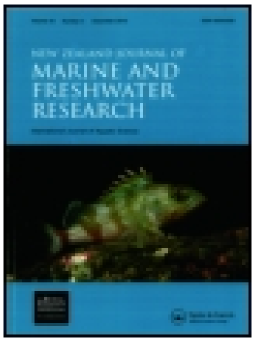

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Abundance of large toheroa (*Paphies ventricosa* Gray) at Oreti Beach, 1971–90, estimated from two-dimensional systematic samples

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Abstract The population of toheroa (*Paphies ventricosa* Gray) at Oreti Beach, South Island, New Zealand, was until recently considered relatively minor in comparison to those of the North Island west coast beaches. It is now the sole remaining toheroa population in New Zealand to support recreational toheroa gathering. This paper analyses count data from 22 systematic surveys of large toheroa (≥ 8 cm) at Oreti Beach between 1971 and 1990. A variance estimator appropriate to two-dimensional systematic surveys is developed to enable computation of confidence intervals for these abundance estimates. It is concluded that the recreational harvest taken during open days can not be reliably estimated by pre- and post-harvest surveys and should instead be determined from inspection and enumeration of open day participants. At current population and harvest levels the impact of occasional open days at Oreti Beach is slight; however, the high annual variability of toheroa populations and the uniqueness of this one remaining harvestable stock suggest a need for continued population surveys.

Keywords abundance; Mesodesmatidae; toheroa; systematic sample; variance estimator

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INTRODUCTION

Toheroa is the Maori name for the large bivalve mollusc *Paphies ventricosa* Gray (Beu & De Rooij-Schuiling 1982). Toheroa are endemic to the mainland of New Zealand and found predominantly on Ninety Mile, Dargaville, and Muriwai Beaches in Northland, Golden Coast Beaches on Wellington's west coast, and Oreti and Bluecliffs Beaches in Southland (Fig. 1). Smaller populations are present on several other beaches around New Zealand (Redfearn 1974).

Toheroa reside primarily between the mean high and mean low water levels on exposed fine sand beaches (Rapson 1952; Cassie 1955; Redfearn 1974). They are active burrowers and may be found down to 20 cm below the beach surface. The Northland populations tend to be aggregated into distinct beds (Greenway 1969), whereas the Southland populations are dispersed over much of the available beach (Street 1971). The existence of populations of large sublittoral toheroa has been mooted (Cassie 1955; Waugh & Greenway 1967; Stace 1991) but all direct attempts at verification, including diving in Te Waewae Bay (Street 1971) and dredging off Dargaville Beach (Redfearn 1974), have failed to support this hypothesis.

As a national delicacy, toheroa have suffered intensive harvesting pressure. The first commercial harvesting of toheroa began on Dargaville Beach in the late 1800s (Stace 1991), and later on Ninety Mile and Muriwai Beaches. By the early 1960s, stocks of toheroa had declined to such levels that canning ceased in 1969 (Redfearn 1974).

Restrictions on the recreational gathering of toheroa were first introduced in 1932 and included a 2-month closed season, minimum takeable size of 3 in. (76.2 mm) and daily bag limit of 50 for Europeans (Redfearn 1974). Despite these restrictions, the North Island populations continued to decline. In 1955 the daily bag limit was reduced to 20 and all beaches were closed to toheroa harvesting except for a 2-month open season each year (Redfearn 1974).

