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EXECUTIVE SUMMARY

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A toheroa survey of Oreti Beach was carried out between 25 February and 1 March 2002 with 60 transects being sampled (16 sieved and 44 non-sieved). A two phase random survey design was used with 45 transects in phase 1 and 15 in phase 2. The population estimates were 612 000 legal-sized toheroa (100 mm and over), 298 000 subadults (40–99 mm), and 10 000 000 juveniles (under 40 mm) with c.v.s of 12%, 11%, and 13%, respectively. The required survey target c.v. for legal-sized toheroa was 20%. Historical population estimates were made for toheroa 80 mm and over and the 2002 estimate was 720 000 with c.v. of 12 %. The length frequency distribution was characterised by a strong mode of juvenile toheroa (under 40 mm), and a less pronounced mode from 100 to 125 mm, with relatively few subadult toheroa between these modes. Toheroa were found in all strata, but were most abundant in the southeast end of Oreti Beach, with a trend of declining density towards the northwest end of the beach. The highest mean number of toheroa per transect was in stratum 1 for all size groups. The size groups occupied different height ranges between high and low water with legal-sized toheroa from about 100 to 190 m (mean = 140 m) below high water, subadult 65 to 175 m (mean = 120 m), and juvenile 10 to 200 m (mean 80 m). Although juvenile toheroa occupied a wide vertical range, the smaller sized toheroa were most abundant higher on the beach and larger toheroa more abundant closer to low water. Of the quadrats sampled, 95% were sand with a further 3.4 % contained coarse sand. Only stratum 7 had quadrats containing gravel and stones. A total of 61 toheroa with mean length of 104 mm (range 55–120 mm) were notched and returned to the sand.

A yield per recruit analysis was carried out using data from northern toheroa populations to obtain some of the required parameters. Because the annual weight increase of toheroa above the minimum legal size was insufficient to compensate for the loss due to natural mortality, the theoretical maximum yield occurred at 100% exploitation. We suggest, however, an exploitation rate of 30%. Based on recent abundance surveys, this would produce a yield of 81 000 toheroa, equal to 15 t of catch and lead to a population of mature toheroa, on average, 47% of virgin biomass. More reliable estimates could be achieved if age and maturity parameters were directly estimated for Oreti Beach toheroa.

A total of 28 toheroa surveys of Oreti Beach from 1969 to 1998 were reviewed. Estimates of numbers of adult toheroa (80 mm or over) on Oreti Beach indicated a trend of declining abundance beginning in 1985 when the population almost halved in two years from about 2 to 1 million and then continued over the next 10 years until 1996 when the population was estimated at only 400 000. The current population is still low compared with the 1970s and early 1980s. In general the size composition of historical surveys was characterised by a strong mode of juvenile toheroa (where juveniles were sampled) and a second mode of adult toheroa, with relatively few of intermediate size. This indicates that mortality of juveniles is probably high and that relatively few toheroa survive through to the subadult size range (40–99 mm). The strong mode between 100 and 140 mm may represent multiple cohorts which 'stack up', and where growth has slowed substantially compared to the subadults. Analysis of historical distributions of toheroa on Oreti Beach indicate that the southeast end of the beach near the Oreti River 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*) are endemic to New Zealand and found intertidally on beaches fully exposed to surf, with fine sand, and with enough moisture to prevent desiccation at low tide (Rapson 1952, Cassie 1955). The main toheroa populations are found in Northland, on the Kapiti coast, and in Southland (Oreti Beach and Te Waewae Bay) (Cassie 1955). Toheroa have been subjected to intensive harvesting over the last 100 years (Cassie 1955, McKinnon & Olsen 1994) and fishing is now prohibited throughout New Zealand in response to declining populations (see Morrison & Parkinson (2001) for a review of the fishery). The only current harvest is through Maori customary take and occasional one-day recreational seasons at Oreti Beach, the last of which was in 1993.

Twenty-eight surveys have been carried out at Oreti Beach since 1969 providing estimates of toheroa abundance, size composition, and distribution. Estimates of the numbers of adult toheroa (80 mm or over) on Oreti Beach in 1996 and 1998 (the two most recent surveys) were about 400 000 and 700 000 toheroa, respectively, indicating that the population has declined markedly since the 1970s and early 1980s when the population fluctuated between 1 and 2.5 million.

Before any further one-day or limited recreational seasons are considered for Oreti Beach it is advisable to determine both the status of the population and a sustainable yield. Yield per recruit analysis has not been attempted for any toheroa population in New Zealand.

This report presents the results of a toheroa survey of Oreti Beach in 2002, a yield per recruit analysis, and a review of toheroa length frequency, abundance, and distribution from historic surveys of Oreti Beach.

The objectives of the survey were as follows:

1. To estimate the abundance of legal-sized (100 mm or over), sub-legal (40–99 mm) and juvenile (under 40 mm) toheroa on Oreti Beach. The target c.v. for the estimate of absolute abundance of legal-sized toheroa is 20%.
2. To estimate the sustainable yield of legal-sized toheroa on Oreti Beach.
3. 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.

2. METHODS

2.1 2002 Oreti Beach survey

2.1.1 Survey design

The Oreti Beach toheroa survey used a two phase, stratified random transect design (Francis 1984). The survey area covered a 17 km stretch of beach from the mouth of the Oreti River in the southeast to the Waimatuku River in the northwest (Figure 1). Eight strata of various lengths (identical to those used in the 1996 and 1998 surveys) were marked out using hand-held GPS. 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. 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. A total of 60 transects was considered sufficient to meet the target c.v. of 20%, based on the simulations for the 1998 survey (Carbines & Breen 1999); that survey achieved a c.v. of 14% using 59 transects.

Forty-five transects (75%) were allocated to phase 1, and the remaining 15 (25%) to phase 2. A minimum of three transects was initially assigned to each stratum. The remainder of phase 1 transects were allocated based on the 1998 survey mean catch of legal-sized 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 legal-sized toheroa per transect from phase 1 of the 2002 survey.

2.1.2 Sampling methods

The survey was timed to coincide with several days of low tides allowing the maxiumum possible extent of the intertidal beach to be surveyed. As in previous surveys, each transect ran down the beach from high water (edge of dunes) to low water. Down each transect, quadrats of 0.5 square metres (1.0 x 0.5 m) spaced at 5 m intervals were excavated to a depth of 30 cm with a spade and 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 was necessary to sieve sand to accurately sample juveniles that might otherwise be missed. Juvenile transects were arbitrarily selected as the outside transects in each stratum. To sample juvenile toheroa, sand from quadrats was placed into a trolley lined with fine steel mesh and then wheeled down to the water where the action of the surf washed out the sand, leaving behind only debris and toheroa. This contrasts with the 1996 and 1998 surveys when sand was fed into nylon mesh bags and dragged to the water (Carbines 1997, Carbines & Breen 1999).

Toheroa in good condition and larger than about 50 mm were notched using a small hacksaw blade to score a line about 1 to 2 mm in depth in the shell from the centre of the shell to the posterior margin. The aim of this is to provide a means of measuring growth rates if these toheroa are recaptured on future surveys. This method was successfully applied to surf clams by Cranfield et al. (1996).

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

2.1.3 Population estimates

The population size of toheroa on Oreti Beach was estimated from the mean density of legal-sized toheroa in each stratum and the area of each stratum. In the ith stratum, the estimated number of legal-sized 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

$$VC_i = var_i/n_i$$

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

$$VN = 100 \Sigma (A_i^2 VC_i)$$

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

The c.v. is

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

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

2.2 Yield per recruit analysis

A first attempt at estimating sustainable yield for toheroa at Oreti Beach was undertaken using a yield per recruit analysis. Bertalanffy growth parameters and length-weight parameters were estimated by fitting Cassie's (1955) Oreti Beach mean length at age data and Rapson's (1952) Northland mean weight at length data using least squares. No maturity data are available for Oreti Beach. We therefore assumed that maturity occurs at about the same size as for northern toheroa. We inferred from Rapson (1952) that maturity occurs on average at 76 mm (3 inches) in northern toheroa. For Oreti Beach the age with the closest correspondence to this length is 6 y (mean length 80.9 mm). We therefore defined the mature or adult stock to be the biomass of toheroa 6 y and older.

From the age-length relationship of Cassie (1955), Oreti toheroa are about 9 y at the minimum legal size of 100 mm, and therefore during fishing only toheroa 9 y and older are taken. We assume zero mortality for undersized toheroa returned to the beach. No maximum age is available for Oreti Beach. Cassie (1955) suggests a maximum age on Muriwai Beach of 20 y and we assumed that this applies at Oreti Beach. We used Hoenig's method (Hoenig 1983) to estimate a natural mortality rate from maximum age.

The population younger than 6 y was not modelled. We calculated the yield per adult (grams per toheroa reaching 6 y) at various constant exploitation rates. We obtained the corresponding hypothetical equilibrium biomass of toheroa 6 y and older assuming constant recruitment and found the exploitation rate that produced the maximum yield. Details of model assumptions are given in Table 1. We tested the sensitivity of the results to variations in the assumed natural mortality rate.

We expressed the annual yield per individual from each equilibrium population as total catch weight divided by the number of adults in the virgin population. We multiplied the yield per adult in the virgin population by the mean of the surveys to obtain an estimate of the yield in tonnes. Since there has been a reduction in mean population size in recent years compared to the 1970s we have also calculated the yield corresponding to the mean population size since 1985.

2.3 Oreti Beach historical toheroa survey data

Two surveys in 1996 and 1998 are documented (Carbines 1997, Carbines & Breen 1999) and the data were available in electronic form. Twenty-six toheroa surveys of Oreti Beach from 1969 to 1990 were collated and raw data in hard copy form were entered onto an electronic database. Of these 26 surveys, only three 1990 surveys are documented (McKinnon & Olsen 1994). Necessary assumptions of surveys before 1990 were that transects were sampled from low to high water and that quadrat numbering was consistent between 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 2002 survey

Oreti Beach was surveyed from 25 February to 1 March 2002 and all 60 transects (45 phase 1 and 15 phase 2) were successfully completed (Table 2). Of the 60 transects, 16 were sieved (2 per stratum). Phase 2 transects were allocated mostly to stratum 3 with a few to strata 2 and 7. The number of quadrats per transect ranged from 30 to 58, with a mean of 41 equating to a mean transect length (beach width) of 205 m. Low tide height throughout the survey ranged from 0 to 0.5 m (mean 0.23).

Mean numbers of toheroa per stratum and population estimates of legal-sized (100 mm or over), subadult (40–99 mm), and juvenile toheroa (under 40 mm) are given in Tables 3 to 5. Population estimates were also calculated for toheroa 80 mm or over to allow comparison with historical estimates (Table 6). The population estimate of legal-sized toheroa is about 612 000, subadults 298 000, juveniles 10 000 000, and 80 mm or over 720 000. Coefficients of variation (a measure of survey precision) were about 12%, 11%, 13%, and 12.4% for the four size classes respectively (see Tables 3–6). The survey target c.v. for legal-sized toheroa was 20%.

Length frequency distributions of toheroa were characterised by a strong mode of juvenile toheroa (under 40 mm), and a less pronounced mode between 100 to 125 mm, with relatively few toheroa between these modes (Figures 2–4). More juveniles were sampled in sieved transects than in non-sieved transects (Figures 3 and 4).

Toheroa were found in all strata but were most abundant in the southeast end of Oreti Beach with the highest mean number of toheroa per transect in stratum 1 for all size groups (see Tables 3–6). Distribution plots of toheroa shows that for all size groups they were most abundant in the middle of the beach between high and low water (Figure 5). The three size groups occupy different height ranges between high and low water

(Figure 6). Legal-sized toheroa occupy the area from about 100 to 190 m (mean = 140 m) below high water, subadult 65 to 175 m (mean = 120 m), and juvenile, 10 to 200 m (mean 80 m). Although juvenile toheroa occupied a wide vertical range, they were most abundant higher on the beach.

