 to 20.

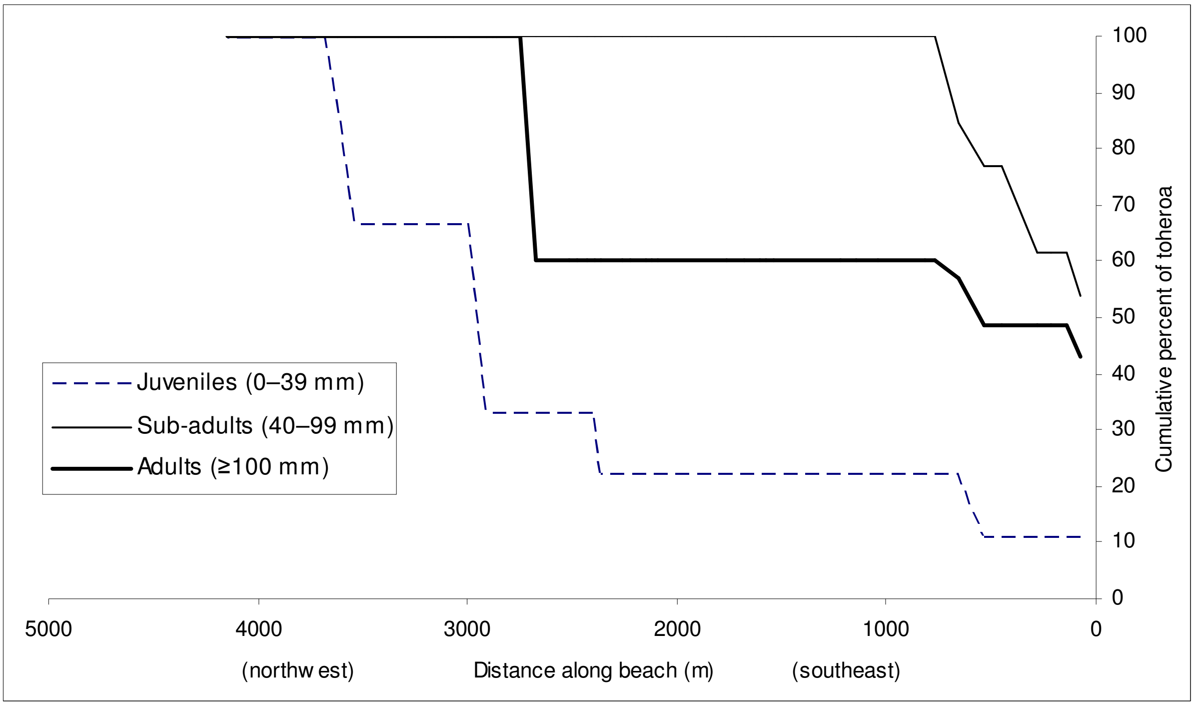


Figure 5: Cumulative distribution of toheroa along Bluecliffs Beach in March 2009 for the three size groups. Distance is from the southeast boundary of stratum 1 near the Grove Burn.

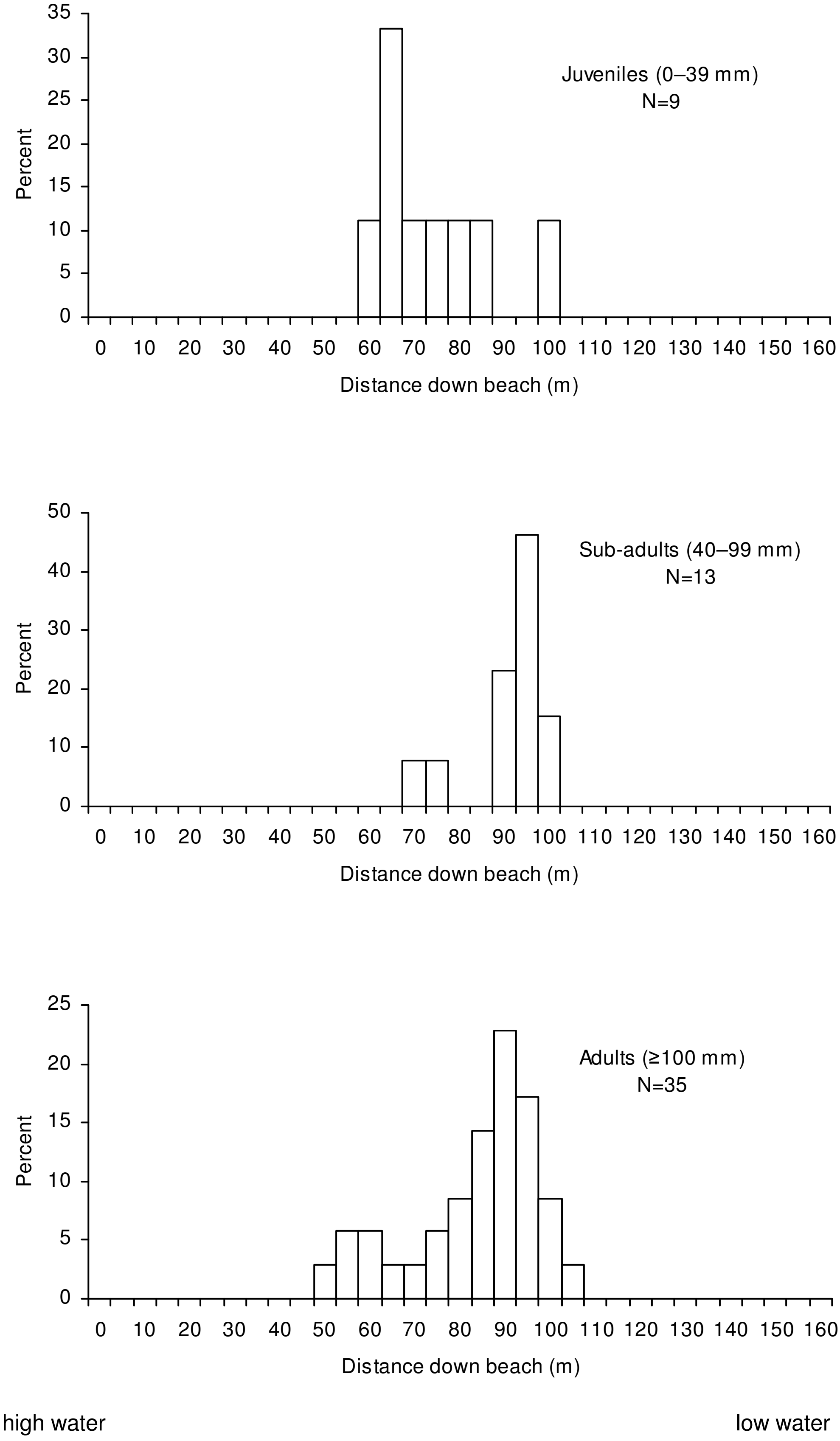
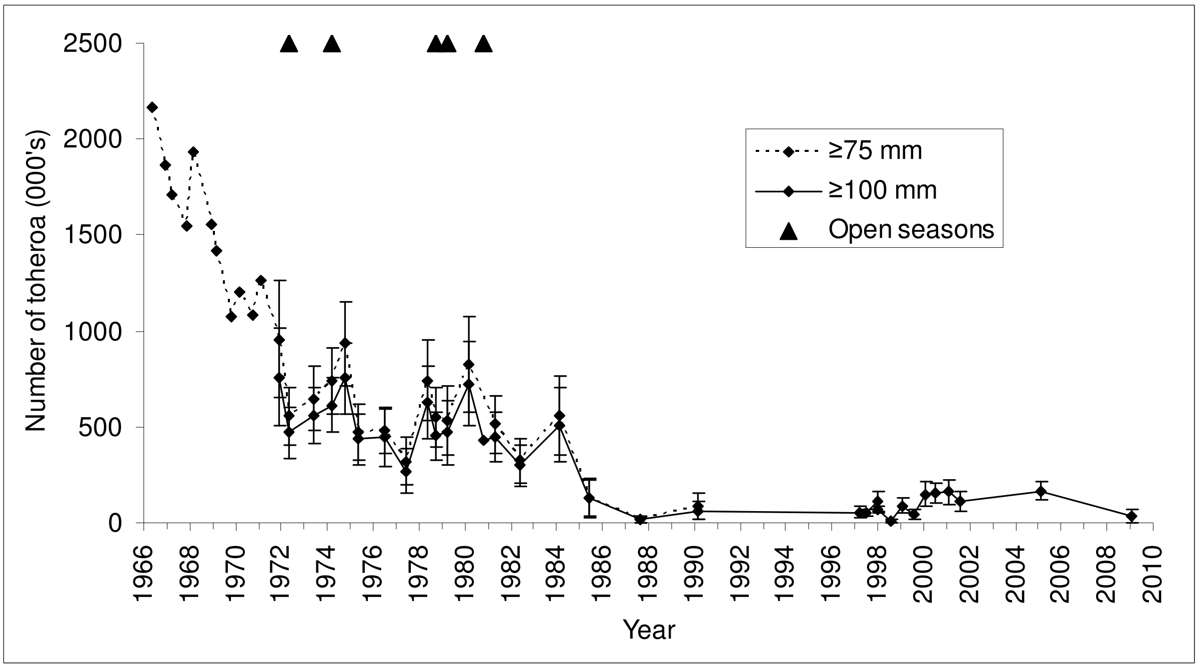


