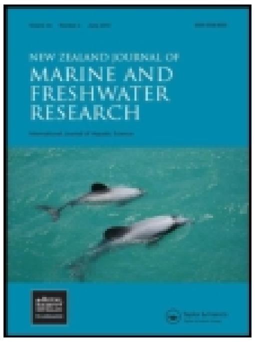

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Abundance, distribution, and size structure of toheroa (*Paphies ventricosa*) at Ripiro Beach, Dargaville, Northland, New Zealand

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Abstract The distribution of toheroa (*Paphies ventricosa* Gray) beds, and the abundance and size structure of toheroa at Ripiro Beach, Dargaville, New Zealand, were determined by a two-phase stratified sample survey. The first phase was undertaken in February and March 1999 and the second phase in June 1999. The first phase located and sized 45 toheroa beds, and stratified the beds according to the observed density of siphon holes. A total of 53 transects were sampled. The transects were run perpendicular to the shoreline and positioned systematically within each stratum. Along each transect the sampling of beds was done at 5 m intervals using a 1 × 0.5 m quadrat. Outside of the beds, sampling was done at 10 m intervals. The total number of toheroa 75 mm (previous minimum legal size) was estimated to be 3.3 million with a standard error of 480 000. This abundance of legal-sized toheroa is roughly comparable with numbers last seen at Ripiro Beach in the late 1960s. The total abundance of toheroa of all sizes was estimated to be 113.5 million with a standard error of 33 million. It appears that there has been good recruitment of 0+ toheroa on Ripiro Beach and the abundance of toheroa of all size ranges has greatly increased since the previous survey in 1974.

Keywords abundance; Dargaville; *Paphies ventricosa*; Ripiro Beach; stratified sampling; toheroa

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INTRODUCTION

Toheroa (*Paphies ventricosa* Gray) are endemic to New Zealand and in earlier times were abundant on west coast beaches of the North Island (Ninety Mile, Ripiro, Muriwai, and Wellington Beaches) and on Oreti and Bluecliff Beaches in Southland (Redfearn 1974). Toheroa were an important food source to Maori in the pre-European era as evidenced by archaeological research into Maori middens (Davidson 1967). By 1900 the shellfish had become a delicacy with the European population and began to be commercially exploited (Redfearn 1974).

Aggregations of toheroa are known to form distinct beds along the length of Ripiro Beach. In addition, isolated toheroa have been found in non-bed locations. Toheroa occur between high tide and low tide with the larger shellfish between low and mid tide and the new recruits settling near the high tide mark. They are found up to a depth of 300 mm under the sand (Redfearn 1974).

Ripiro Beach (Dargaville) has traditionally been the most abundant source of toheroa in Northland. A cannery was opened in 1904 and a second opened in 1911. Commercial production peaked in 1940 with 77 t of canned product coming from toheroa harvested from Muriwai and Ripiro Beaches. By the mid 1960s stocks of toheroa had declined to such levels that commercial exploitation became uneconomic and ceased in 1969 (Redfearn 1974).

Restrictions on recreational gathering were first introduced in 1932. They included a 2-month closed season, a minimum takeable size of 3 inches (76.2 mm) and a daily bag limit of 50 (Redfearn 1974). In 1955 the quota and length of open season