Ninety-five percent of the quadrats sampled were sand with a further 3.4 % containing coarse sand (Table 7). Only stratum 7 had quadrats containing gravel and stones.

Sixty-one toheroa (mean length 104 mm, range 55–120 mm) were notched and returned to the sand.

Maori customary take from Oreti Beach is monitored and records kept by Waihopai Runaka (Table 8). Removals have varied between 2000 and 9000 toheroa each year.

3.2 Yield per recruit analysis

The von Bertalanffy growth equation was estimated as,

$$l = 186.4\{1 - \exp[-0.07510(t + 1.582)]\}$$

where l is the mean length in millimeters , and t is age in years.

The length-weight relationship was estimated as,

$$w = 0.00006825\ (l)^{3.151}$$

where w is the mean weight in grams. Fits to the mean length and mean weight data are shown in Figure 7 (data converted from inches and ounces).

Hoenig's method (Hoenig 1983) for estimating natural mortality gave,

$$M = \frac{-\log(0.01)}{20} = 0.23\ y^{-1}$$

We used $M = 0.23\ y^{-1}$ at all ages older than 6 y.

Yield per adult increased with exploitation rate to produce a theoretical maximum at 1.0 (Figure 8). Therefore the maximum yield is taken by harvesting all toheroa when they reach 9 y. This is because the annual weight increase of toheroa older than 9 y was insufficient to compensate for the loss in biomass due to natural mortality. The maximum yield was 65 g per toheroa reaching adulthood (Table 9). This exploitation rate would clearly not be a practical or acceptable proposition. However, it can be seen that the yield remained relatively high at considerably lower exploitation rates. At an exploitation rate of 0.5 (i.e., harvest half the toheroa 9 y and older) the yield was 62 g and at an exploitation rate of 0.3 it was 56 g. At an exploitation rate of 1.0 the biomass of toheroa 6 y and older was 26% of its virgin size, whereas at an exploitation rate of 0.3 it was 47%.

The choice of exploitation rate is arbitrary. We suggest that an exploitation rate of 0.3 would be a reasonable compromise between yield and population size, giving a relatively high yield without severely reducing the virgin population size. We expressed annual yields as total catch weight divided by the number of adults in the virgin population (Table 9). This gave a yield of 13 g per virgin population adult and would result in the population midway through fishing being 47% of virgin biomass. If we take the survey estimates (Table 10) to

be estimates of virgin population size (harvesting has been minimal), we can estimate the annual sustainable yield from their mean,

Yield = 1 574 000 × 13 g = 20 t.

If we use the smaller mean population size since 1985,

Yield = 1 145 000 × 13 g = 15 t.

At this exploitation rate the mean weight of toheroa in the catch would be 184 g (equivalent to a mean length of 110 mm). Hence the yield in numbers would be 111 000 using the overall mean survey numbers and 81 000 using the mean survey numbers since 1985.

Variation of the assumed natural mortality rate did not cause major change in the base case estimates. The estimates obtained, assuming a lower natural mortality rate, were a higher yield per adult at a lower proportion of virgin biomass and conversely (Table 11). The yield per toheroa in the virgin population did not vary greatly for natural mortality rates between 0.20 and 0.30 y^{-1}. In another case, we assumed that the maximum age of toheroa was 14 y, and that they died at the start of their 15th year (senescent mortality). Again, this did not result in substantial change in our estimates of yield.

3.3 Oreti Beach historical toheroa surveys

3.3.1 Historical survey data

Surveys up until 1998 used a systematic sampling design with transects every 330 m along the beach, except the April 1990 survey where transects were every 660 m (Table 12). The precise locations of transects are unknown, but it is likely that they varied between surveys in the absence of documented benchmarks and without the aid of GPS. Quadrats (1 x 0.5 m) were excavated every 5 m down these transects. All surveys started close to the Oreti River mouth at the southeast end of the beach (similar to the 2002 survey) with the number of transects ranging from 20 to 78, but most often about 54 were used. When 54 transects were used, spatial coverage along the beach was the same as in the 2002 survey (about 17 km). The cross-sectional area of the beach surveyed (low to high water) was on average a about 115 m, with sampling beginning near the 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. By comparison, the 1998 and 2002 surveys sampled on average about twice the number of quadrats per transect (low water to high water), and mean length of transects was 205 m.

All surveys before 1998, with the exception of April 1990, were adult surveys with no attempt made to search for juvenile toheroa. In April 1990, a dedicated survey was undertaken using transects spaced every 660 m along the length of the beach (17 km) from mid to high water with excavated sand being carefully examined for the presence of juveniles.

3.3.2 Historical abundance estimates

Millar & Olsen (1995) estimated numbers of toheroa 80 mm or over from 22 Oreti Beach surveys between 1971 and 1990. They restricted their estimates to surveys that they considered provided representative sampling of the beach (Figure 9). The three most recent surveys, in 1996 (Carbines 1997), 1998 (Carbines & Breen 1999), and 2002 (this report), estimated abundance for legal-sized toheroa (100 mm or over), but to allow comparison with earlier estimates we also calculated the abundance for toheroa 80 mm or over. Between

1971 and 1990, the population of toheroa 80 mm or over varied between 1 and 2.5 million toheroa (There were one-day open seasons in 1972, 1973, 1974, 1978, 1980, 1981, and 1990). The 1996 survey indicated that *the population had declined markedly to about 400 000 toheroa 80 mm or over, the lowest estimate to date.* Surveys between 1971 and 1996 estimated only abundance within the area surveyed (115 m cross-section of beach) and did not extrapolate to take into account toheroa below mean low water or above mean high water, and therefore may have underestimated abundance. The 1998 survey indicated recovery to about 1 million toheroa 80 mm or over toheroa, but by 2002 numbers had declined again to 700 000. These latter two surveys covered substantially more cross-sectional area of the beach than earlier surveys (dunes to well below mean low water), and comparison with earlier surveys may not be appropriate. The 1998 and 2002 surveys will have overestimated toheroa abundance compared with earlier surveys, and given that these estimates are relatively low compared to historical estimates, we conclude that the population remains low.

3.3.3 *Historical length frequency*

Length frequency histograms of toheroa on Oreti Beach from 26 historical surveys between 1969 to 1998, and 2002 are shown in Figure 10. The difficulty in interpreting these data 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 placed into searching for juveniles. Additionally, the upper section of the beach, where juveniles are most abundant, was not sampled. Length frequency distributions from 1969 to 1974 suggest that some attempt was made to sample juveniles (under 40 mm), because they were well represented. From 1975 to 1990 the size distributions were remarkably similar and characterised by a strong adult mode between about 100 and 140 mm, with few subadults (40–99 mm), and even fewer juveniles. The April 1990 juvenile survey (shown in Figure 10 combined with the March 1990 adult survey) provides the first indication that juveniles were also present on Oreti Beach between 1975 and 1988, but were probably not sampled. 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 in 1998 and 2002 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 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 using software such as MULTIFAN because only one or two modes are present and no progression of these modes is apparent between years.

3.3.4 Historical distribution

Distribution plots of toheroa (all sizes) on Oreti Beach surveys between 1975 to 1998 and in 2002 are shown in Figure 11. The surveys between 1975 and 1996 used systematic transects; those in 1998 and 2002 used random stratified transects. The latter are designed to provide higher precision in estimating abundance of toheroa and consequently transects were concentrated where toheroa beds are most dense. The distribution of toheroa from the 1975 to 1996 surveys includes only the area of the beach from mean low water to mean high water. In contrast, the 1998 and 2002 surveys show the distribution of toheroa from the dunes to low water.

Between 1975 and 1984 toheroa were distributed along the entire length of the beach, but were densest in the first 6 km of the southeast end of the beach, within 50 m of mean low water. The numbers of quadrats with no toheroa in the upper section of the beach are suspicious, given the distributions from the 1998 and 2002 surveys. Further, anecdotal evidence suggests that not all transects were sampled up to mean high water – where several consecutive quadrats revealed no toheroa, it was assumed that there were no toheroa higher up

the beach and zeros were allocated to the unsampled quadrats. From 1985 to 1996 the pattern of distribution changed and toheroa were less concentrated in the southeast end of the beach. Although the 1998 and 2002 distributions were to some degree influenced by the random allocation of transects within strata, they indicate that the densest beds were again in the southeast end of the beach.

4. DISCUSSION

4.1 2002 survey

The 2002 population estimates of legal-sized, subadult, juvenile, and 80 mm or over toheroa were 612 000, 299 000, 10 500 000, and 720 000, with a c.v. for legal-sized toheroa of 12%, which is well below the 20% target. Population estimates were all less than those from the 1998 survey by 13%, 54%, 36%, and 32 % respectively (Carbines & Breen 1999) (see Figure 9). Although numbers have declined over the four years between the 1998 and 2002 surveys, overall numbers may have stabilised since 1990.

The Oreti Beach toheroa population size structure is marked by the presence of a strong juvenile mode (under 40 mm) comprised of 0+ year class individuals (Redfearn 1974). The absence of a distinguishable mode in the subadult size range (40–99 mm) is puzzling because although mortality of juvenile toheroa is known to be high (Morrison & Parkinson 2001), larger toheroa were consistently present throughout the time series. Sampling bias that could potentially contribute to an underestimate of subadult toheroa is very unlikely, especially given that smaller juvenile toheroa (under 40 mm) were sampled reasonably well in non-sieved transects.

Beentjes & Carbines (2001) suggested that the large variation in seasonal estimates of toheroa on Bluecliffs Beach may have been the result of vertical migrations between the intertidal and sub littoral zone related to availability of suitable sand substrate. Fluctuations in Northland toheroa populations have also prompted workers to suggest that toheroa migrate between the sublittoral and littoral zones of the beach (Cassie 1955, Waugh & Greenway 1967, Greenway 1969). It is possible that subadult toheroa inhabit areas of Oreti Beach below low water, providing a plausible explanation for the consistently relatively low numbers of subadult toheroa, although there is no evidence to support this theory.

Highest densities of toheroa in 2002 were found at the southeast end of Oreti Beach. This differs from 1998 when, apart from juveniles, toheroa were distributed more evenly along the entire beach. Density may have more to do with environmental conditions at the time of recruitment than a preference for a section of the beach as 95% of the beach was sand (see Table 7), and can be regarded as suitable habitat. 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 three size groups, to some extent, occupied different height ranges between high and low water, with juveniles more abundant near high water and adults near low water (see Figure 6). The implications of this are that larger toheroa, on average, will be submerged for longer on each tidal cycle.

Maori customary take from Oreti Beach is monitored, and although sizes are not recorded, most are probably legal-sized toheroa (see Table 8). Based on the current legal toheroa population estimate, assuming a customary harvest of about 7000 toheroa, this represents about 1% of the population.

4.2 Yield per recruit

The yield estimates obtained are preliminary, being dependent on population parameters that were obtained from Northland. Oreti Beach parameter estimates for natural mortality, age at maturity, and the length-weight relationship, as well as new age-length data would reduce the uncertainty in the present yield per recruit estimate. The yield estimates also rely on the assumption that recruitment to the adult population would not be affected by harvesting. If the disturbance caused by harvesting reduced the settlement of spat or caused incidental mortality to juveniles, then potential yields would be lower than those estimated. Alternatively, if reductions in the population density caused by harvesting increased the average growth rate, then potential yields would be higher. Choice of an appropriate exploitation rate is arbitrary. Considerations include total yield, catch rate, amount of modification of the population from its virgin state, and relative change in population size from year to year. Our suggestion of an exploitation rate of 0.3 would produce a yield somewhat below the maximum possible, result in average catch rates being about half what they would be in a very lightly fished population, and reduce the population to about half its virgin biomass, with the average size of toheroa in the population being reduced from 256 to 184 g. The year-to-year variability in population size would increase, but without more detailed modelling of recruitment variability we cannot estimate by how much.