Figure 6: Proportion of toheroa population versus distance down the beach for adult, subadult, and juvenile toheroa on Bluecliffs Beach in March 2009.



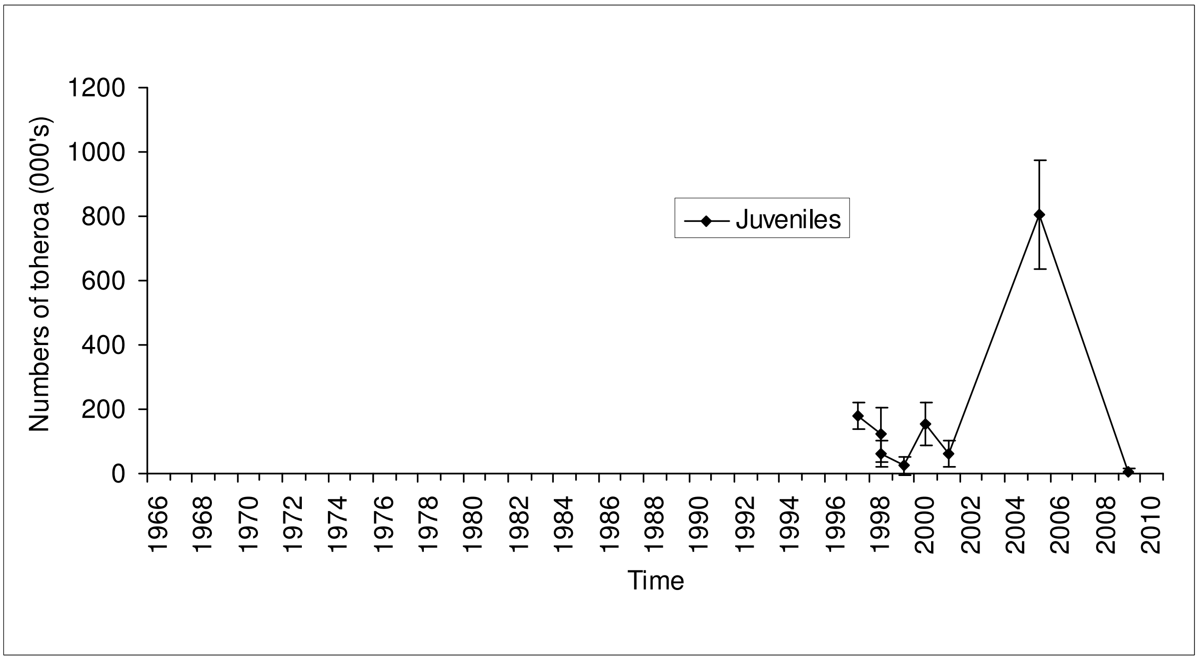


Figure 7: Bluecliffs Beach population number estimates for toheroa ≥75 mm (1966–1990), ≥100 mm (1971–2009) (top panel), and juveniles (1997–2009) (bottom panel). Juveniles defined as <40 mm for Ministry of Fisheries January 1998 and 2005 survey, and <45 mm for others (= Meridian Energy surveys). 95% confidence intervals are shown for surveys from 1971 onward.

Population estimate sources:
May 1966– Feb 1971 (Street 1972)
Dec 1971–Mar 1990 (estimated in this report)
Mar 1997–Aug 2001 (Meridian Energy Ltd)
Jan 1998 MFish survey (Carbines & Breen 1999)
Nov 1980 (McKinnon & Olsen 1994)
Feb 2005 (Beentjes & Gilbert 2006)
Mar 2009 (this report)

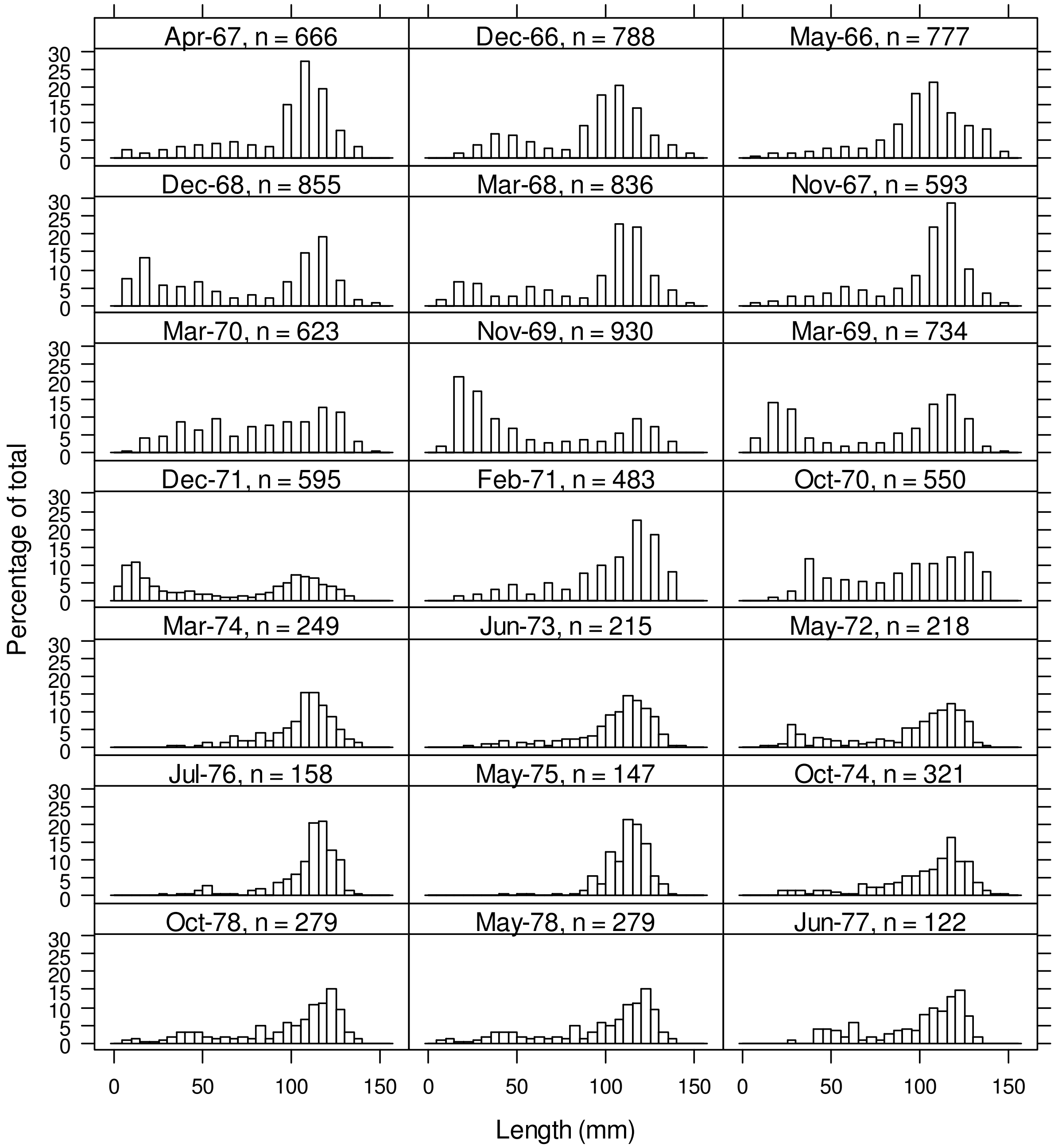


Figure 8: Length frequency distributions of toheroa from Ministry of Fisheries Bluecliffs Beach surveys between 1966 and 1990. All adult surveys. n, number of individuals measured.