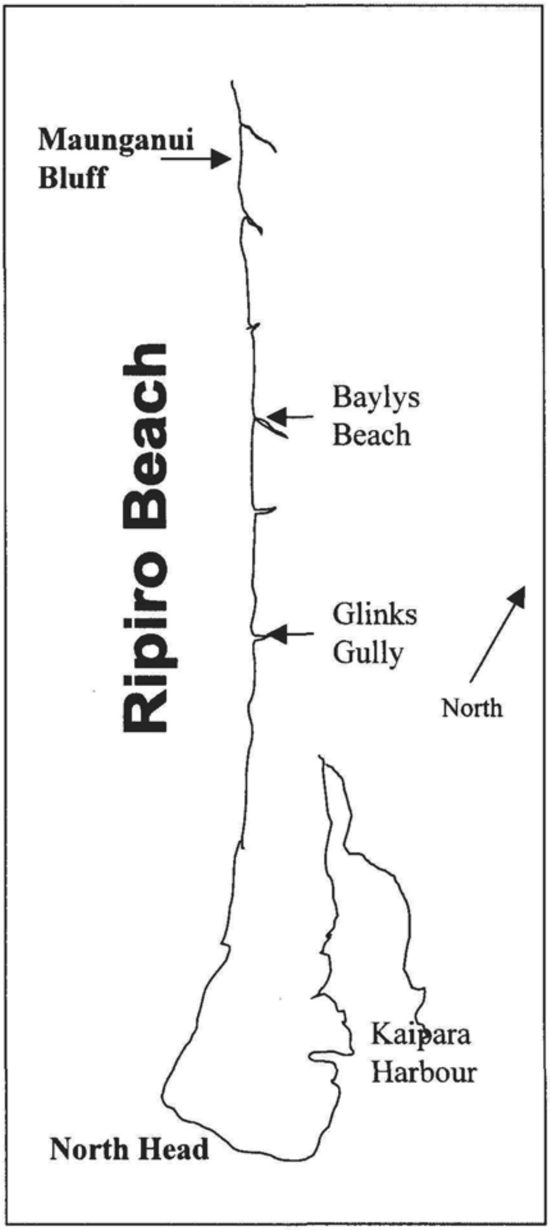

Fig. 1 Ripiro Beach, Dargaville, New Zealand.

harvests were further reduced and in 1967 all North Island beaches were closed for that year. Since that time, because of extremely low abundance of toheroa, there have been further restrictions with only the occasional open days, until finally all North Island beaches were closed. The last open day for Ripiro Beach was in 1980.

Before 1962 only occasional surveys for toheroa were undertaken at Ripiro Beach but from 1962 to 1971 the Marine Department conducted annual surveys of Ripiro Beach to monitor the population and to provide recommendations for changes in the regulations to ensure the conservation of toheroa. These surveys did not cover the northernmost portion of the beach (south of Maunganui Bluff, Fig. 1) because this region was known to be of low toheroa abundance. Moreover, they did not use a sieve to retain small toheroa and hence numbers of toheroa < 30 mm are likely to have been underestimated and toheroa < 15 mm grossly underestimated. Thus, these surveys could be expected to give reasonable estimates of abundance of legal-sized toheroa, but severe underestimates of the total population.

The survey estimates of the abundance of legal-sized toheroa from 1962 to 1971 were highly variable, partly because of statistical variability, but primarily the result of widely fluctuating and irregular recruitment and natural mortality (Greenway 1969, 1972; Redfearn 1974). These surveys showed the general trend in abundance to be one of decline between 1962 and 1971, the estimated legal-sized abundance dropping from c. 10 million to fewer than 3 million. The Ministry of Agriculture and Fisheries continued these surveys from 1972 to 1974, and abundance of legal-sized toheroa was estimated to be c. 1 million throughout this period (Greenway 1974, 1975). Pilot surveys conducted by the Ministry of Agriculture and Fisheries in 1990 and 1993 found insignificant levels of legal-sized toheroa (none in 1990 and one in 1993) to warrant the implementation of a full survey (Ministry of Fisheries pers. comm.).

Since 1993 there have been no reported Ministry surveys. However, independent surveys have been carried out by local Kaitiaki who are the customary guardians of the beach. The results have indicated a steady improvement of toheroa abundance and evidence of several years of exceptional recruitment (Searle & Te Tuhi pers. comm.). The increased abundance is largely attributed to two factors—good natural recruitment and the active role of locals in managing and protecting the beds.

There is presently no commercial or recreational fishery for toheroa at Ripiro Beach. However, there is a controlled customary take managed by the local Kaitiaki. Permits are issued by the Kaitiaki, to Maori and pakeha, for special occasions such as huis and tangis and for the sick and elderly. Evidence of poaching is frequently seen, but the size of this illegal toheroa harvest is unknown.

METHODS

A two-phase stratified sample survey was used. The first phase determined the distribution of the beds and the strata definitions. The second phase employed a systematic stratified design to estimate the abundance and age structure of toheroa. The survey covered the entire 72.4 km length of Ripiro Beach from Maunganui Bluff to North Head (Fig. 1).