4.3 Historical surveys of Oreti Beach

Despite the shortcomings in the historical survey designs, the time series indicates a decline in abundance of adult toheroa 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 (80 mm or over) (Figure 9). The current population is low compared with the 1970s and early 1980s. Toheroa are known to be subject to mass mortalities, but the cause of these mortalities is largely speculative and has been ascribed to unusual weather conditions (Morrison & Parkinson 2001). It was suggested that unusually cold temperatures and blooms of the toxic alga *Gymnodinium mikimotoi* may have been responsible for the decline in Oreti Beach toheroa numbers in 1996 (Carbines 1997). Because the historical surveys on Oreti Beach did not target juveniles, the magnitude of annual recruitment and the extent to which recruitment strength translates into adult numbers, cannot be determined.

The consistency in length frequency distributions over many years of surveys is notable. 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. This indicates that mortality of juveniles is probably high and that relatively few toheroa survive through to the subadult size range (40–99 mm). The strong mode between 100 and 140 mm probably represents multiple cohorts which 'stack up' where growth has slowed substantially compared to the sub-adults, and mortality is low. Toheroa at Bluecliffs beach have similar size distributions (Beentjes & Carbines 2001). A recent survey of tuatua (*Paphies donacina*) at New Brighton Beach in Christchurch showed a similar length frequency distribution (Cranfield et al. 2002), suggesting that this may be common to many intertidal shellfish species. Size structure of populations of toheroa in Northland differ from those in Oreti Beach in that subadult toheroa are well represented, but large legal-sized (100 mm or over) toheroa have been largely absent in recent surveys (Morrison & Parkinson 2001). Northland toheroa also grow much faster than those from Oreti Beach (Cassie 1955), but given the smaller maximum sizes, may not live as long. This may explain the difference in size compositions between Northland beaches and Oreti Beach.

Analysis of historical distributions of toheroa on Oreti Beach indicate that the southeast end of the beach near the Oreti River mouth is an area where toheroa have consistently been densest. The reasons for this are unknown but may be a result of alongshore currents which deposit spat more often at the southeast end. The beach substrate is homogenous fine sand along all but small sections of the beach, and this is unlikely to have influenced distribution. In contrast, the distribution of toheroa at nearby Bluecliffs Beach is strongly correlated

with substrate type, and much of the suitable sand substrate has been scoured away by wave action (Beentjes & Carbines 2001). Juvenile surveys of Oreti Beach in 1990, 1998, and 2002 indicate the importance of the upper beach for juveniles which are often located only a few centimetres below the sediment surface.

5. ACKNOWLEDGMENTS

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NIWA acknowledge the kaitiaki role of local iwi in regard to kai moana, and recognise the rangatiratanga of Ngai Tahu and the Waihopai Runaka.

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Table 1. Yield per adult model details.

Model process	Description	Value
Maximum age	Toheroa cease growing at the maximum age, but continue to suffer the same natural and fishing mortality rates.	20 y
Maturity age	All toheroa reach adulthood at this age.	6 y
Virgin biomass	The biomass of toheroa at or older than maturity age when there is no fishing.	Survey estimates
Recruitment age	All toheroa reach minimum legal size at this age.	9 y
Recruitment	Constant.	–
Natural mortality	Constant with age from maturity age (not modelled younger than this age).	0.23 y^{-1}
Fishing	Fishing occurs in a pulse after half the natural mortality has occurred (the exploitation rate is the proportion taken).	–
Growth	All toheroa of an age have the mid-year mean weight and length for that age.	See above

Table 2: Strata and transects used in the toheroa survey at Oreti Beach in February 2002. Two transects in each strata were sieved (N=16) in phase 1, and all other transects were non-sieved (N=44).

		Transects		
Stratum	Length (m)	Phase 1	Phase 2	Total
1	900	3	0	3
2	1 000	5	2	7
3	3 500	6	11	17
4	1 100	3	0	3
5	1 000	3	0	3
6	2 700	9	0	9
7	2 800	5	2	7
8	4 247	11	0	11
Total	17 247	45	15	60

Table 3: Population estimates of legal-sized (≥ 100 mm) toheroa at Oreti Beach in February 2002.

Stratum	Mean number per transect	Variance	Numbers per stratum	Area squared variance
1	7.7	80.333	69 000	21 690 000
2	7.4	12.619	74 286	1 802 721
3	7.0	20.375	245 000	14 681 985
4	2.3	1.333	25 667	537 778
5	0.3	0.333	3333	111 111
6	3.4	9.528	93 000	7 717 500
7	2.0	0.667	56 000	746 667
8	1.1	3.691	46 331	6 052 087
Total			612 617	53 339 849
		c.v.	11.9%	
		95% CI	± 143 146	

Table 4: Population estimates of sub-adult (40–99 mm) toheroa at Oreti Beach in February 2002.

Stratum	Mean number per transect	Variance	Numbers per stratum	Area squared variance
1	4.3	10.333	39 000	2 790 000
2	2.7	1.571	27 143	224 490
3	3.1	5.235	109 118	3 772 491
4	1.3	2.333	14 667	941 111
5	1.3	2.333	13 333	777 778
6	1.7	1.000	45 000	810 000
7	0.3	0.238	8000	266 667
8	1.0	1.000	42 470	1 639 728
Total			298 731	11 222 265
		c.v.	11.2%	
		95% CI	± 65 659	

Table 5: Population estimates of juvenile (< 40 mm) toheroa at Oreti Beach in February 2002 (two transects per stratum were sieved).

Stratum	Mean number per transect	Variance	Numbers per stratum	Area squared variance
1	128.5	2244.500	1 156 500	909 022 500
2	100.0	98.000	1 000 000	49 000 000
3	67.5	60.500	2 362 500	370 562 500
4	58.5	60.500	643 500	36 602 500
5	42.5	12.500	425 000	6 250 000
6	43.0	288.000	1 161 000	1 049 760 000
7	71.0	4232.000	1 988 000	16 589 440 000
8	40.5	40.500	1 720 035	365 249 432
Total			10 456 535	19 375 886 932
		c.v.	13.3%	
		95% CI	± 2 728 266	

Table 6: Population estimates of toheroa ≥ 80 mm at Oreti Beach in February 2002.

Stratum	Mean number per transect	Variance	Numbers per stratum	Area squared variance
1	10.3	140.333	93 000	37 890 000
2	9.3	17.571	92 857	2 510 204
3	8.2	33.029	286 176	23 800 606
4	3.0	4.000	33 000	1613 333
5	0.7	0.333	6667	111 111
6	3.7	9.250	99 000	7 492 500
7	2.0	0.667	56 000	746 667
8	1.3	3.618	54 053	5 932 834
Total			720 753	80097 255
		c.v.	12.4%	
		95% CI	± 175 414	

Table 7: Summary of substrate types in quadrats sampled in each strata on Oreti Beach in 2002. 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						Total quadrats
Strata	1	2	3	4	5	6	
1	95						95
2	215	10	16				241
3	725						725
4	127						127
5	153						153
6	387						387
7	207	49	5	3	7	2	273
8	434	25					459
Totals quadrats	2 343	84	21	3	7	2	2 460
Percent quadrats	95.2	3.4	0.9	0.1	0.3	0.1	

Table 8: Estimated customary take of toheroa from Oreti Beach for calendar years 1998–2001. Data provided quarterly by Waihopai Runaka to the Ministry of Fisheries, Dunedin.

Year	Number of toheroa	Comment
1998	2257	
1999	2692	
2000	8853	
2001	6813	Represents first half of year only
2002	–	Data not yet available

Table 9. Base case annual equilibrium yield per adult at various exploitation rates. Adults are defined as toheroa aged ≥ 6 y (80 mm) but minimum legal-sized (100 mm) is reached at age 9 y.

Exploitation rate of toheroa ≥ MLS	Yield per toheroa recruit that reaches adulthood (g)	Yield per toheroa in a virgin adult population (g)	Mean weight in catch ≥ MLS (g)	Adult equilibrium biomass relative to virgin biomass (%)
1.0	65	15	146	26
0.7	64	15	156	33
0.5	62	14	166	38
0.3	56	13	184	47
0.0	0	0	256	100

Table 10. Survey estimates of number of adult toheroa (≥ 80 mm) on Oreti Beach.

Survey	Number (1000s)
Dec 71	860
May 73	1 310
Mar74	2 400
Nov 74	1 990
May 75	1 730
Jan 76	2 430
May 77	2 290
Nov 77	2 270
Apr 78	2 300
Dec 78	1 970
Apr 79	1 550
Jun 80	1 940
Nov 80	1 250
May 81	1 610
Apr 82	1 300
Jul 83	1 350
Jul 84	1 640
Jun 85	2 090
Sep 87	1 150
Jun 88	1 290
Mar 90	1 190
Oct 90	1 270
June 96	388
Mar 98	1 064
Feb 2002	721
Mean	1 574
Mean (1985–2002)	1 145

Table 11. Annual equilibrium yield per adult at various assumed natural mortality rates. The corresponding exploitation rate that gives the maximum yield is 1.0 in all cases. Adults are defined as toheroa aged ≥ 6 y but minimum legal size is reached at age 9 y.

Changes to assumptions	Exploitation rate of toheroa ≥MLS	Yield per toheroa that reaches adulthood (g)	Yield per toheroa in a adult virgin population (g)	Adult equilibrium biomass relative to virgin biomass (%)
Base case: natural mortality=0.23 y^{-1}	1.0	65 (maximum)	15	26
	0.3	56	13	47
Natural mortality=0.20 y^{-1}	1.0	73 (maximum)	15	22
	0.3	65	13	41
Natural mortality=0.30 y^{-1}	1.0	51 (maximum)	15	36
	0.3	39	12	58
Maximum age=14 y All die at age 15 y	1.0	65 (maximum)	17	38
	0.3	52	14	65

Table 12: Toheroa surveys of Oreti Beach, including the 2002 survey. Transect 1 begins at south east end of Oreti Beach near the Oreti River mouth.