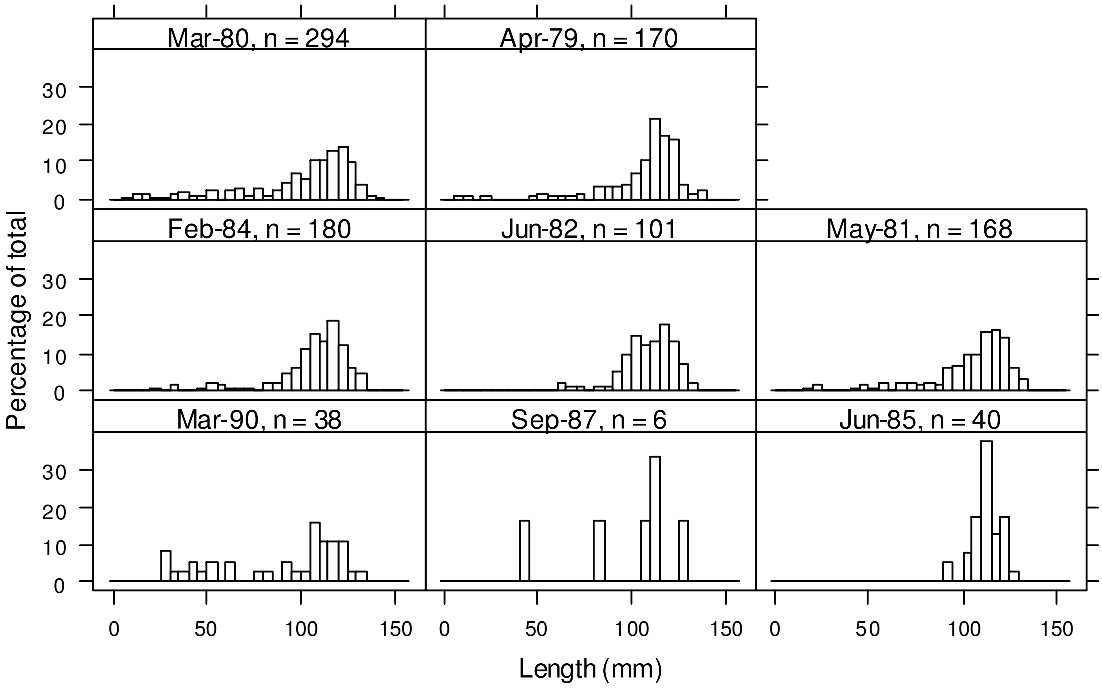


Figure 8 – ***continued***

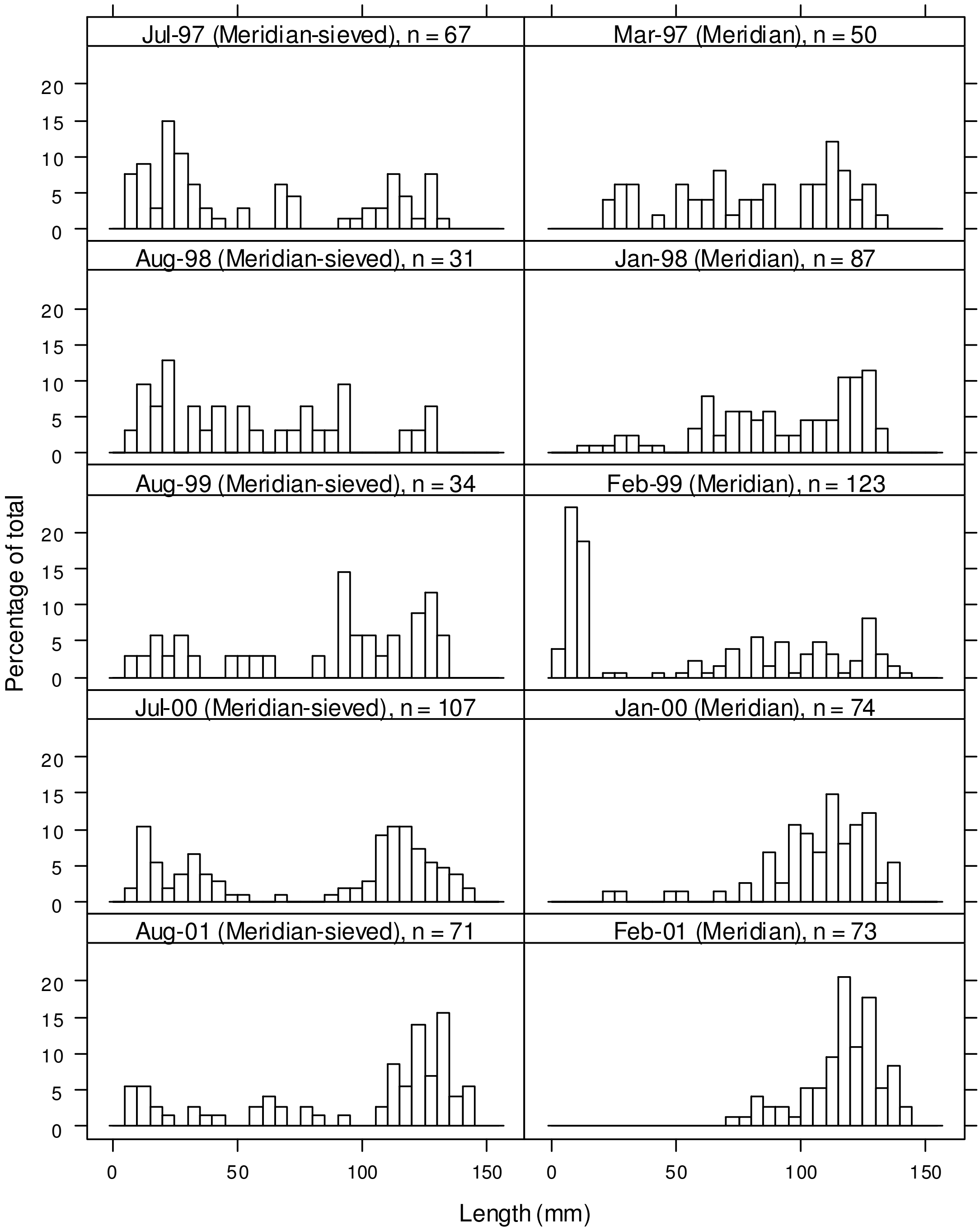


Figure 9: Length frequency distributions of toheroa on Bluecliffs Beach from surveys between 1997 and 2001 funded by Meridian Energy Ltd. During the winter surveys every second transect was sieved and the length distributions shown include data from both sieved and unsieved transects.