Phase 1: strata determination (February–March 1999)

Because the major toheroa beds lie in the area between Baylys Beach and just south of Glinks Gully, beds in this area were located by teams of four to six sampling staff walking along the beach line abreast, from high to low tide marks. Beds were identified by the location and density of siphon holes.

Outside this area the beds were located and recorded by travelling slowly along the beach on the back of a four-wheel-drive truck and observing where siphon holes occurred. Subsequently, a location check was made against records held by two Kaitiaki responsible for management of the toheroa beds on behalf of Ripiro iwi. This check ensured that all major beds were identified in Phase 1 of the survey.

The geographical position of the beds was recorded using Global Position Fixing equipment (GARMAN GPS II Plus). The approximate length (parallel to shoreline) and breadth of the beds were measured using the criterion that the edge of the bed was the point where siphon hole densities were less than 1 m^{-2}.

Within each bed the number of siphon holes was counted within a 25 m^2 area marked by placing a stick in the approximate centre of the bed and scribing a circle of radius 2.82 m. In addition, within this circle a 814 cm^2 area (size of clip chart carried by samplers) was chosen randomly and counted for siphon holes and then dug to determine the actual number of toheroa. These data were used to determine the strata and relative sampling efforts to be used in the Phase 2 sampling.

Phase 2: quadrat sampling (June 1999)

This phase was delayed until June at the request of Maori because they considered that the new spatfalls which had occurred during the spring and summer months needed protection.

Phase 1 of the survey found that the presence of siphon holes could be used to demark extensive and well defined beds of toheroa lying entirely within the intertidal region. Beds were defined as low or high density according to whether the number of siphon holes within the 25 m^2 area exceeded 1000, leading to the definition of three transect strata: (1) non-bed transect; (2) low-density bed transect; (3) high-density bed transect.

The horizontal intertidal breadth of Ripiro Beach is c. 90 m, and it was decided to space quadrats every 10 m in the non-bed transect stratum. However, the median breadth of the beds was just over 10 m, and consequently for the bed transects it was decided to

Table 1 Description of transect strata.

Transect stratum	No. of siphon holes	Cumulative length (km)	No. of transects	Between-transect distance (m)
(1) Non-bed	0	68.7	8	8600
(2) Low-density bed	0< and <1000	1.8	18	99.8
(3) High-density bed	>1000	1.9	27	70.6

Table 2 Quadrat strata and scaling factors. (LD and HD denote low-density and high-density toheroa (*Paphies ventricosa*) beds, respectively.)

Quadrat stratum	No. of quadrats	No. of legal-sized toheroa counted	Scaling factor	Estimated no. legal size	Variance
(1) Non-bed	59	5	172 000	860 000	1.4×10^{11}
(2a) Inside LD	43	990	998	988 020	5.9×10^{10}
(2b) Above/below LD	95	40	1996	79 840	8.5×10^{8}
(3a) Inside HD	78	1771	706	1 250 326	3.3×10^{10}
(3b) Above/below HD	150	54	1412	76 248	5.4×10^{8}
Total	425	2860		3 254 434	2.4×10^{11}

use a quadrat spacing of 5 m within the beds but retain the spacing of 10 m above or below the bed. In a typical bed transect, the quadrats at distances 0, 10, 20, 30, 40, 50, 60, 70, 80, and 90 m from the top mark would first be staked. Then, any additional 5-m-spaced quadrats within the bed would be staked. For example, if the upper and lower edges of the bed lay at 43 and 58 m, respectively, then additional quadrats would be staked at 45 and 55 m. This method of placement ensured the validity of the sampling fraction calculations in the Statistical Analysis section.

The necessary distinction between quadrats lying in a bed and those lying above or below a bed resulted in a five-way stratification of the sampled quadrats: (1) on a non-bed transect; (2a) in a low-density bed; (2b) above or below a low-density bed; (3a) in a high-density bed; and (3b) above or below a high-density bed.