Survey number	Survey date	Survey design	Transects	Distance between transects (m)	Target size	Reference
1	Jun-1969	Systematic transects	7–77	330	Adults	Undocumented
2	May–Jun-1971	Systematic transects	7–78	330	Adults	Undocumented
3	Oct–Jan-1971	Systematic transects	1–44	330	Adults	Undocumented
4	Jun-1972	Systematic transects	1–20	330	Adults	Undocumented
5	May-1973	Systematic transects	1–70	330	Adults	Undocumented
6	Nov-1974	Systematic transects	1–44	330	Adults	Undocumented
7	May-1975	Systematic transects	1–53	330	Adults	Undocumented
8	May–June-1976	Systematic transects	1–77	330	Adults	Undocumented
9	May-1977	Systematic transects	1–53	330	Adults	Undocumented
10	Nov-1977	Systematic transects	1–53	330	Adults	Undocumented
11	Dec-1977	Systematic transects	1–9	330	Adults	Undocumented
12	Mar–Apr-1978	Systematic transects	1–55	330	Adults	Undocumented
13	Nov–Dec-1978	Systematic transects	1–55	330	Adults	Undocumented
14	May–Apr-1979	Systematic transects	1–55	330	Adults	Undocumented
15	Apr–Jun-1980	Systematic transects	1–56	330	Adults	Undocumented
16	Nov-1980	Systematic transects	1–55	330	Adults	Undocumented
17	Mar–May-1981	Systematic transects	1–54	330	Adults	Undocumented
18	Mar–Apr-1982	Systematic transects	1–57	330	Adults	Undocumented
19	Mar, Jun–Jul-1983	Systematic transects	1–52	330	Adults	Undocumented
20	Jun-Jul-1984	Systematic transects	1–53	330	Adults	Undocumented
21	Jun-1985	Systematic transects	1–55	330	Adults	Undocumented
22	Jan-1900	Systematic transects	1–54	330	Adults	Undocumented
23	Jun-1988	Systematic transects	1–44	330	Adults	Undocumented
24	Mar-1990	Systematic transects	1–43	330	Adults	McKinnon & Olsen 1994
25	Apr-1990	Systematic transects	1–45	660	Juveniles	McKinnon & Olsen 1994
26	Oct-1990	Systematic transects	1–44	330	Adults	McKinnon & Olsen 1994
27	Jun-1996	Systematic transects	1–49	330	Adults	Carbines 1997
28	Mar–April-1998	Random stratified transects	1–60	Variable	All sizes	Carbines & Breen 1999
29	Feb–Mar-2002	Random stratified transects	1–60	Variable	All sizes	This report

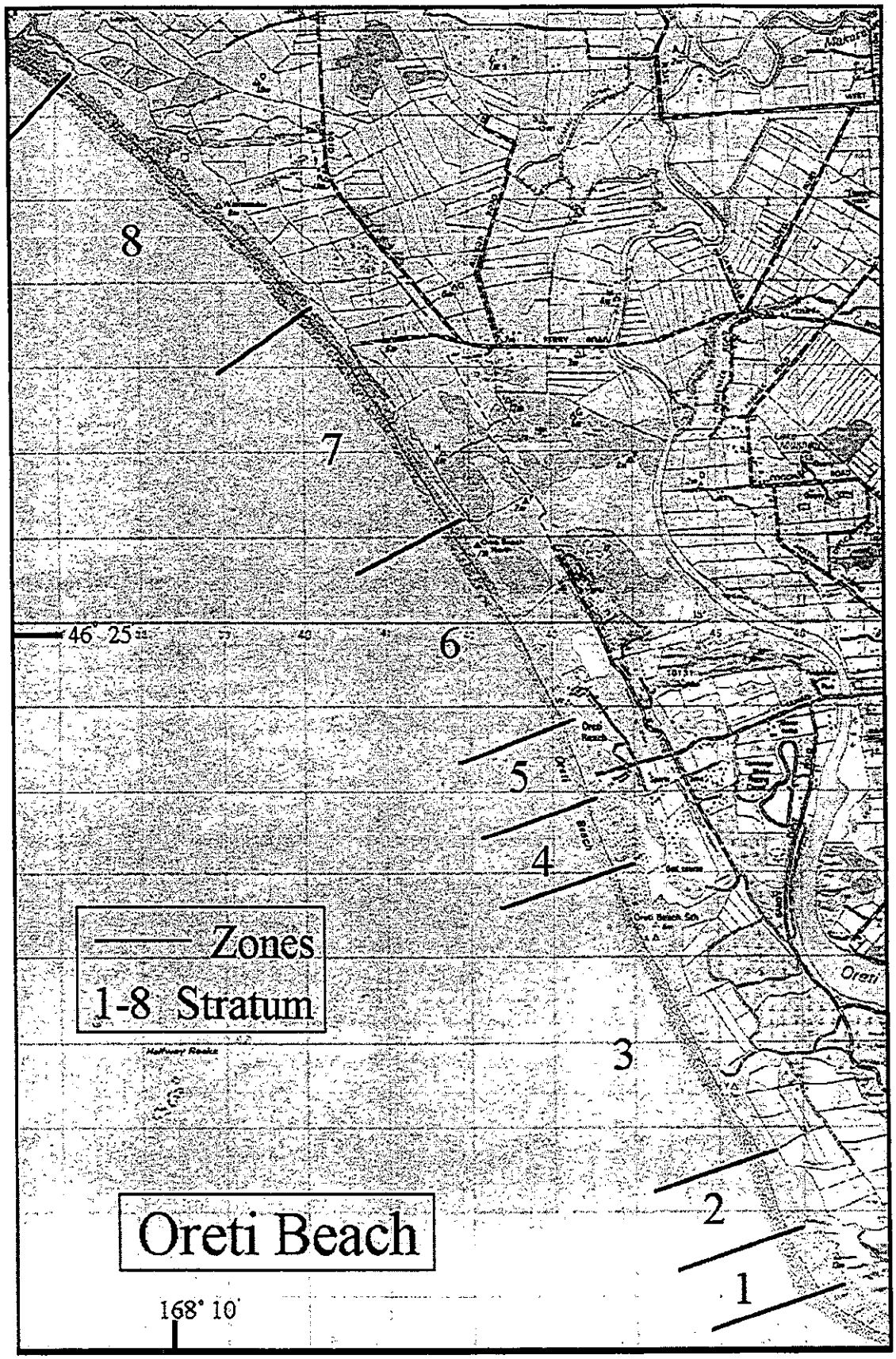


Figure 1: Map of Oreti Beach showing strata used in the survey. Crown copyright reserved. Reproduced by permission of Land Information New Zealand.

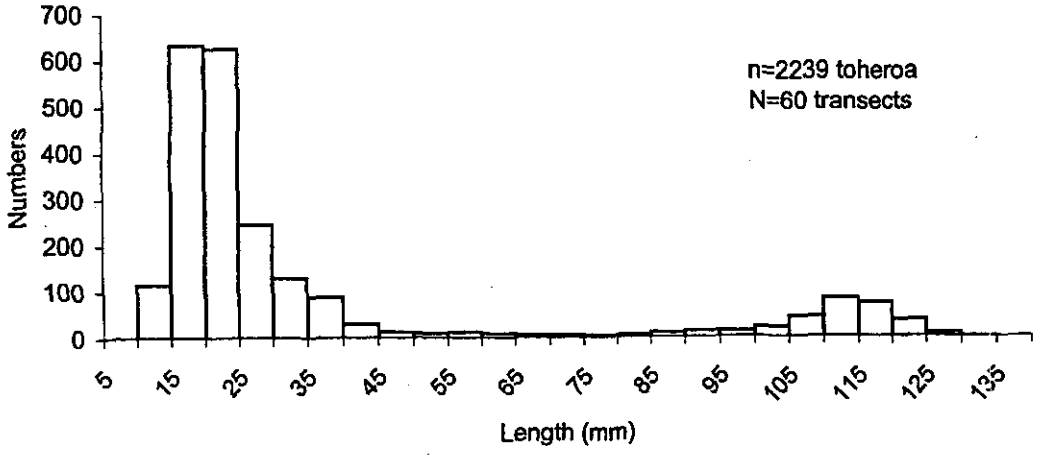


Figure 2: Length frequency distribution of sampled toheroa on Oreti Beach in February 2002 from all transects combined.

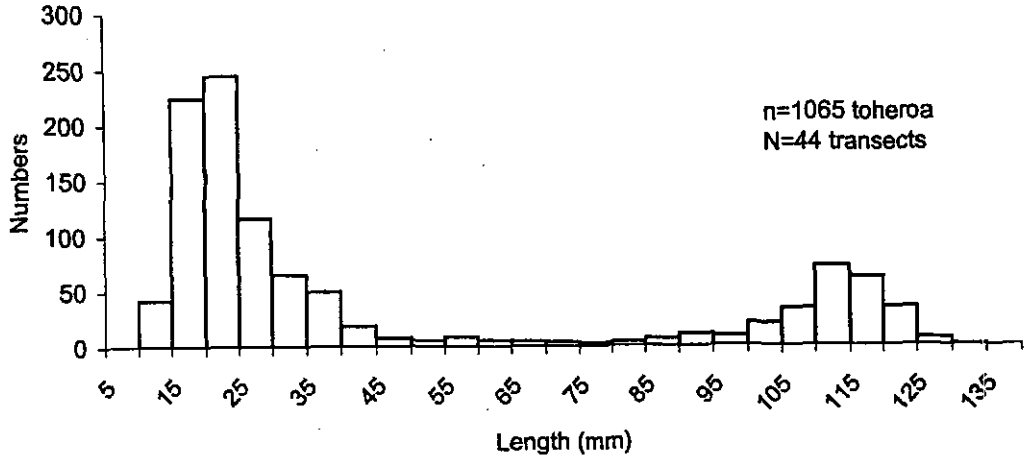


Figure 3: Length frequency distribution of sampled toheroa on Oreti Beach in February 2002 from non-sieved transects.

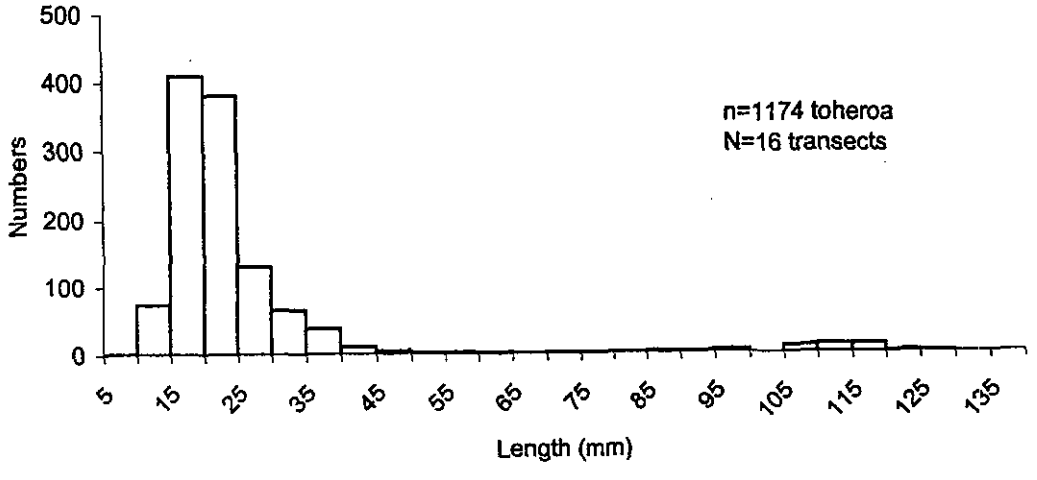


Figure 4: Length frequency distribution of sampled toheroa on Oreti Beach in February 2002 from sieved transects.