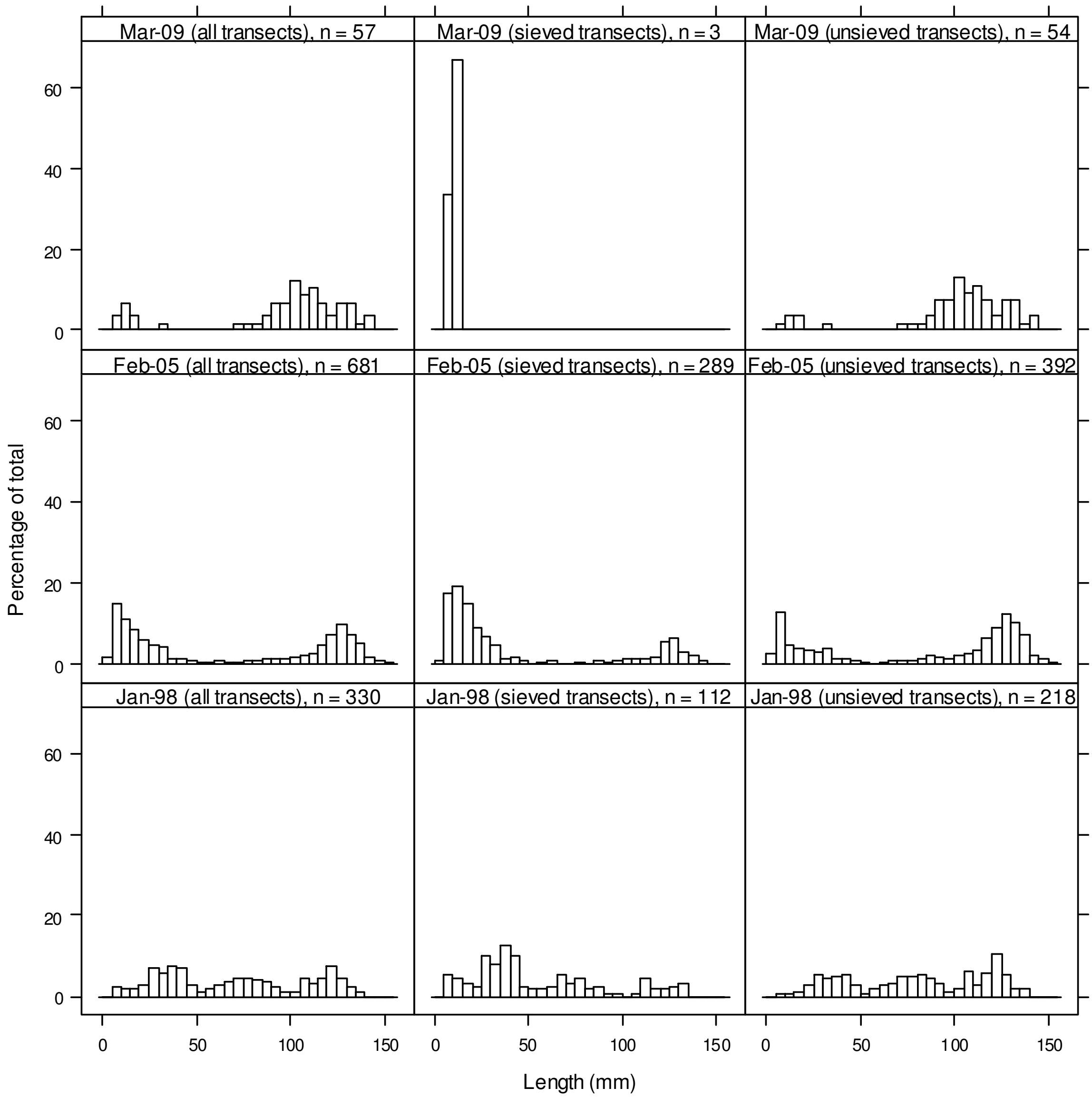


Figure 10: Length frequency distributions of toheroa on Bluecliffs Beach from 1998, 2005, and 2009 surveys, partitioned by method of sampling. Surveys used random stratified transects. All, all transects; sieved, sieved transects; unsieved, unsieved transects.

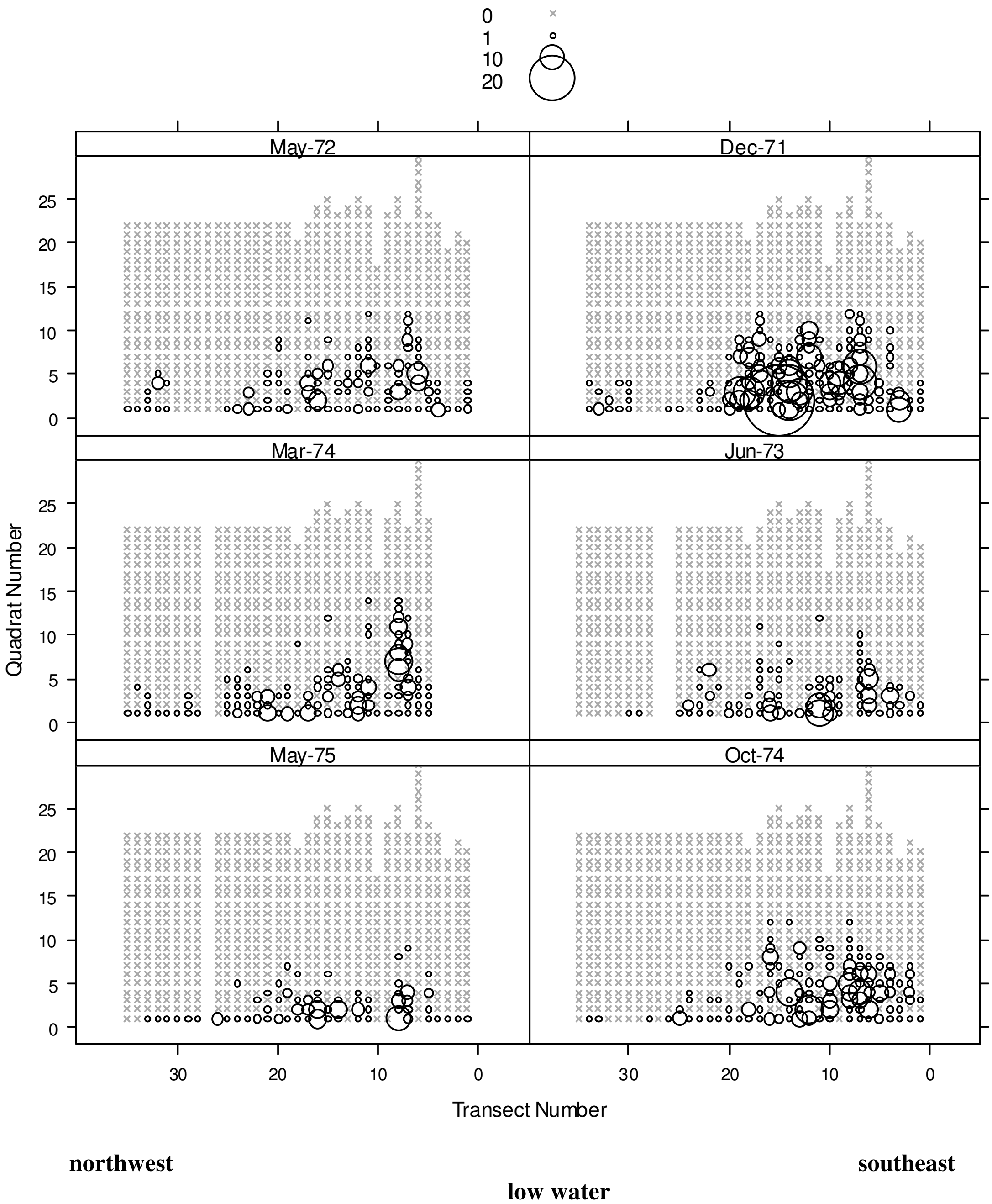


Figure 11: Distribution bubble plots of toheroa (all sizes) on Bluecliffs Beach from surveys carried out between 1971 and 1990. All surveys used systematic transects along the beach targeting adults. Maximum toheroa per quadrat was 33. Grey crosses indicate where samples were taken, but no toheroa were recorded.