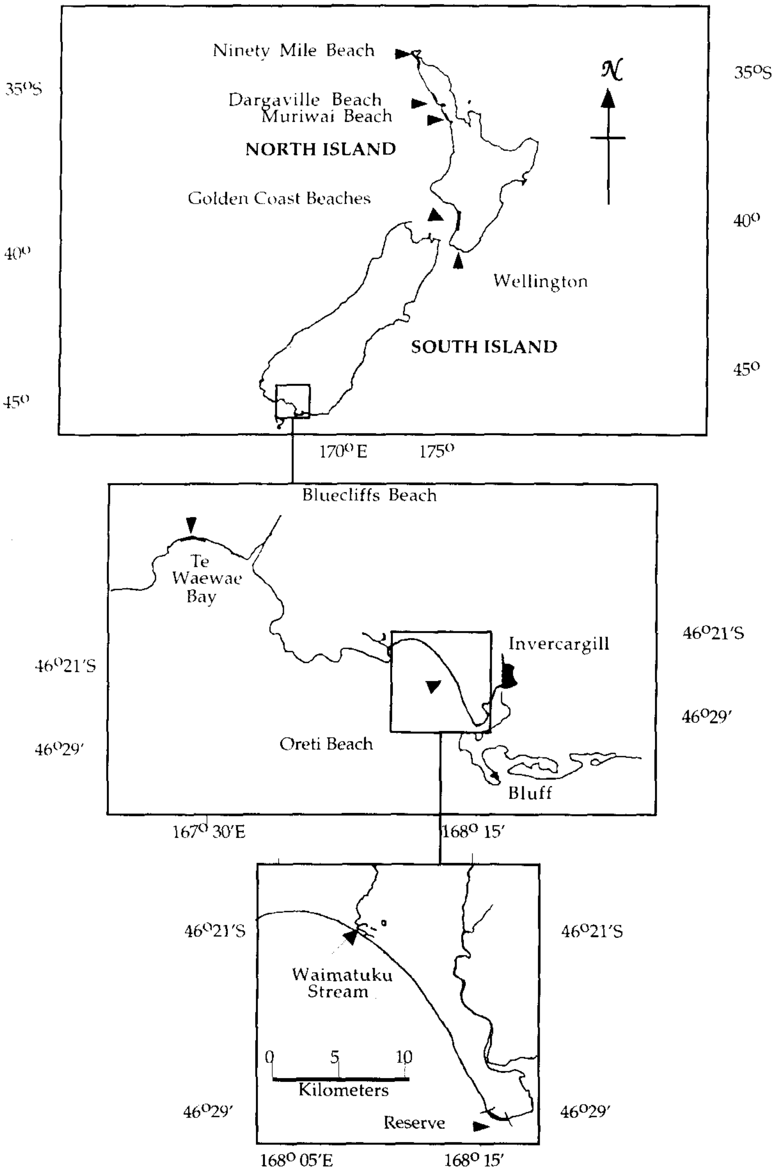

Fig. 1 Locations of some important toheroa beaches of New Zealand. The surveyed region of Oreti Beach runs 17.2 km SSE from the Waimatuku Stream, with the southernmost 1.8 km being a toheroa reserve.

Intermittent population surveys began in 1934 to monitor the effects of the increased harvesting pressure, but they did not become annual events at the major toheroa beaches (Ninety Mile, Dargaville, and Muriwai) until 1962. These surveys were used to monitor the population and to provide timely amendments to the regulations for purposes of conserving the toheroa stocks. Successive annual stock abundance estimates were highly variable, due in part to statistical variability, but primarily due to widely fluctuating and irregular recruitment and natural mortality (Redfearn 1974). However, the dominant trend in abundance was of further decline, with the Dargaville Beach population dropping from about 20 million to 3 million between 1962 and 1971 (Greenway 1972; Redfearn 1974). Tighter restrictions on recreational gathering were announced in 1972 but the decline continued, ultimately leading to the long-term closure of all North Island toheroa gathering.

Today, Oreti Beach hosts the only toheroa population to have been harvested since 1980.

Since 1981 only two open days have been held on Oreti Beach, one of 11 hours duration in 1990 and another of 9 hours duration in 1993. Harvesters were restricted to a bag limit of five takeable (≥ 10 cm) toheroa per person.

This study estimates the abundance of large toheroa (≥ 8 cm) at Oreti Beach using data from 22 systematic surveys completed between December 1971 and October 1990. The reliability of these estimates is used to determine whether it is feasible to assess the impact of an open day from pre- and post-harvest surveys. This required application of a variance estimator appropriate to systematic surveys.

METHODS

Systematic sampling

Oreti Beach (Fig. 1) is about 5 km west of Invercargill and the toheroa surveys since 1971 are within the region stretching 17.2 km south-south-east from the Waimatuku Stream, with the southernmost 1.8 km being a reserve that is permanently closed to harvesting.

The sampling is systematic, with parallel transects at right angles to the beach, made at distances of about 0.2 mile (322 m) along the beach. Quadrats of 1 m by 0.5 m are dug at 5 m intervals down each transect (McKinnon & Olsen 1994) and the quadrats thus roughly fall on a grid. A garden fork is used to quickly dig each quadrat to a sufficient depth (approximately 30 cm) to minimise escape of the rapidly burrowing toheroa. Each 1 m by 0.5 m quadrat can be considered to be in the centre of a corresponding 322 m by 5 m area of the beach, and the sampling fraction is therefore $(1 \times 0.5) / (322 \times 5) = 1 / 3220$.