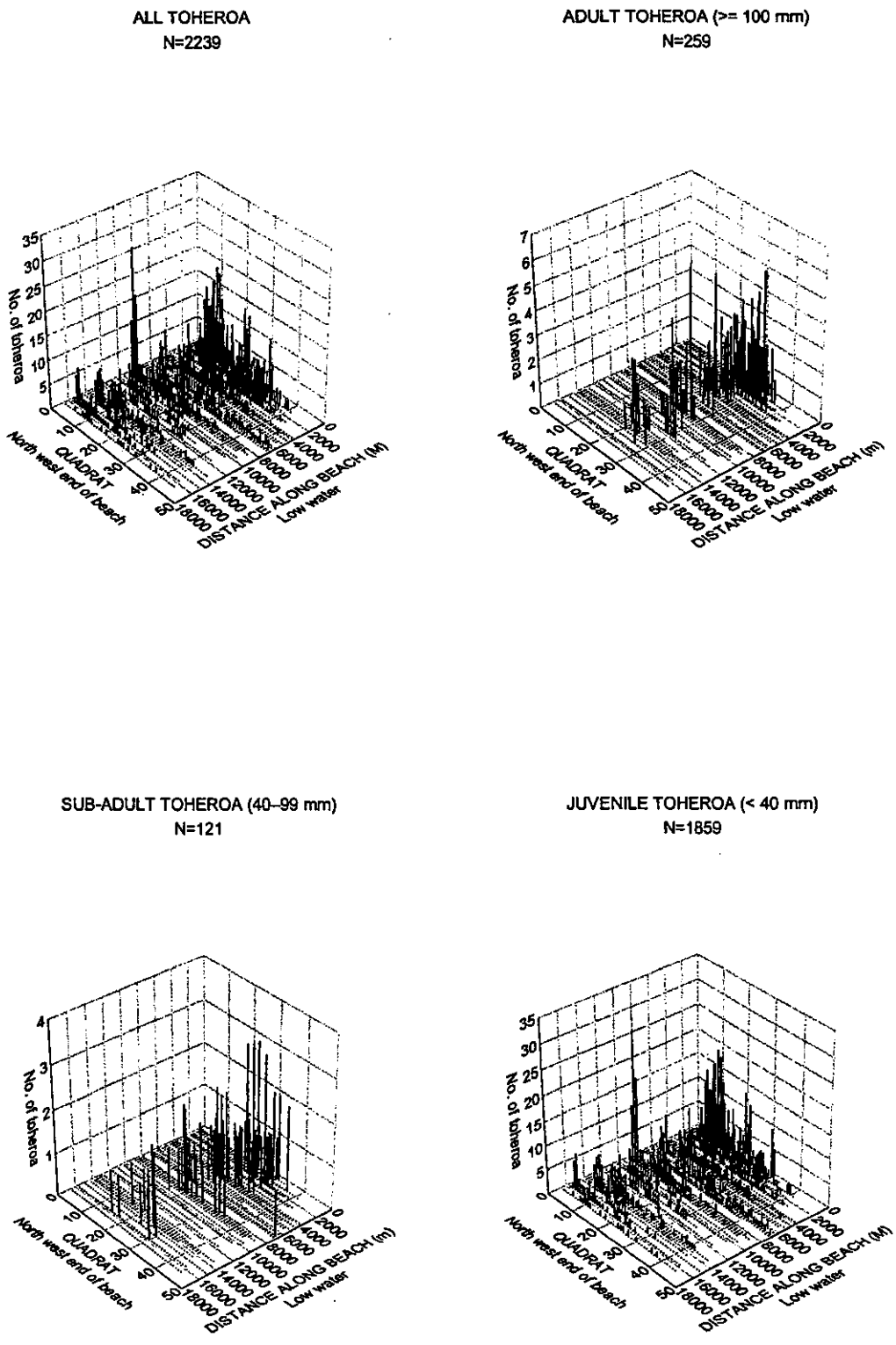


Figure 5: Distribution plots of toheroa on Oreti Beach from the February 2002 survey.

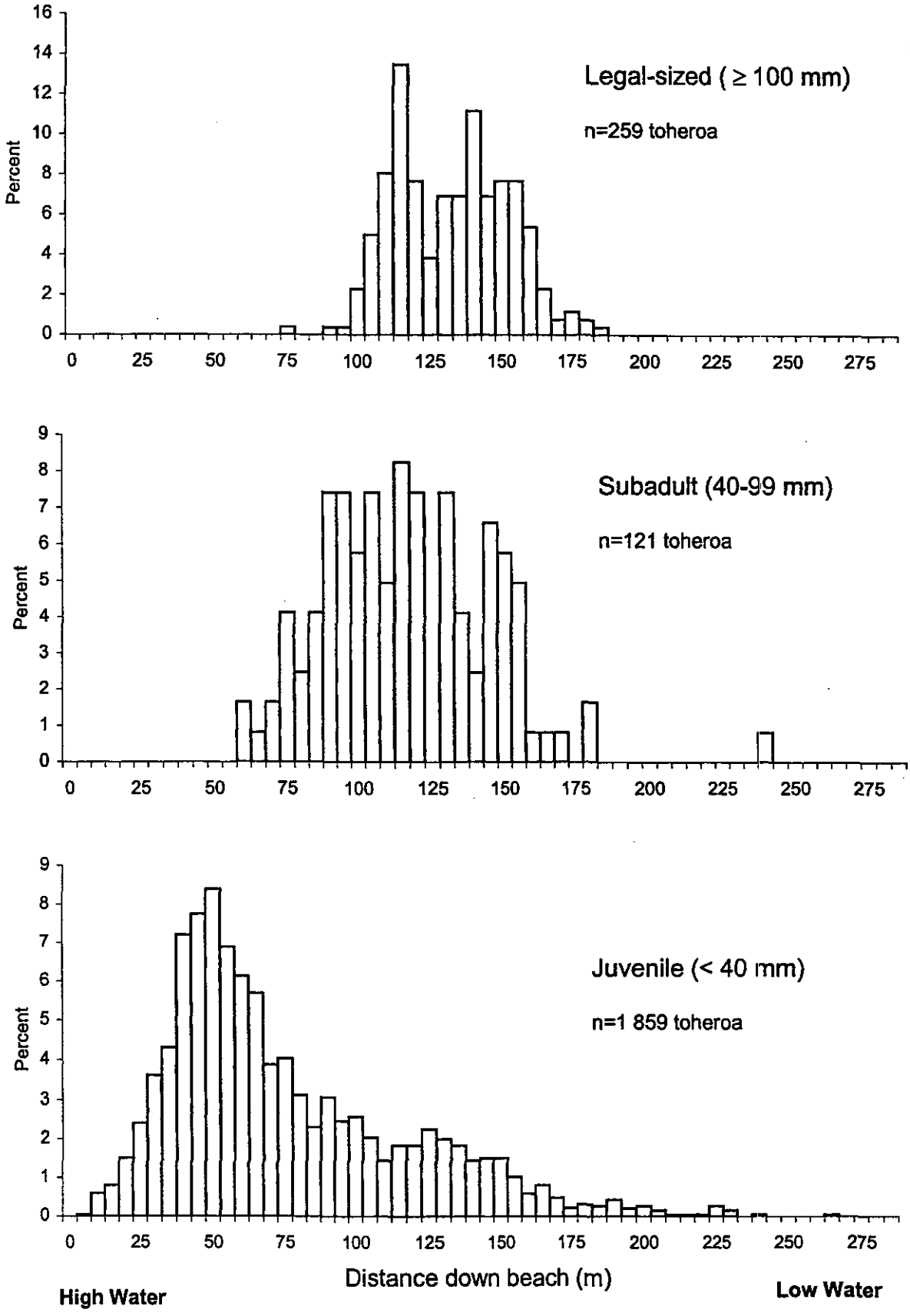


Figure 6: Proportion of toheroa population versus distance down the beach for legal-sized, subadult, and juvenile toheroa on Oreti Beach in February 2002.

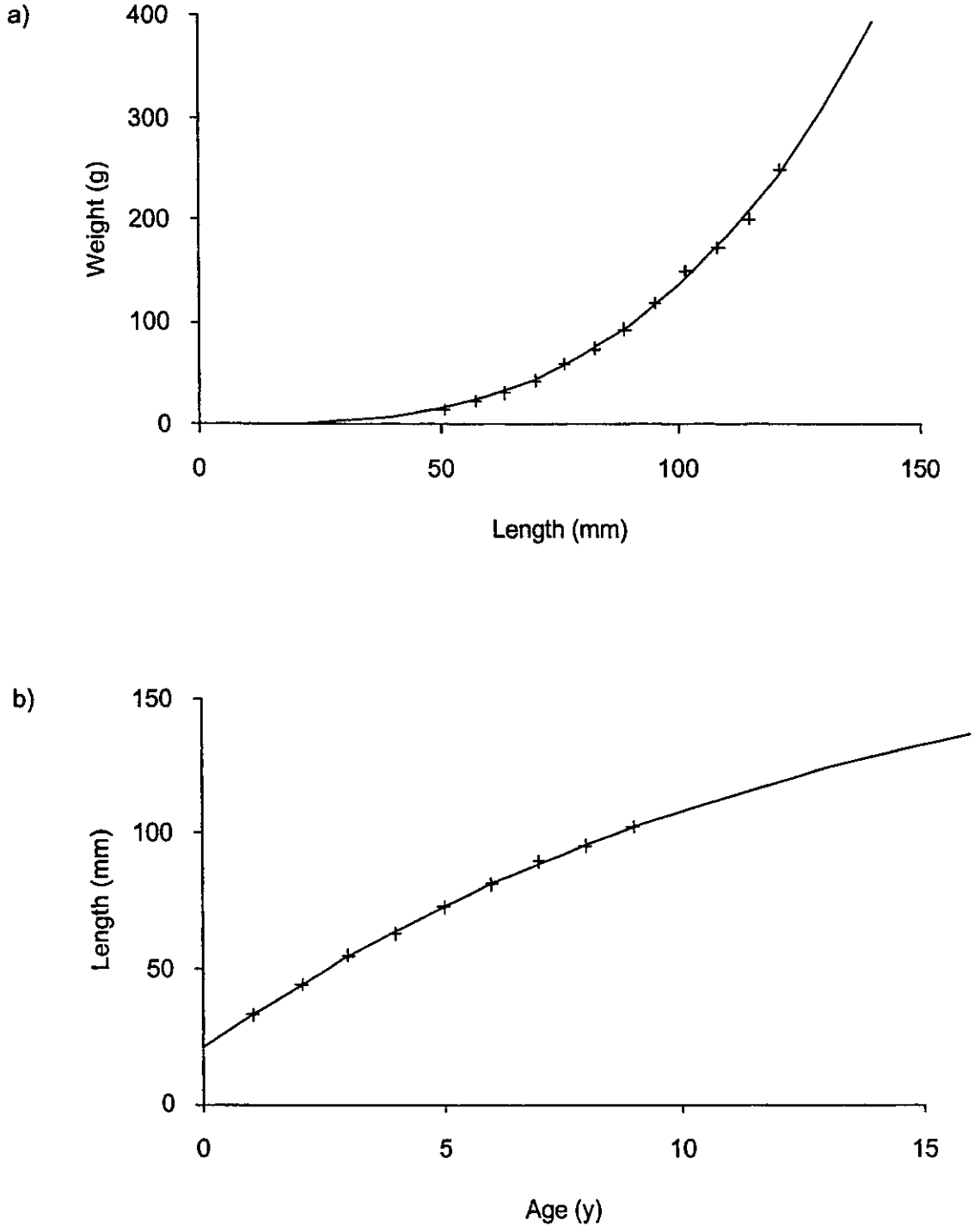


Figure 7: Growth of Oreti Beach toheroa. (a) Weight-length relationship fitted to the data of Rapson (1951), and (b) von Bertalanffy relationship fitted to the data of Cassie (1955). Crosses represent reported means. Fitting was by least squares.