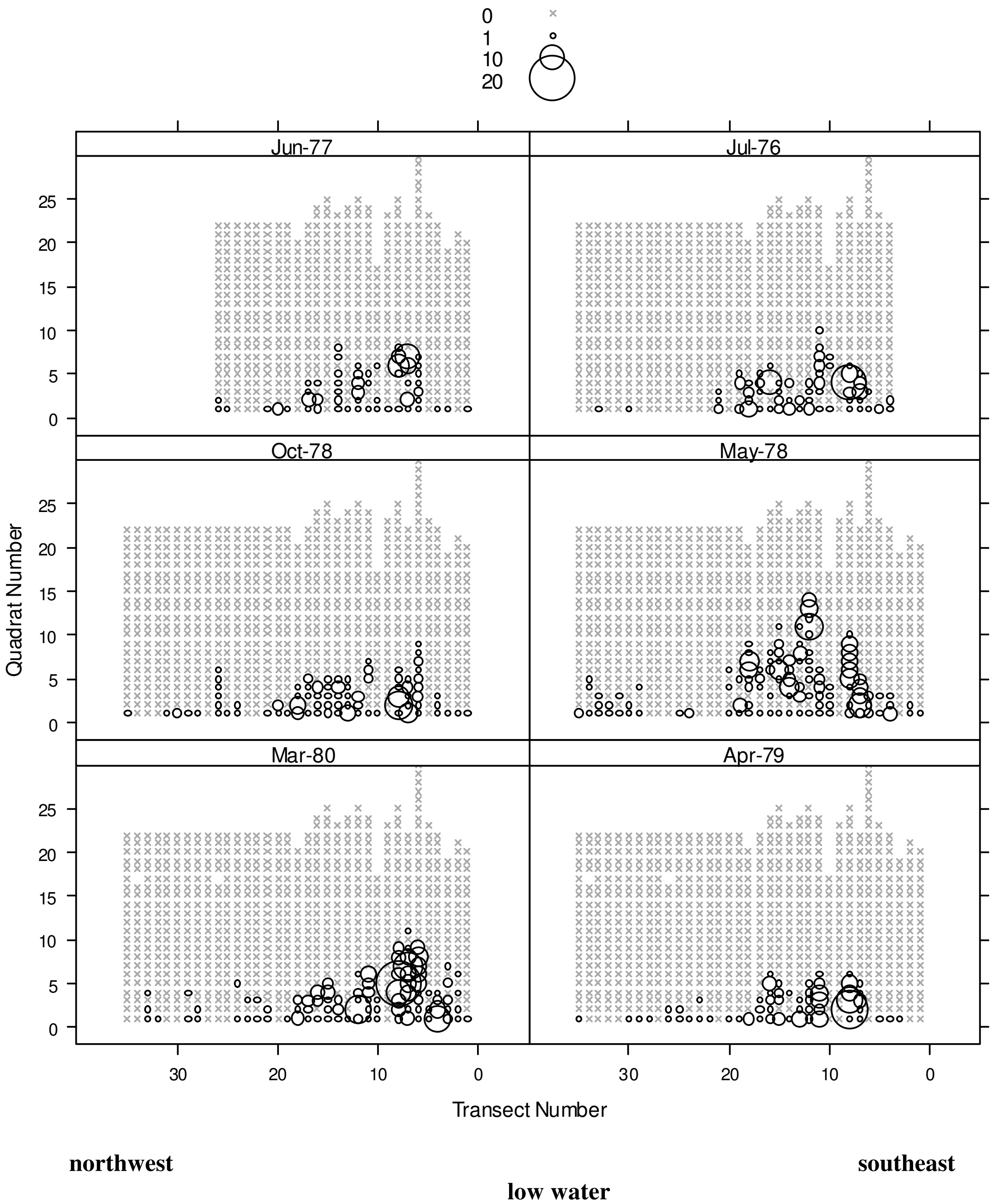
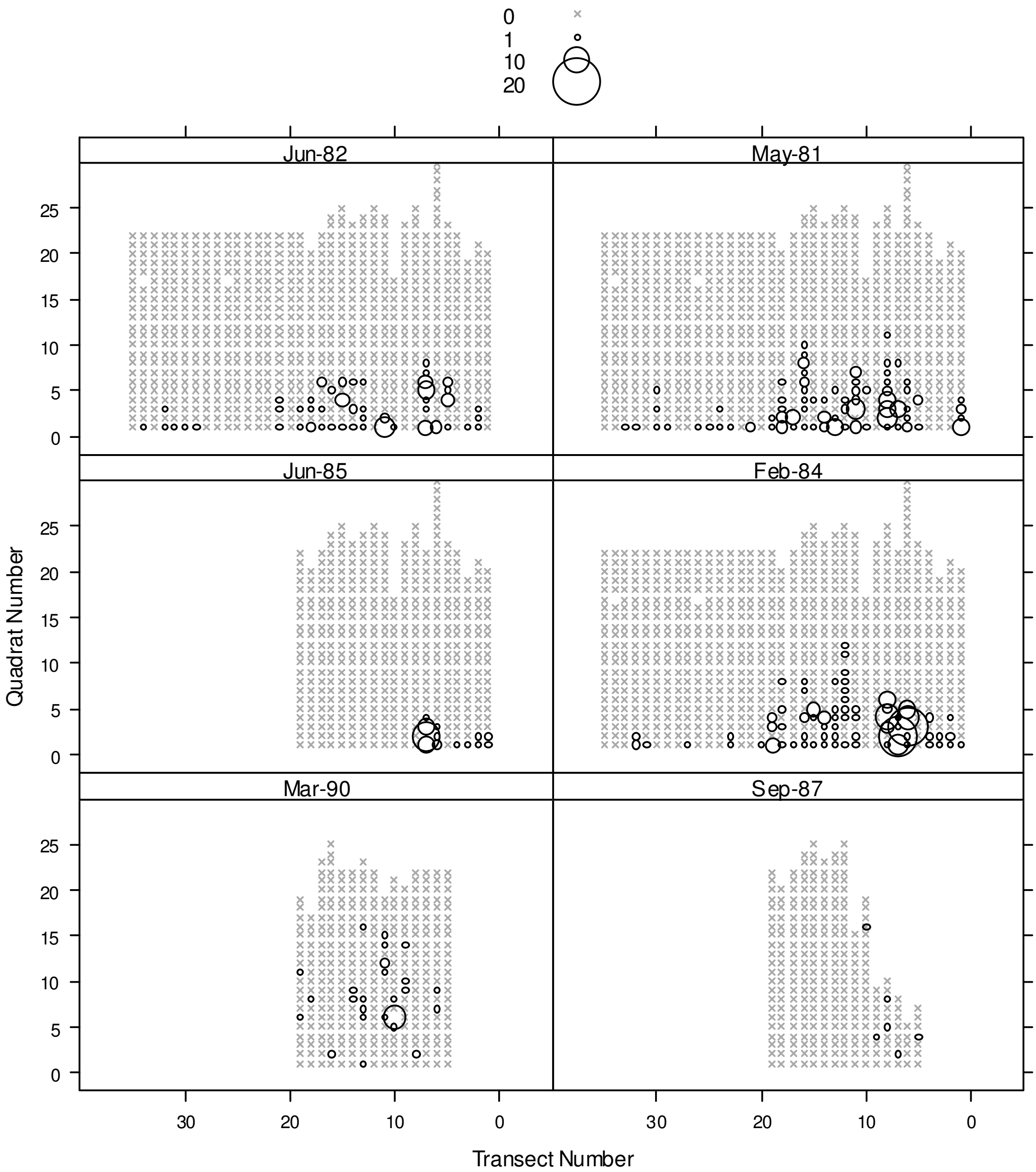