Six of the 22 datasets analysed are shown in Fig. 2. Anomalies in some datasets were evident. Five surveys did not include all 54 (approximately) transects necessary to cover the full 17.2 km length of the beach and two (including one of the above five) did not include the reserve area. A further three surveys (May 1971, June 1972, and December 1977) were available but not analysed because they were incomplete and it was not clear how the survey had deviated from the specified sampling scheme.

Analysis

Let $Y_{i,j}$, $i = 1,\dots,I$, $j = 1,\dots,J$ be the counts of large toheroa at each quadrat and let Y_{++} be their sum. The estimated number of large toheroa at Oreti Beach $\hat{N}$ is given by scaling up Y_{++} using the inverse of the sampling fraction, 3220. That is, $\hat{N} = 3220\, Y_{++}$.

The theory of simple random sampling does not apply to this analysis because the sampling locations are totally determined from the position of the first quadrat. That is, the sample is systematic. Milne (1959) and Ripley (1981) suggest that treating the sample as random remains a reasonable approach, and that the usual variance estimator

$$\hat{V}_{ran}(Y_{++}) = IJ \frac{\sum_{i=1}^{I} \sum_{j=1}^{J} \left(Y_{i,j} - \frac{Y_{++}}{IJ} \right)^2}{IJ - 1} \qquad (1)$$

provides satisfactory performance. However, Payandeh (1970) and Dunn & Harrison (1993) caution that this approach can seriously over-estimate the sampling error and that a systematic sample variance estimator should be used.

There is no consensus on estimation of sampling error from systematic samples, with the virtues of competing variance estimators depending upon spatial properties (e.g., periodicity, correlation structure) of the population under study. Wolter (1984) compared eight different variance estimators and, in the absence of specific information about the spatial structure of the population, expressed a preference for an estimator based on post-sampling stratification (Cochran 1963: 225; Murthy & Rao 1988: eq. 32). Dunn & Harrison (1993) used a similar variance estimator in a simulation study and showed that it outperformed the random sample variance estimator (Eq. 1). A version of this estimator, based on post-stratification with 2 by 2 overlapping strata is used here.

The variance estimator calculates the variance within each 2 by 2 strata. They are permitted to overlap (Fig. 3), resulting in $(I - 1)(J - 1)$ such strata. Let s_{ij}^2, $i = 1,\dots,I-1$, $j = 1,\dots,J-1$ denote the sample variance of the 2 by 2 strata with upper left corner at $Y_{i,j}$. That is, s_{ij}^2 is the sample variance of the four observations $(Y_{i,j}, Y_{i+1,j}, Y_{i,j+1}, Y_{i+1,j+1})$, given by $s_{ij}^2 =$

$$\frac{\left(Y_{i,j} - \bar{Y}_{i,j}\right)^2 + \left(Y_{i+1,j} - \bar{Y}_{i,j}\right)^2 + \left(Y_{i,j+1} - \bar{Y}_{i,j}\right)^2 + \left(Y_{i+1,j+1} - \bar{Y}_{i,j}\right)^2}{3}$$

where $\bar{Y}_{i,j}$ is the average of $(Y_{i,j}, Y_{i+1,j}, Y_{i,j+1}, Y_{i+1,j+1})$. The variance of Y_{++} is estimated to be

$$\hat{V}_{sys}(Y_{++}) = IJ \frac{\sum_{i=1}^{I-1} \sum_{j=1}^{J-1} s_{ij}^2}{(I-1)(J-1)} \qquad (2)$$