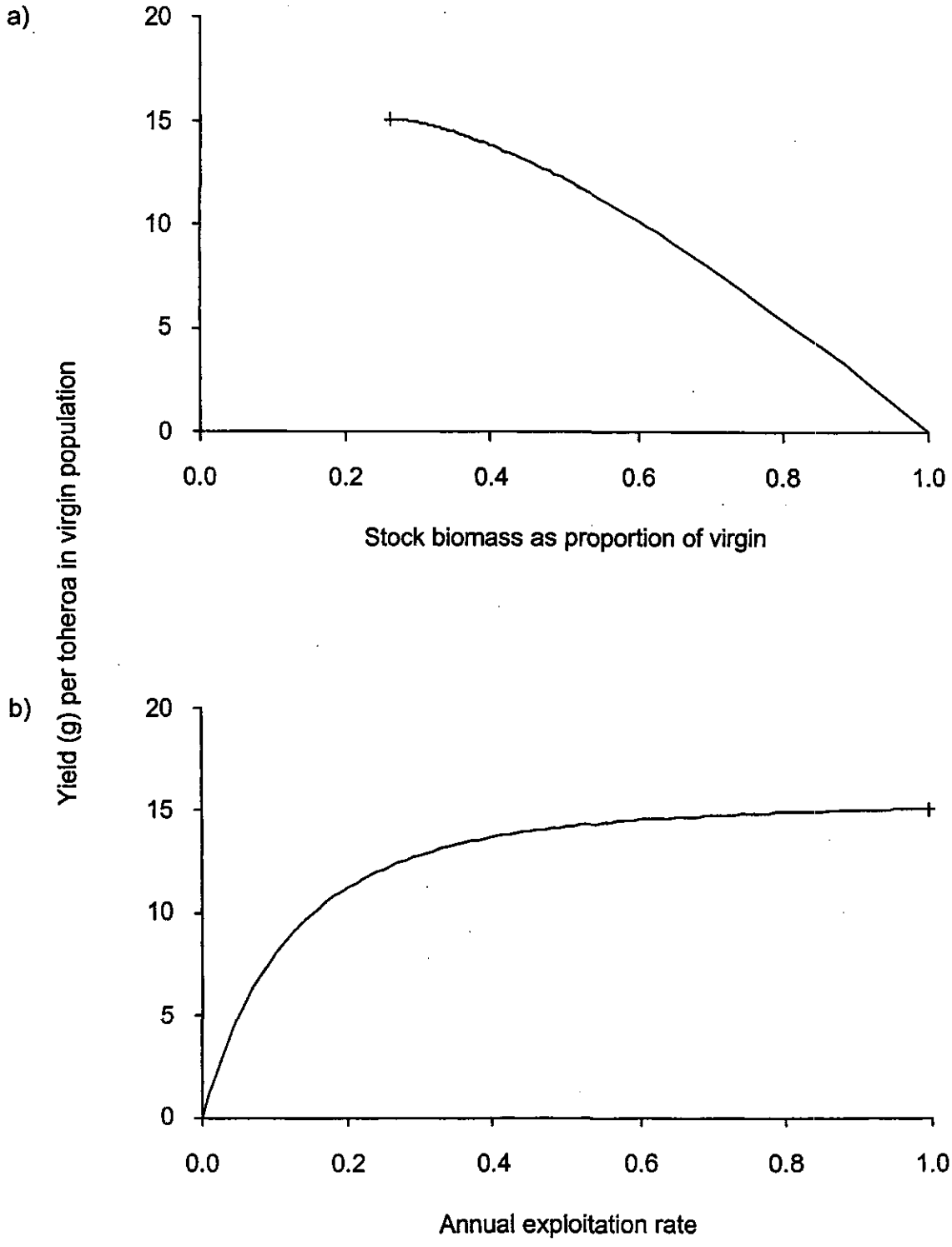


Figure 8: Yield estimates at constant recruitment and constant exploitation rates for Oreti Beach toheroa. (a) Hypothetical yields per adult in a virgin population are plotted against corresponding biomass of toheroa 6 y and older. Biomass is expressed as a proportion of the virgin biomass. (b) Yields plotted against exploitation rates.

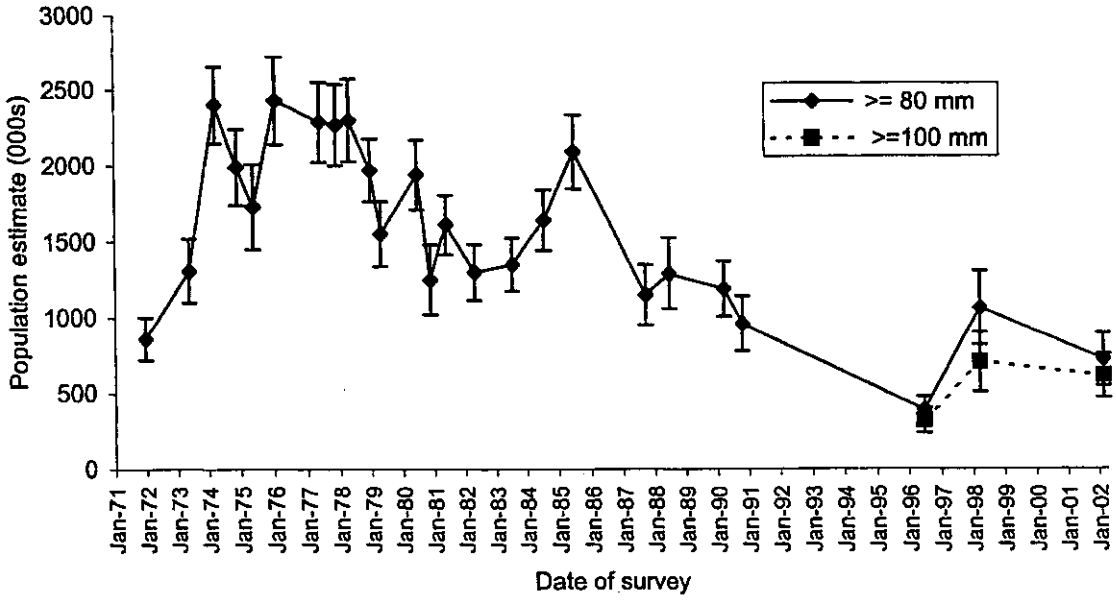


Figure 9: Historical population estimates and 95% confidence intervals of toheroa ≥ 80 mm for Oreti Beach between 1971 and 2002. Estimates are also given for legal-sized toheroa (≥ 100 mm) (1996–2002). Estimates before 1996 are from Millar & Olsen (1995), 1996 estimates from Carbines (1997), and 1998 estimates from Carbines & Breen (1999).

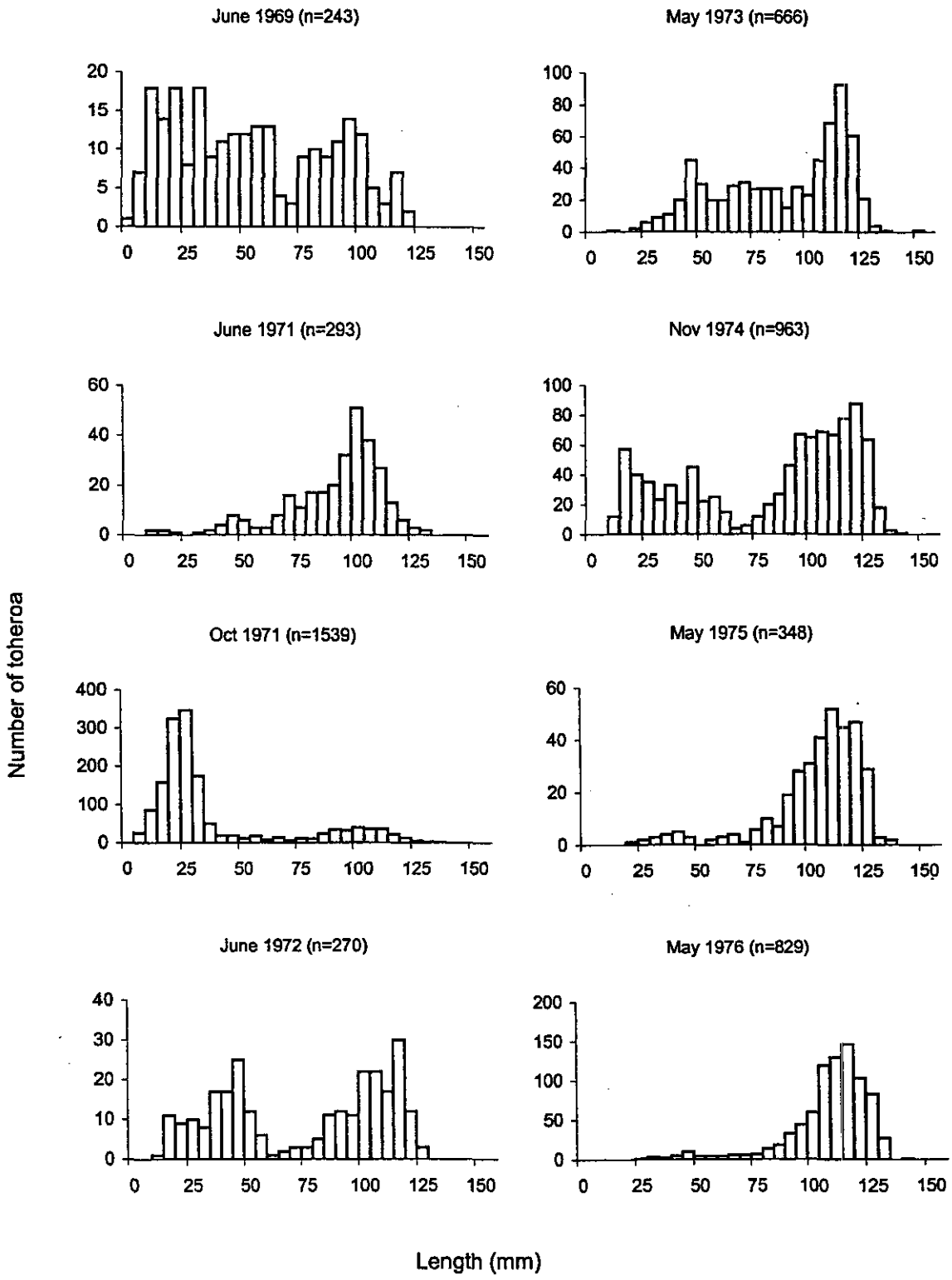


Figure 10: Length frequency distributions of toheroa on Oreti Beach from surveys between 1969 and 2002. n, number of individuals measured.