Figure 11 – ***continued***



northwest **southeast**
low water

Figure 11 – ***continued***

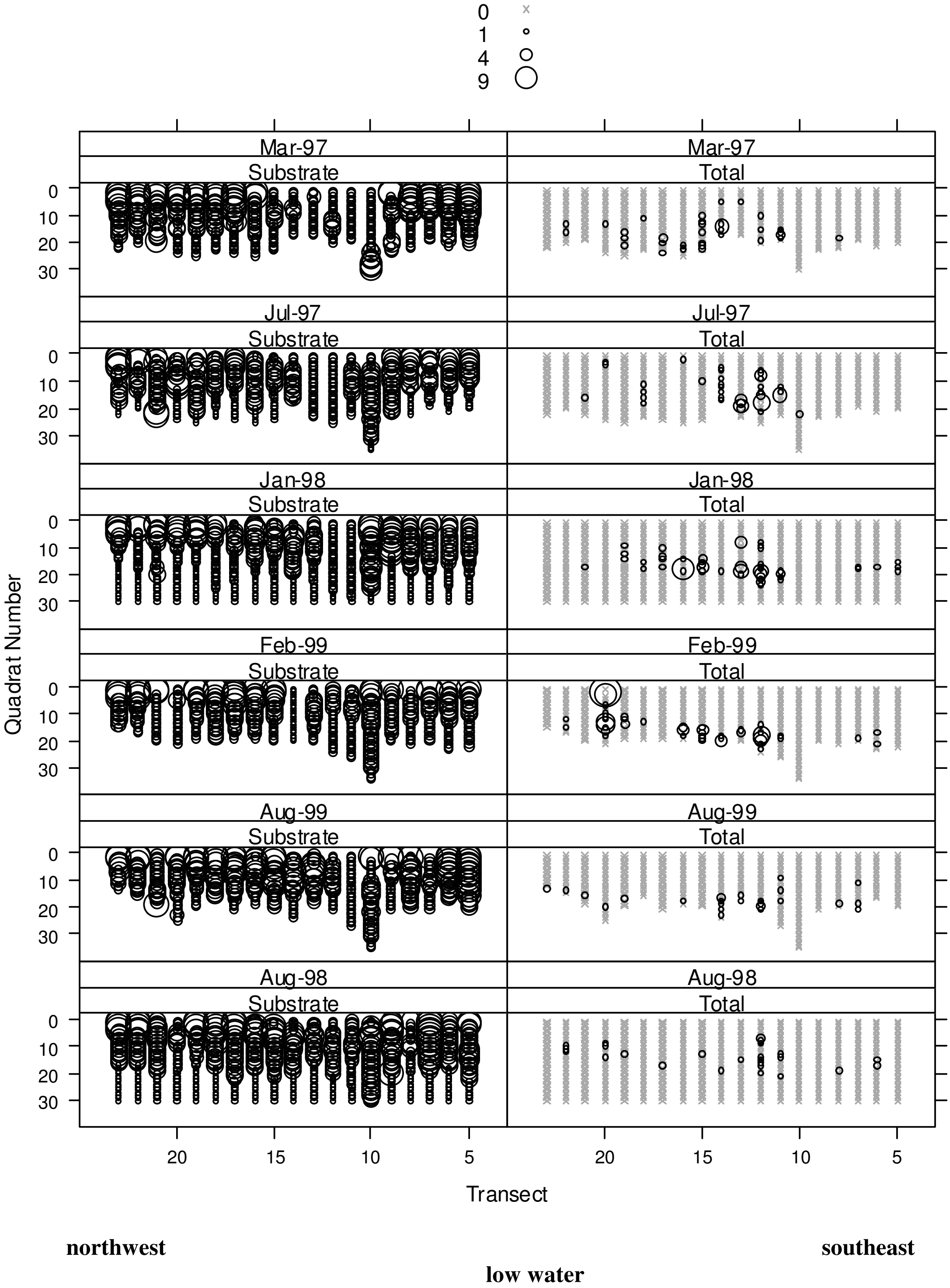


Figure 12: Distribution bubble plots of toheroa number (right) and substrate type (left) on Bluecliffs Beach from surveys carried out between 1997 and 2001 for Meridian Energy Ltd. Bubble size is proportional to toheroa number where maximum number per quadrat is 33, and grey crosses indicate where samples were taken, but no toheroa were recorded. Bubble size is also proportional to substrate coarseness where 1 represents fine sand, increasing in coarseness to 7 which represents mainly rocks (see Methods). All surveys used systematic transects along the beach with winter surveys also including sieved transects.

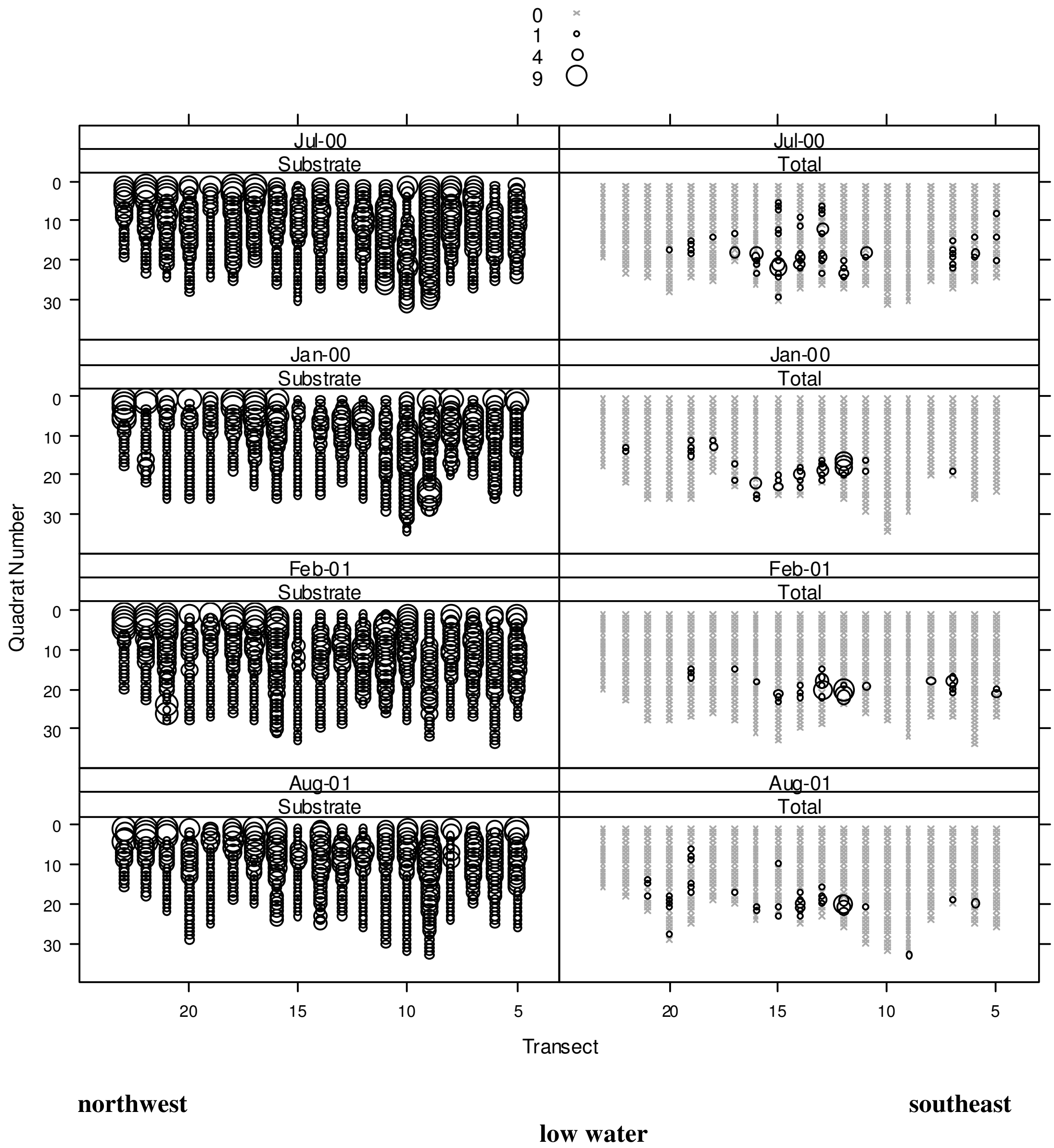
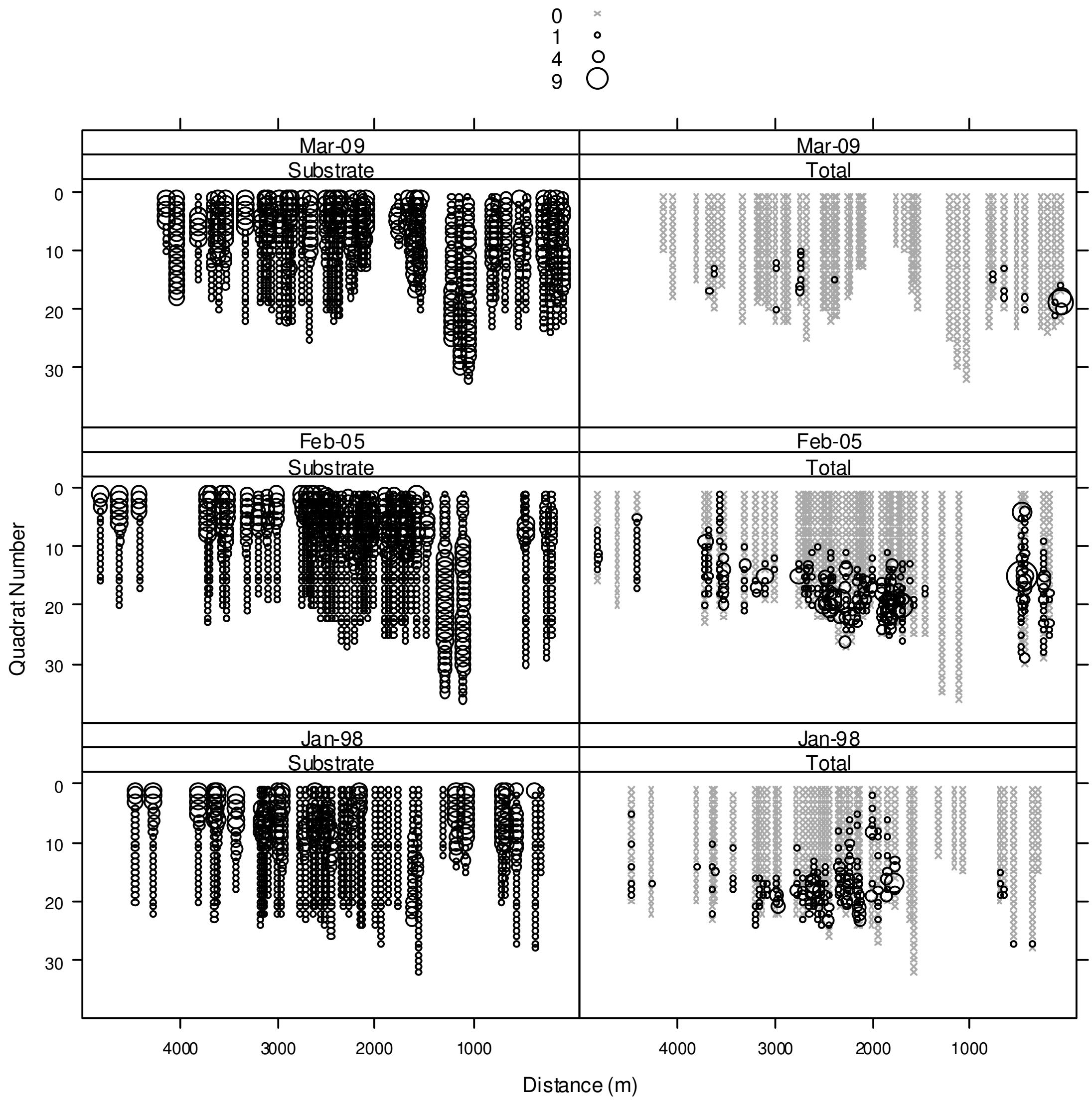