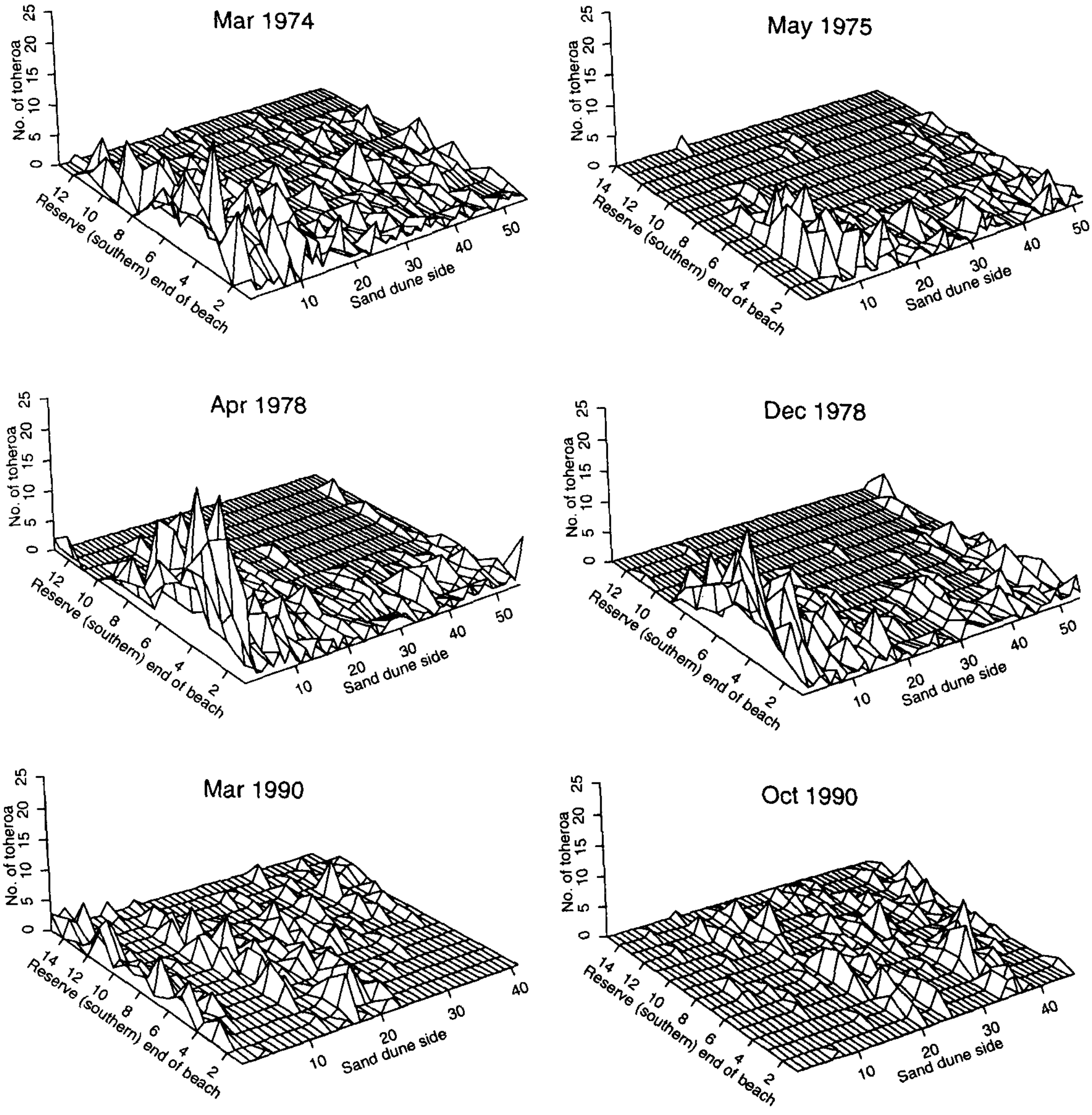

Fig. 2 Perspective plots of toheroa quadrat counts observed from six systematic samples of Oreti Beach. Transect numbers are shown on the horizontal axes.

This formula is simply calculating the average of s_{ij}^2, $i = 1,\ldots,I-1$, $j=1,\ldots,J-1$, and multiplying by IJ because Y_{++} is the total of IJ observations. The estimated standard error of $\hat{N}$ is then

$$\hat{S}_{sys}\left(\hat{N}\right) = 3220\sqrt{\hat{V}_{sys}\left(Y_{++}\right)} \quad (3)$$

RESULTS

For each of the 22 surveys $\hat{V}_{sys}$ was smaller than $\hat{V}_{ran}$, and typically by about 50%. When counts at neighbouring quadrats are positively correlated then $\hat{V}_{ran}$ overestimates the true variance (Wolter 1984). Such positive correlation provides a degree of