The formula for optimal allocation states that sample size should be proportional to the size of the stratum multiplied by the standard deviation within the stratum (Snedecor & Cochran 1989). The standard deviations of toheroa counts within the low-density and high-density beds were estimated using the counts of toheroa obtained by the exploratory quadrats dug in the first phase. These calculations suggested that c. 40% of the within-bed quadrats should be dug in the low-density beds, and hence the transects were placed so that c. 40% of transects passing through beds were placed through low-density beds. There was inadequate information from Phase 1 to formally determine sampling effort for the non-bed transect stratum.

Available field resources permitted 45 transects through beds, with 18 allocated to low-density beds and 27 to high-density beds. Eight transects were placed in the non-bed transect stratum. Within each transect stratum, transects were placed in a systematic fashion by using equal spacing on the basis of the cumulative distance within each stratum along the beach (Table 1). For example, the high-density beds cumulatively had a length of 1906 m, and hence the 27 transects were placed 70.6 m apart in terms of distance within this stratum.

The quadrats were dug to a depth of 30 cm and all toheroa in the sample were collected. All quadrats were sieved using a 5-mm mesh, and all toheroa were measured to the nearest millimetre in length.

Statistical analysis

The sampling fraction for each of the five strata was calculated from the between transect and between quadrat spacing. For example, for quadrat stratum 3a (within a high-density bed) transects were 70.6 m apart and quadrats were 5 m apart. Hence, each 0.5 m^2 quadrat was representative of a $70.6 \times 5 = 353$ m^2 area, corresponding to a sampling fraction of 1 in 706 (Table 2). Similarly, above or below a high-density bed the quadrat spacing increased to 10 m, corresponding to a sampling fraction of 1 in 1412 in quadrat stratum 3b. This method of determining the sampling fraction has the advantage that it does not require accurate estimation of strata areas, which is problematic when the beds are not perfectly rectangular in shape, and it does not require the initial quadrat to be precisely placed. Instead, in a transect passing through a bed, it simply required the sampler to walk along the transect and to determine which quadrats were within the bed and which were above or below, and to mark the quadrats accordingly. This was done before digging commenced, and of course, there was the requirement that the transect span the entire range over which toheroa may be present.

Strictly speaking, the above statement that a quadrat in stratum 3a is representative of a 353 m^2 area will not apply to a quadrat near the edge of the bed—but the statement is valid when interpreted as applying on average. Some stratum 3a quadrats near the edge of the bed will be representative of a bed area larger than 353 m^2 (those that are between 2.5 and 5 m from the edge), but a similar number will be representative of a bed area smaller than 353 m^2 (those less than 2.5 m from the edge). Similarly for the other quadrat strata sampling fractions.

The inverse of the sampling fraction gave the scaling factor to be used in multiplying the number of toheroa sampled to obtain an estimate of the total number of toheroa in the stratum. These were summed over strata to give the overall total abundance. That is, the total abundance of toheroa, M, was estimated to be:

$$M = \sum_i w_i M_i$$

where M_i is the number counted in stratum i and w_i is the scaling factor.

The usual random sample formula for the variance of the estimated total abundance (Millar & Olsen 1995) was used within each stratum. This was because the strata were not contiguous, the result of interbed separation, and hence it would be inappropriate to use the (standard) systematic variance estimate. The use of the random sample formula is known to be moderately conservative in the sense that it overestimates variance by a modest

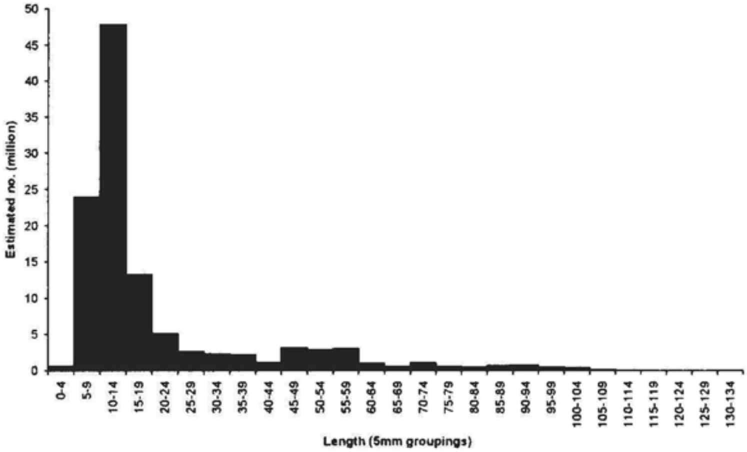

Fig. 2 Estimated length frequencies for all toheroa (*Paphies ventricosa*).

amount (Ripley 1981). The standard error (SE) of the above estimate of the population total is then given by Snedecor & Cochran (1989):

$$\mathrm{SE} = \sqrt{\sum_i w_i^2 \mathrm{SE}_i^2}$$

where SE_i is the standard error of the mean of stratum *i*.