Figure 12 – ***continued***



northwest **southeast**

low water

Figure 13: Distribution bubble plots of toheroa (all sizes) (right) and substrate type (left) on Bluecliffs Beach from the Ministry of Fisheries 1998, 2005, and 2009 surveys. Bubble size is proportional to toheroa number where total number of toheroa and maximum number per quadrat were as follows (1998, N = 330, max = 8; 2005, N = 681, max = 13; 2009, N = 57, max = 10), and grey crosses indicate where samples were taken, but no toheroa were recorded. Bubble size is also proportional to substrate coarseness where 1 represents fine sand, increasing in coarseness to 7 which represents mainly rocks (see Methods). These surveys used a random stratified transect design, targeting all sizes.

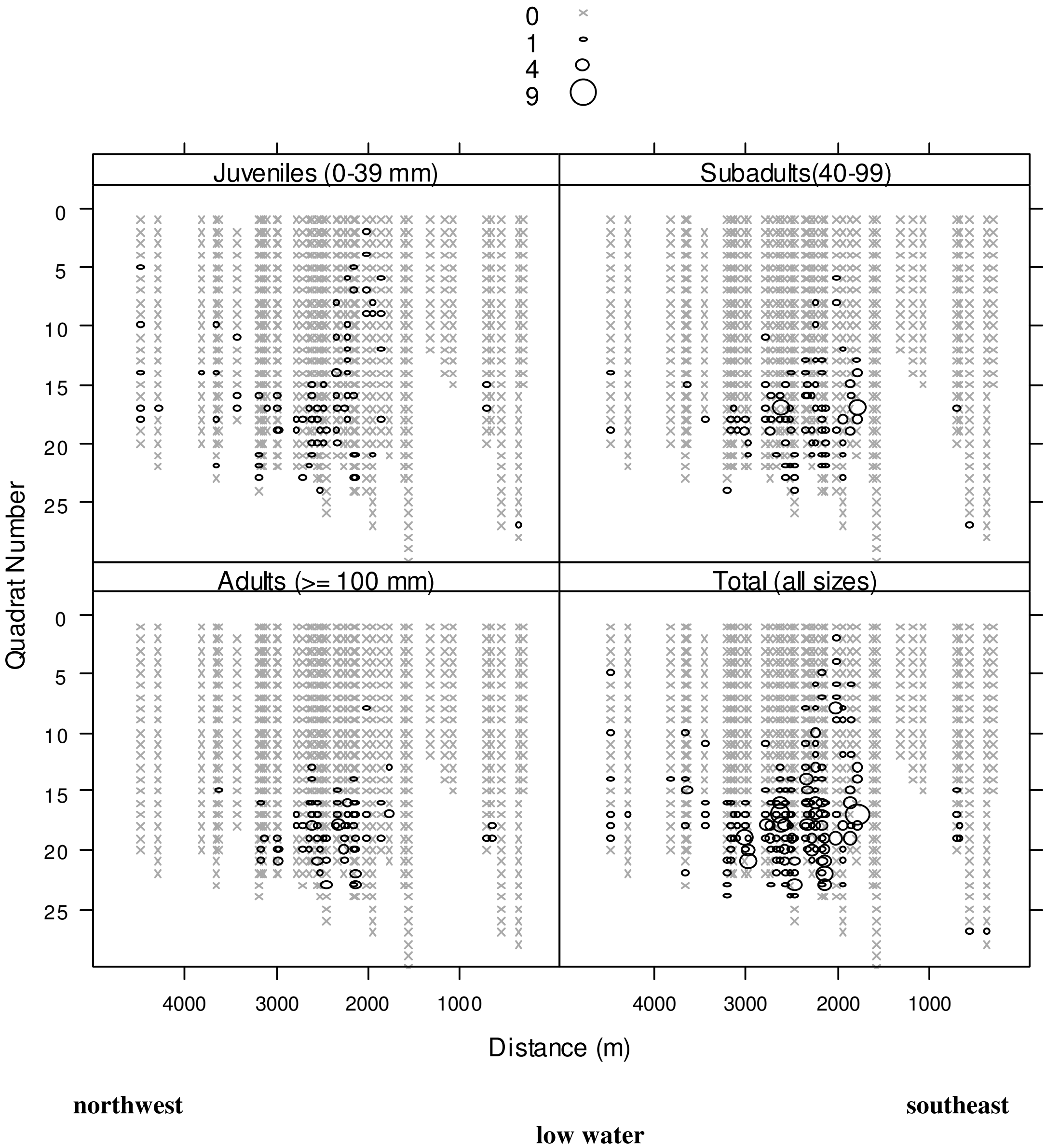


Figure 14: Distribution plots of toheroa on Bluecliffs Beach from the January 1998 survey. Distributions are shown for all toheroa (N = 330), adults (N = 98), subadults (N = 131), and juveniles (N = 101). The bubbles are proportional to the number of toheroa found at each quadrat where the maximum number per quadrat = 8, and grey crosses indicate where samples were taken, but no toheroa were recorded. The survey used a random stratified transect design, targeting all sizes.