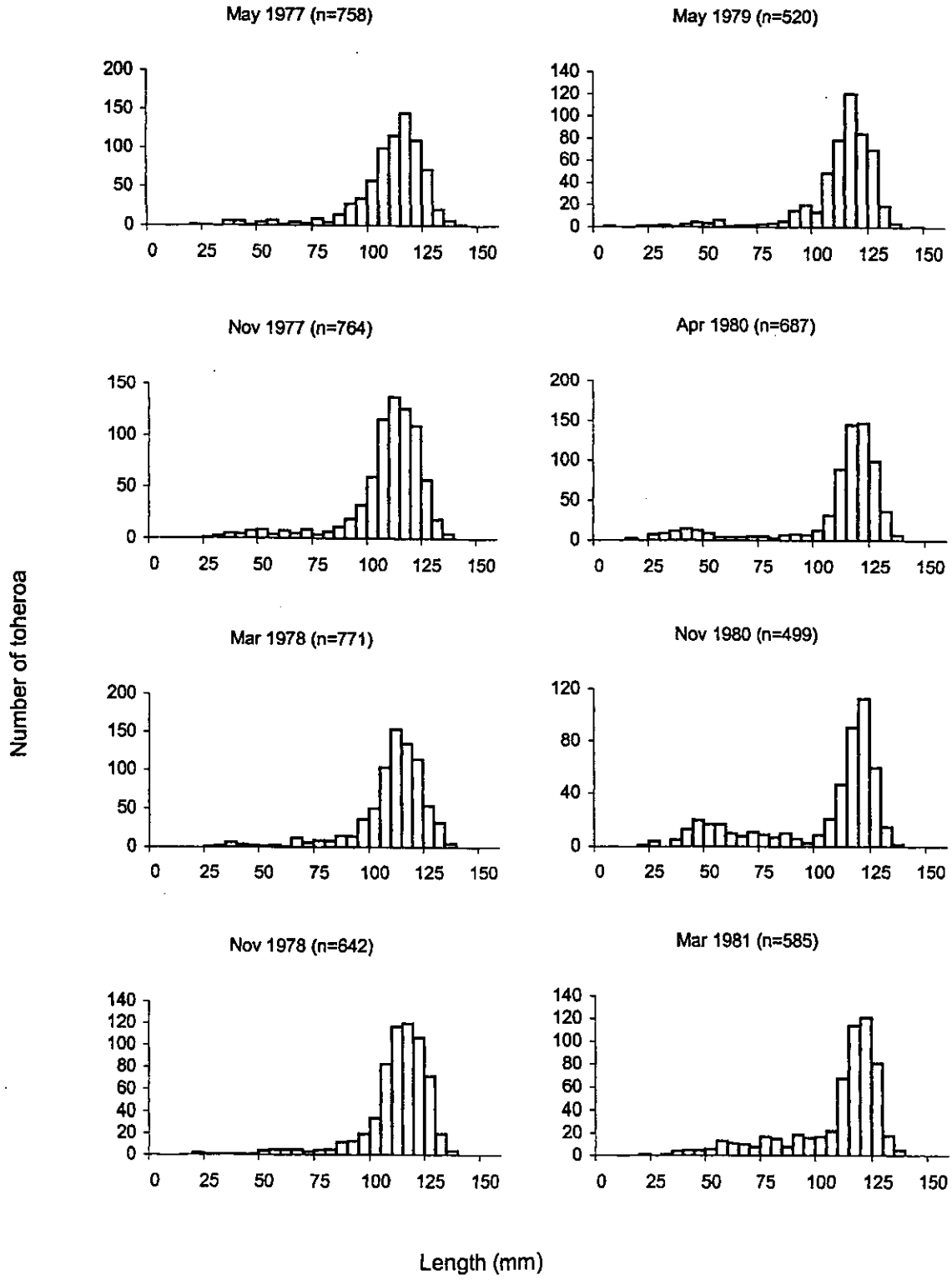


Figure 10 – ***continued***

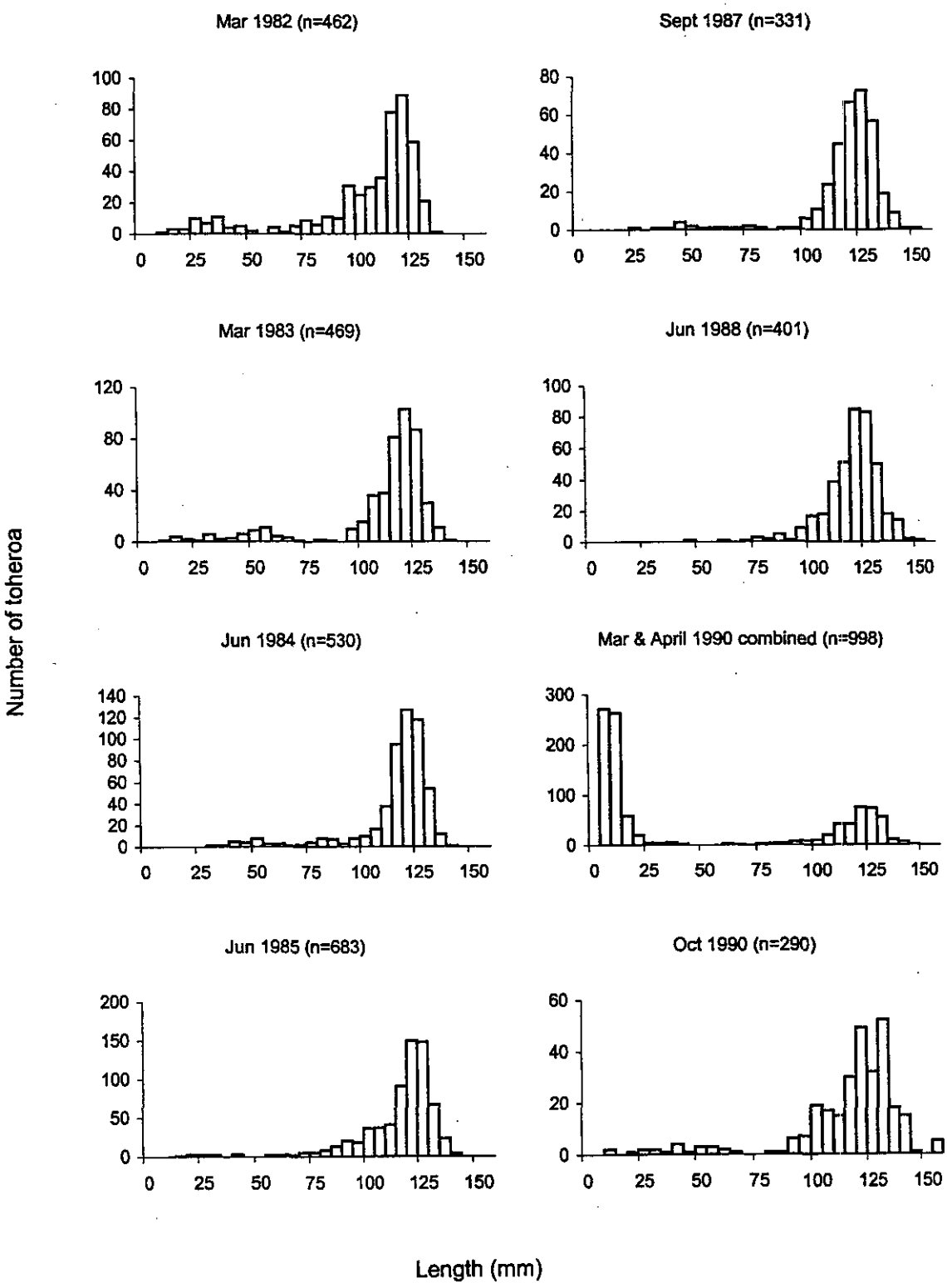


Figure 10 – ***continued***

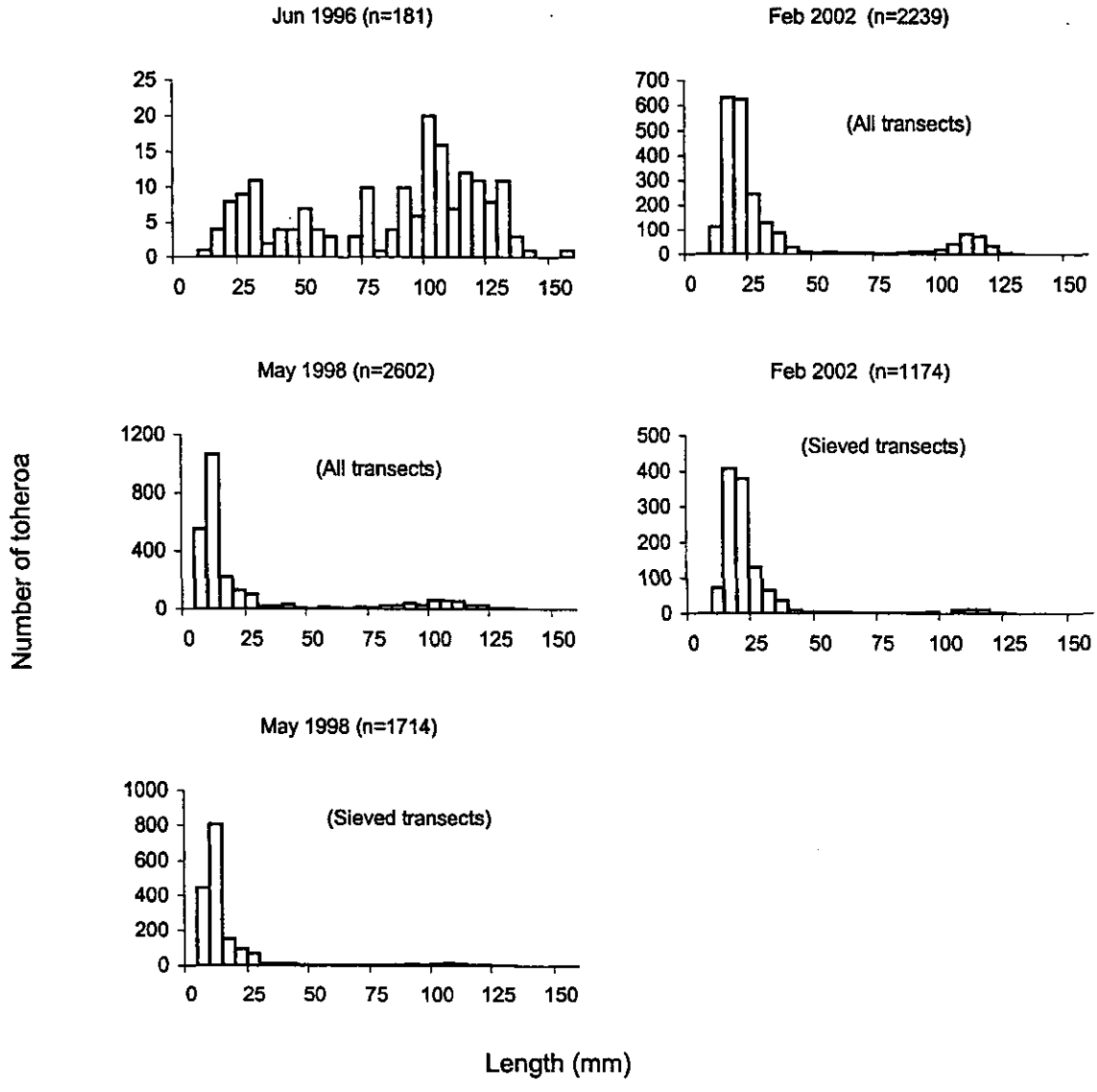


Figure 10 – *continued*

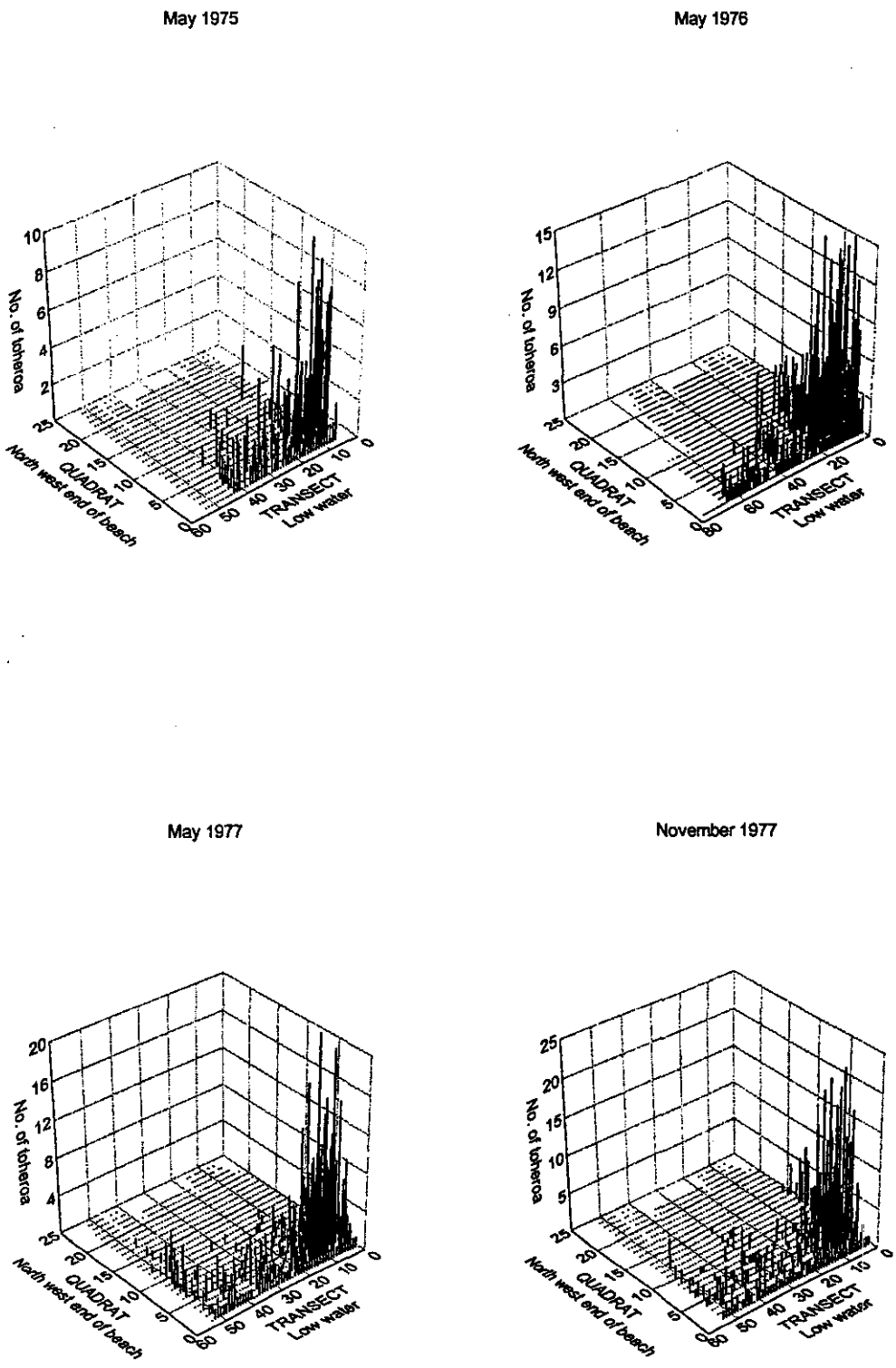
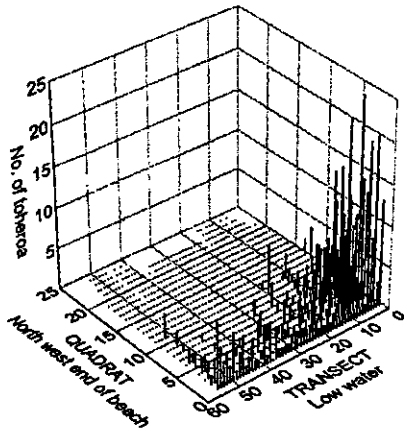
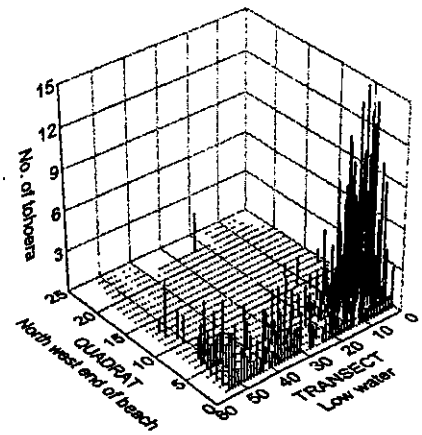


Figure 11: Distribution plots of toheroa (all sizes) on Oreti Beach from surveys carried out between 1975 and 2002. All surveys used systematic transects along the beach except 1998 and 2002 which used stratified random transects.

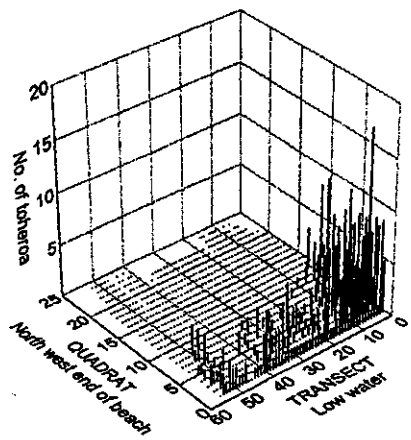
March 1978



November 1978



May 1979



April 1980

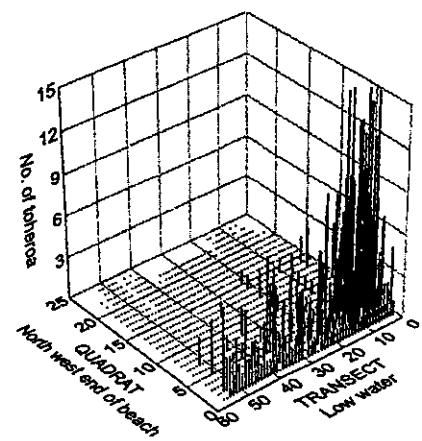
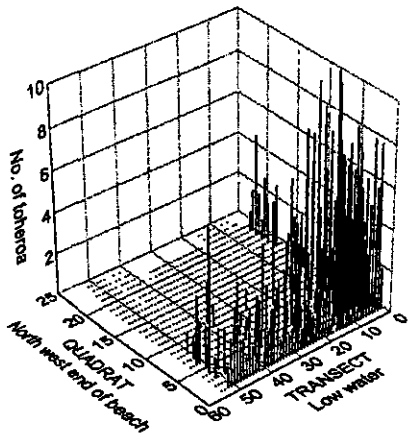