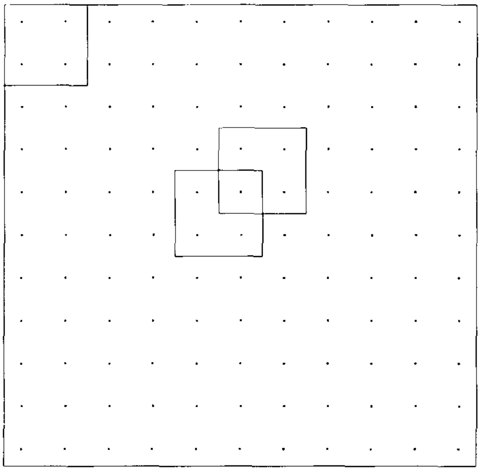

Fig. 3 Examples of overlapping 2 by 2 strata used in calculation of the systematic sampling variance estimator $\hat{V}_{sys}$.

homogeneity within the 2 by 2 strata and results in $\hat{V}_{sys}$ being a better estimator of the true variance.

The sequence of abundance estimates (Table 1, Fig. 4) suggest that the population of large (≥ 8 cm) toheroa at Oreti Beach approximately doubled between 1971 and 1974, remained stable until 1979, and then dropped back to the levels of the early 1970s. To some extent, this pattern appears to have been repeated in the 1980s, though the comparison is weakened by the absence of a survey in 1986. The most recent estimates of abundance place the population once more at the low part of this cycle.

The three most recent surveys have not provided complete coverage of the beach. In such surveys the beach samplers terminated the survey at a point, north of which few toheroa appeared to be present as indicated by the absence of the twin siphon holes used by toheroa for feeding and excreting. The underestimation should not be severe, and indeed, the data from complete coverage surveys suggest that the omitted portion would contribute at most 10% to the total.

The surveys conducted in May 1975 and October 1990 did not cover the reserve area. An estimate of total abundance was obtained by including the reserve abundance from the previous survey.

Raw data on the length distribution of toheroa were not available for this study. However, length frequency plots for the surveys since June 1980 are given in McKinnon & Olsen (1994). They show that there are relatively few toheroa in the 8–10 cm size range (Fig. 5), and most of the enumerated toheroa (≥ 8 cm) are therefore of takeable (≥ 10 cm) size.

DISCUSSION

The estimated standard errors of $\hat{N}$ (Eq. 3, Table 1), varied between 71 000 (December 1971) and 144 000 (January 1976). Using counts of cars at Oreti Beach, the number of toheroa taken during the 1990 open day was estimated to have an upper bound of 56 500 (McKinnon & Olsen 1994). The large standard errors of $\hat{N}$ preclude the use of pre- and post-harvest surveys for purposes of reliably

Table 1 Estimates of abundance of large (≥ 8 cm) toheroa at Oreti Beach.

Survey	Abundance (1000s)	Std. error (1000s)	95% CI (1000s)
Dec 71[1]	860	71	720–1010
May 73*	1310	104	1100–1520
Mar 74*	2400	126	2150–2650
Nov 74[1]	1990	125	1740–2240
May 75[2]	1730	140	1450–2010
Jan 76	2430	144	2140–2720
May 77	2290	134	2020–2560
Nov 77	2270	132	2010–2530
Apr 78*	2300	136	2020–2570
Dec 78	1970	104	1760–2180
Apr 79	1550	106	1330–1760
Jun 80*	1940	115	1710–2170
Nov 80	1250	115	1020–1480
May 81*	1610	97	1410–1800
Apr 82	1300	91	1120–1490
Jul 83	1350	86	1180–1520
Jul 84	1640	100	1440–1840
Jun 85	2090	122	1840–2330
Sep 87	1150	99	950–1350
Jun 88[1]	1290	116	1060–1520
Mar 90*,[1]	1190	91	1010–1370
Oct 90[1,2]	1270	100	1070–1470

*survey made before an open season
[1]the survey did not cover the entire length of the beach (the northern end of the survey area was sometimes not sampled if the surveyors felt that few toheroa were present)
[2]the reserve area was not sampled. In these two instances, the reserve abundance estimated from the previous survey was added to obtain the estimate of total abundance.