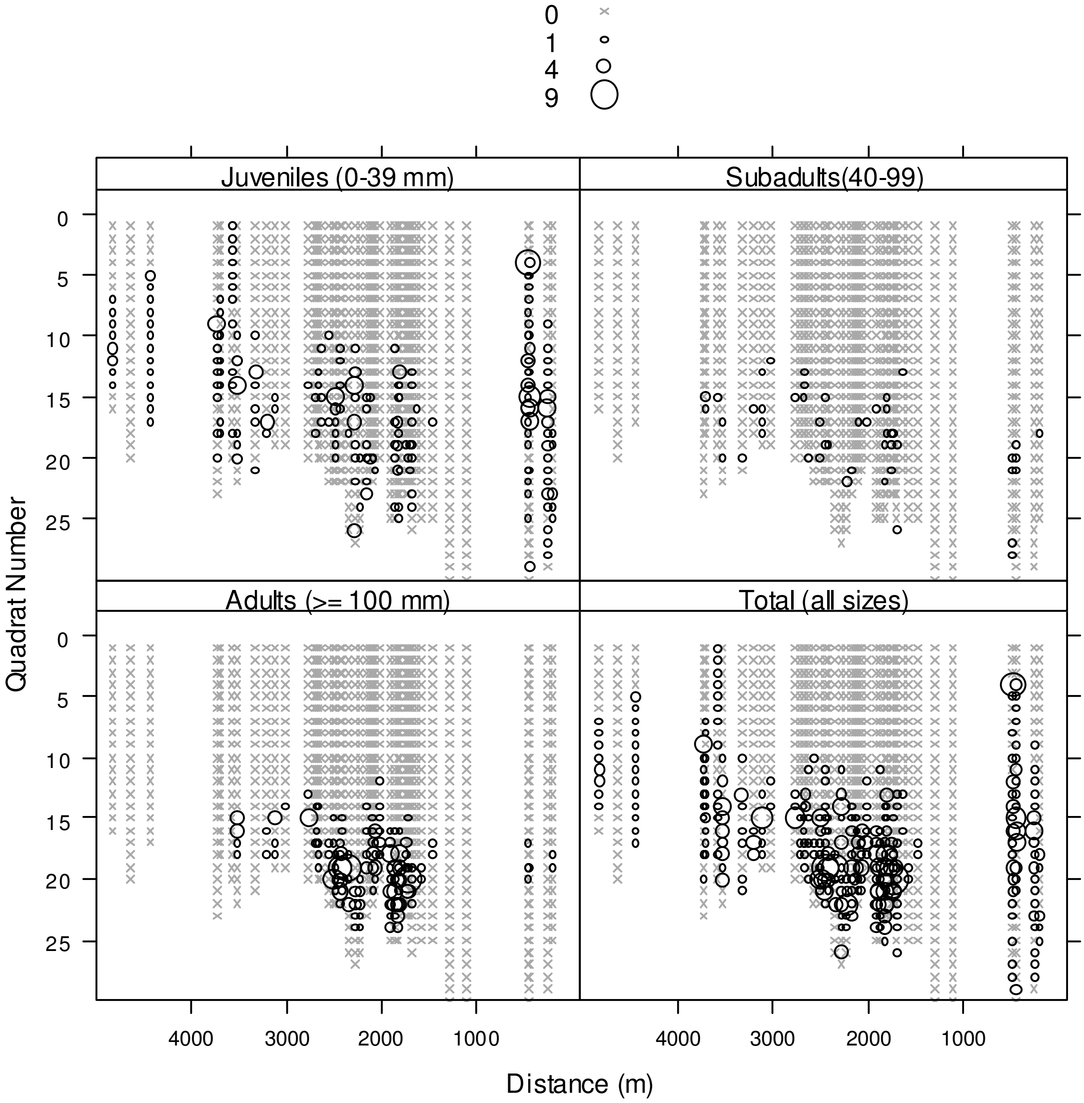


Figure 15: Distribution plots of toheroa on Bluecliffs Beach from the February 2005 survey. Distributions are shown for all toheroa (N = 681), adults (N = 345), subadults (N = 53), and juveniles (N = 283). The bubbles are proportional to the number of toheroa found at each quadrat where the maximum number per quadrat = 13. The dots indicate that no toheroa were found at that quadrat. The survey used a random stratified transect design, targeting all sizes.

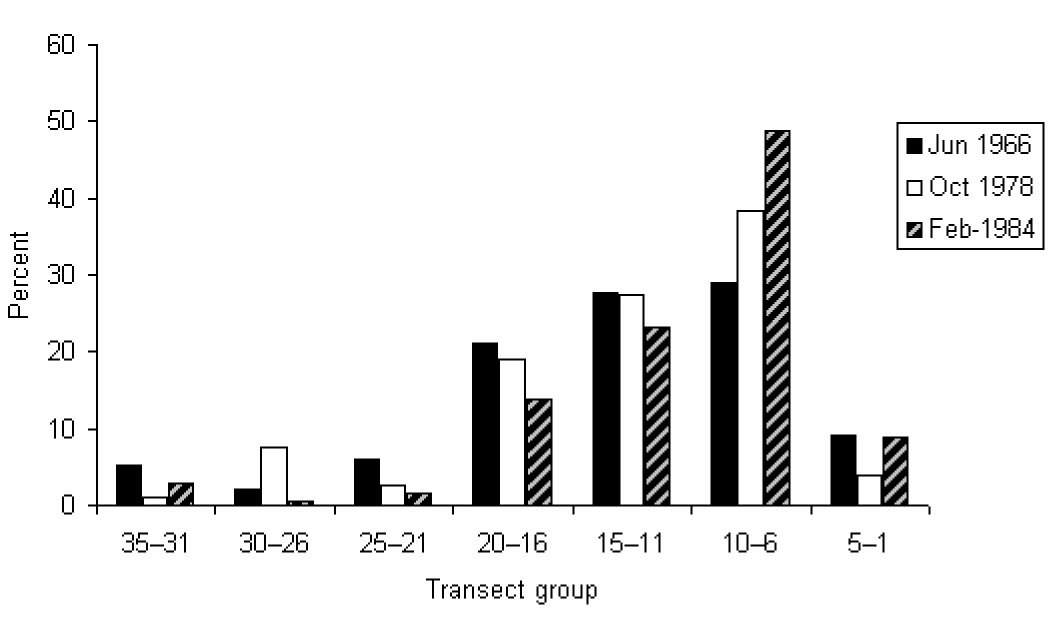


Figure 16: Historical distribution of toheroa on Bluecliffs Beach from surveys in June 1966, October 1977, and February 1984 (see Figure 2 for transect locations).

Appendix 1. Coordinates (Geodetic Datum 1984) of the southeast strata boundaries used in the Bluecliffs Beach March 2009 toheroa survey.

Strata	Latitude	Longitude
1	46° 9' 43.199"	167° 31' 53.039"
2	46° 9' 29.159"	167° 31' 10.920"
3	46° 9' 24.120"	167° 30' 48.599"
4	46° 9' 19.079"	167° 30' 25.920"
5	46° 9' 16.919"	167° 30' 14.759"
6	46° 9' 14.759"	167° 30' 3.240"
7	46° 9' 8.640"	167° 29' 28.679"
8	46° 9' 6.480"	167° 29' 5.280"