Population length frequencies were estimated by adjusting the length frequencies within each stratum by the scaling factor, and summing over the five strata.

RESULTS

In total, 53 transects were sampled and 425 quadrats were dug. The total number of toheroa 75 mm (previous legal minimum size limit) was estimated to be 3.3 million (Table 2) with estimated variance of 2.4×10^{11}, corresponding to a SE of 480 000. The ratio of SE to estimated abundance equates to a coefficient of variation of 15%.

The total abundance of all sizes was 113.5 million with a SE of 33 million. The estimated length frequencies (Fig. 2) show a large number of toheroa <20 mm dominating the histogram. Weaker modes are evident around 45–59, 70–74, and 85–94 mm.

DISCUSSION

Forty-five discrete toheroa beds were identified. Although beds were found the length of the beach, by far the majority (33 beds) occurred around the middle of the beach between Baylys Beach and just south of Glinks Gully (Fig. 1, 3, and 4). Major beds were also observed to occur in and around all the freshwater stream areas. Rapson (1952) suggested a possible correlation between freshwater seepage and the presence of toheroa. Redfearn (1974) also commented on aggregations generally occurring in areas where the water table lies close to the sand surface at low tide. Such areas are low lying and many are in small bays along the beach which are the sites of small streams.

The modes in the length frequency histogram at around 10–14, 45–59, 70–74, and 85–94 mm (Fig. 2) correspond very well with the typical lengths of 0+, 1+, 2+, and 3+ toheroa (Redfearn 1974). The high abundance of 0+ toheroa <20 mm suggests that there have been major settlements of new recruits during the past year. However, until future surveys are undertaken, it will not be known how many of these will survive. In past studies it has been shown that many may not survive owing to a combination of weather, environmental conditions, and heavy bird predation (Redfearn 1974).

The bar plots of Greenway (1972, 1974) show that the number of legal-sized toheroa were c. 10 million in the early 1960s, 5 million in the mid 1960s, 2 million in 1971, and 1 million through to 1974. Thus, the present abundance of legal-sized toheroa is the greatest number seen since the late 1960s.

Currently a limited amount of toheroa is taken under customary permits managed by Kaitiaki appointed by Te Uri O Hau. This seems to work very well. Permits are only granted for very special occasions and in some cases to the elderly and sick. The toheroa population has improved over the last decade and if the beds continue to improve then Maori, locals, and the Ministry of Fisheries will need to work together to decide how best to manage this fishery.