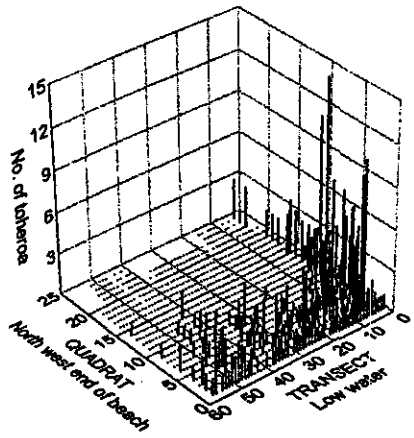


Figure 11 - *continued*

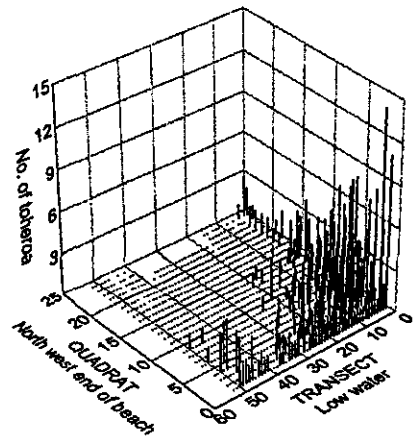
March 1981



March 1982



March 1983



June 1984

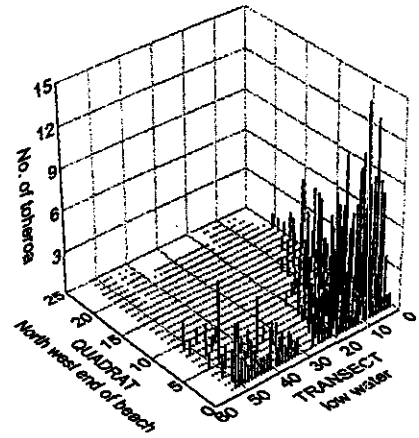
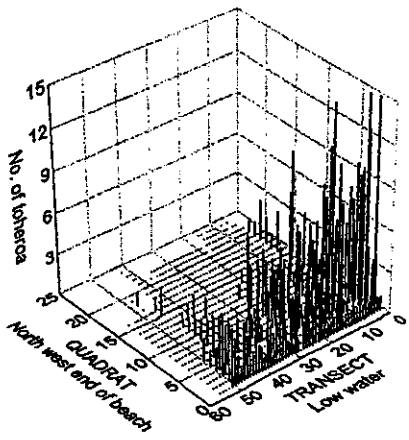
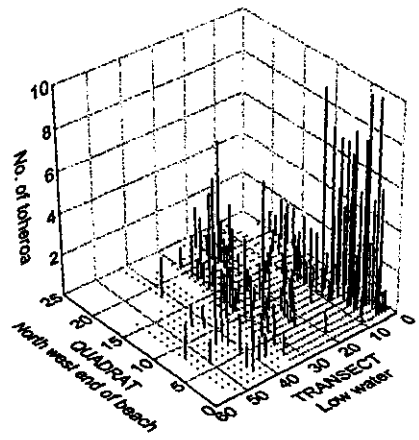


Figure 11 - *continued*

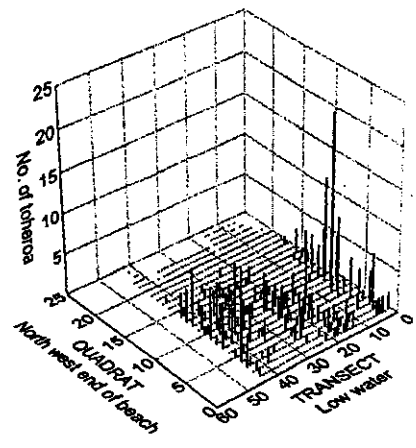
June 1985



September 1987



June 1988



March 1990

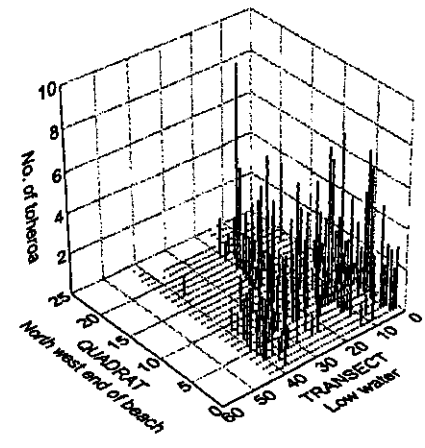
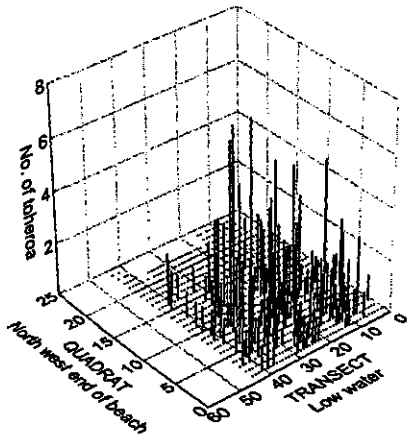
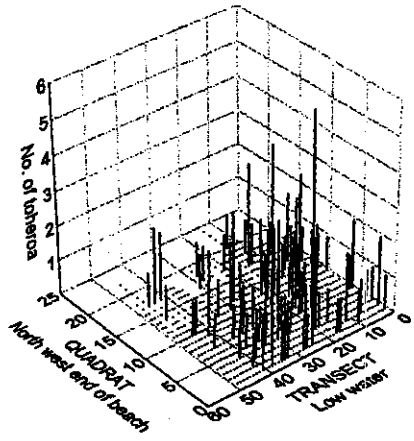


Figure 11 - *continued*

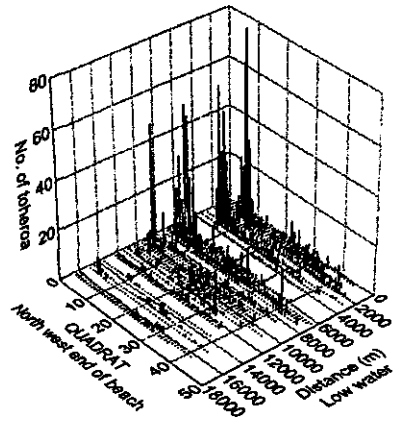
October 1990



June 1996



April 1998



FEBRUARY 2002

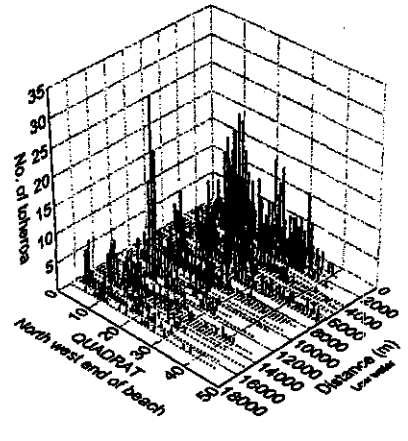


Figure 11 - *continued*