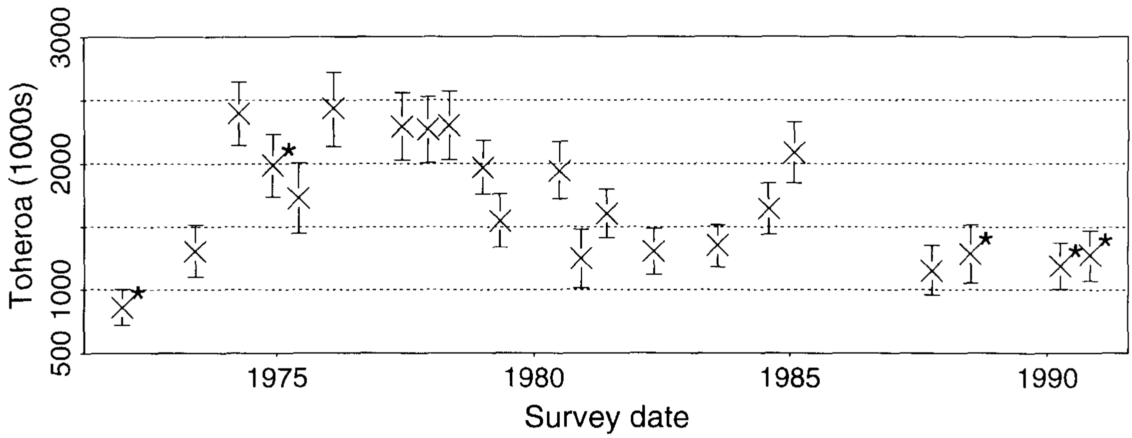

Fig. 4 Estimated abundance of large (≥ 8 cm) toheroa and associated 95% confidence intervals. Surveys marked with an asterisk did not fully cover the northernmost portion of Oreti Beach. They are unlikely to underestimate by more than 10%.

estimating the recreational take. For example, an estimate of the 1990 recreational harvest was made by comparing the estimated non-reserve abundance of toheroa in March 1990 with that in October 1990. Removing the reserve from the March survey reduces estimated abundance by 350 000, leaving a non-reserve abundance of 840 000. The October (non-reserve) abundance was estimated to be 920 000, implying that there were more toheroa after the harvest than before.

Information on the population dynamics of Oreti Beach toheroa is limited. It is known that toheroa are susceptible to extreme natural mortality in unfavourable environmental conditions. For example, in 1938 the early onset of easterly winds and sudden rise in beach temperature when the tide did not cover the toheroa are believed to have contributed to a devastating decline in the Muriwai Beach toheroa population: abundance dropped from 15 million to 1 million in that year (Rapson 1954; Redfearn 1974; Stace 1991). The Oreti Beach population does not appear to be as variable, although there have been reports of large numbers of dead toheroa washing up on Southland beaches (Street 1971; Eggleston & Hickman 1972).

The Southland toheroa are much slower growing than their northern counterparts, reaching takeable size at between 7 and 9 years of age (Cassie 1955; McKinnon & Olsen 1994) by which time they will have been mature for several years (McKinnon & Olsen 1994). The lifespan of toheroa is considered to be about 20 years (Cassie 1955). Thus, at the levels of abundance indicated by the 1990 surveys, an open day harvest of about 50 000 would, by itself, have little impact on the Oreti Beach toheroa. However, the North Island populations of toheroa have remained at low levels, despite more than two decades without legal harvesting at some beaches.

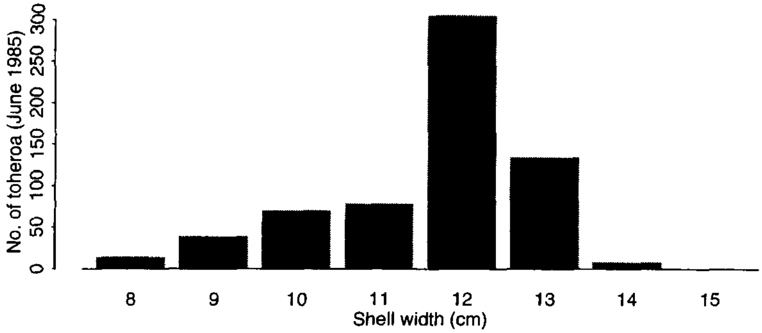

Fig. 5 Length–frequency plot from the June 1985 survey (from McKinnon & Olsen 1994).

In addition to environmental effects, large toheroa are vulnerable to poaching and smaller toheroa are at risk to crushing by vehicular traffic (Stace 1991). In combination, these stresses warrant continued monitoring of the Oreti Beach toheroa.

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