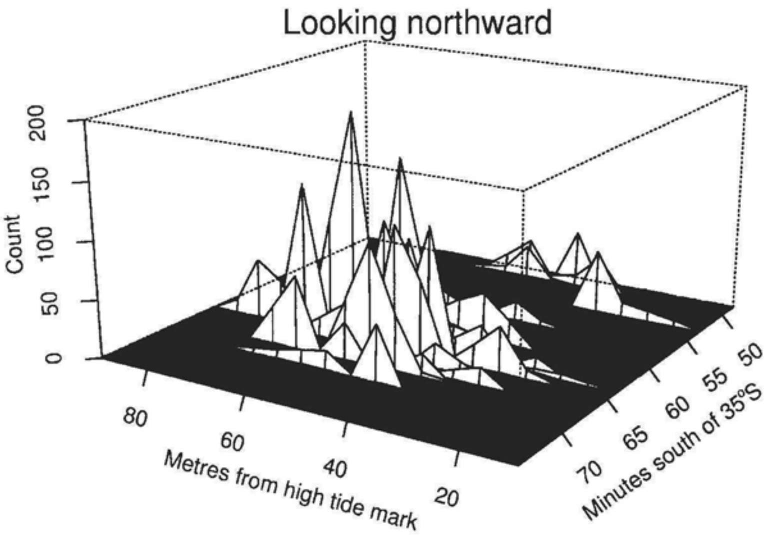

Fig. 3 Perspective plot of quadrat counts of legal-sized toheroa as seen looking northward from the southern end of Ripiro Beach, Dargaville, New Zealand. The plot required uniform spacing along both horizontal axes, which is not the case with the data because the stratified design resulted in differing between-transect and within-transect spacings. Thus, the plot uses a within-transect spacing of 5 m, and in strata with 10-m spacing it estimates the missing quadrat counts by interpolation (i.e., averaging the two adjacent quadrat counts).

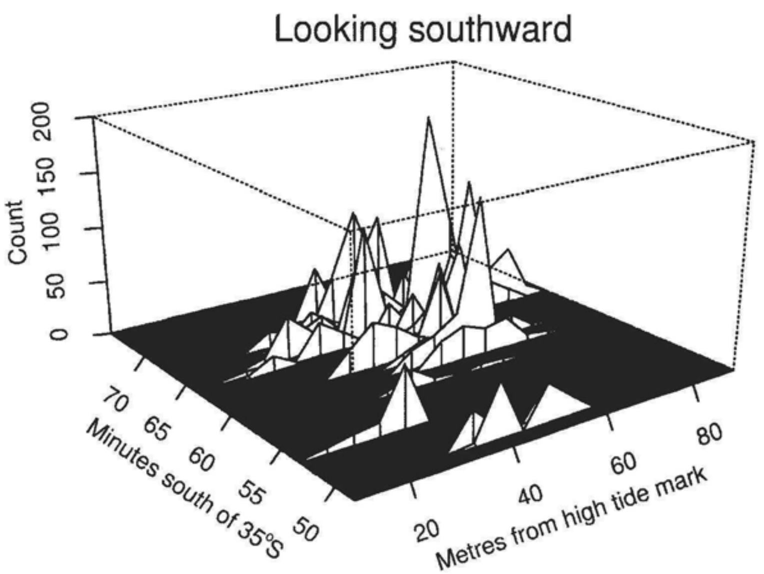

Fig. 4 Perspective plot of quadrat counts of legal-sized toheroa (*Paphies ventricosa*) as seen looking southward from the northern end of Ripiro Beach, Dargaville, New Zealand.

The survey methodology worked well, especially considering the unexpected result that legal-sized toheroa abundance would be in the millions. However, we feel it must be used with caution. The sampling fraction of the non-bed stratum was 1 in 172 000 and this makes the total abundance sensitive to the count of toheroa in this stratum (Table 2). That is, a single toheroa encountered in a non-bed area adds 172 000 to the overall estimate of abundance. If a non-bed transect did in fact pass through a bed, even one of relatively low density, then the estimate of total toheroa abundance will be drastically overestimated. In this particular study, five non-bed quadrats had a single toheroa, and the remaining 54 had no toheroa. The limited sampling effort (relative to the size of the beach) also causes the overall estimate of abundance to be sensitive to single quadrats within other strata. For example, the highest abundance quadrat within the high density beds had 194 legal-sized toheroa, and this single quadrat therefore contributed $194 \times 706 = 137\,000$ to the overall estimate of abundance. These numbers are of only moderate size relative to the estimated 3.3 million toheroa and the SE of 480 000.

If further surveys were to be carried out on Ripiro Beach, it would be worthwhile to use the present data to adjust the sampling design. Here, the non-bed stratum contributed most to the overall variance of the abundance estimate (Table 2) and the number of transects in this stratum should be increased in future studies. This would have the added advantage of protecting against the consequences of encountering a small patch of toheroa in what had been identified as a non-bed transect.

The two-phase stratified sampling methodology used here was viable because toheroa beds were clearly identifiable. If this were not so then a simpler sampling design would be preferable. Greenway (1969) noted that the toheroa beds on Ripiro Beach are generally easy to see, except on certain occasions such as after heavy rain causing excessive seepage on the beach.

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