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Distribution and abundance of toheroa (*Paphies ventricosa*) and tuatua (*P. subtriangulata*) at Ninety Mile Beach in 2010 and Dargaville Beach in 2011

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J. Williams,
H. Ferguson,
I. Tuck

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Williams, J.; Ferguson, H.; Tuck, I. (2013). Distribution and abundance of toheroa (*Paphies ventricosa*) and tuatua (*P. subtriangulata*) at Ninety Mile Beach in 2010 and Dargaville Beach in 2011.

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Toheroa (*Paphies ventricosa*) and tuatua (*P. subtriangulata*) are two closely related species of infaunal surf clam endemic to New Zealand. Toheroa are of special importance to Maori as a customary fishery species, and also previously supported intensive commercial and recreational fisheries. The smaller but more robust shelled tuatua coexist with toheroa at some beaches, particularly in Northland, and are also sought after as a valued customary and recreational fishery species. This report documents the findings of two intertidal survey projects conducted to determine the distribution, abundance and size structure of toheroa and tuatua populations in Northland at Ninety Mile Beach in 2010 and Dargaville Beach in 2011. Historically, these beaches supported two of the largest populations of toheroa in New Zealand, but despite the cessation of commercial and recreational harvesting over three to four decades ago, the abundance of large toheroa has remained low; little is known of historical tuatua abundances on these beaches.

The designs for the Ninety Mile 2010 and Dargaville 2011 toheroa and tuatua surveys were reviewed prior to each survey. For both surveys, a two-phase stratified random transect sampling design was used. Transect allocation was optimised for estimating the abundance of toheroa 40 mm or more in shell length (i.e., the putative spawning stock), but also permitted the estimation of toheroa and tuatua of various sizes. At Ninety Mile Beach, because of the expected low number of toheroa, stratification was based on historical information on toheroa distribution, with the beach divided along its length into four strata that also made sense geographically. At Dargaville Beach, pre-survey fieldwork conducted in March 2011 found 45 toheroa beds of varying density patchily distributed along the beach between stretches of low or zero densities of toheroa; from our estimations of bed dimensions we divided the beach length into five non-contiguous strata. Each survey was timed to coincide with four days of spring low tides during daylight hours to allow the maximum possible intertidal slope of the beach to be surveyed. Transects were run down the beach between high and low water, along which 0.25 m^2 quadrats spaced at 5 or 10 m intervals were dug to a depth of 30 cm, the contents sieved on 5 mm mesh, and toheroa and tuatua retained were counted and measured for shell length.

The Ninety Mile survey was conducted from 26 to 29 April 2010, with totals of 744 quadrats along 50 transects sampled. Toheroa densities were very low but tuatua densities were high. Only 38 individual toheroa (length range 7–62 mm) were encountered during the survey, whereas 13 982 tuatua were found. The estimated population abundance of toheroa 40 mm or more shell length was 1.6 million with a c.v. of 24%. No large adults (75 mm or larger) were observed. The estimated population abundance of tuatua (all sizes) was 854 million with a c.v. of 14%. This estimate does not include tuatua in the subtidal zone because it was not surveyed. The Dargaville survey was conducted from 14 to 17 April 2011, with totals of 942 quadrats along 62 transects sampled. Toheroa densities were substantially higher at Dargaville than Ninety Mile, especially in the medium and high density bed strata (mean approximately 3000 toheroa per transect), whereas tuatua densities were low. Totals of 7891 toheroa (length range 3–120 mm) and 1191 tuatua were found. The estimated population abundance of toheroa 40 mm or more shell length was 12.8 million with a c.v. of 15%, of which 1 million (c.v. 26%) were 75 mm or larger. The estimated population abundance of tuatua (all sizes) was 15.3 million with a c.v. 25% in the intertidal area of the beach surveyed. The length frequency distribution for toheroa at both beaches contained two clear modes, comprising a juvenile mode (at about 10–20 mm) and a small adult mode (at about 40–60 mm), plus evidence of a weaker third mode of larger adults (at about 70–80 mm) at Dargaville only, particularly in the medium and high density toheroa beds. These probably represent toheroa in the 0+, 1+ and 2+ year classes. Tuatua length

frequencies at both beaches were dominated by small tuatua (less than 40 mm), with larger tuatua usually found at the lower parts of the intertidal zone.

Patterns in spatial distribution along the beach and down the shore were described. At Ninety Mile, only a few toheroa individuals were found and no beds of toheroa were encountered, but tuatua were found in high density beds particularly in the central and northern parts of the beach. At Dargaville, the high and medium density toheroa beds were mainly distributed in the central and northern parts of the beach; there were relatively low densities of tuatua compared with those of toheroa, but the highest tuatua densities were found within toheroa beds. Toheroa abundance was also generally higher in or near to freshwater seeps and streams compared to drier beach areas; no such pattern was evident for tuatua. At both beaches, there was a characteristic downshore (vertical) distribution of toheroa, with the highest densities of juveniles found near the high water mark, larger juveniles and small adults found between high and mid tide, and the largest individuals found predominantly in the mid tide zone. Toheroa density was low between the mid and low water marks. Tuatua showed a similar pattern of increasing size down the shore, but, unlike toheroa, high densities of larger tuatua could be found in the lower part of the intertidal bordering on the subtidal.

Estimates from the time series of toheroa surveys show that the populations at Ninety Mile and Dargaville beaches have undergone major fluctuations in abundance, although substantial uncertainty is associated with most of the estimates because of differences in both the areas surveyed and the sampling methods employed over time. For large adult toheroa, estimated abundance up until about 1980 varied by an order of magnitude from over 10 million to less than 1 million (75 mm or more); there were few surveys in the 20 years that followed until 1999. Estimates in the last decade or so (1999–2011) suggest a decline to historically low levels has occurred at Ninety Mile. Over the same period at Dargaville, while the number of small adult toheroa has reached high levels similar to the level in the early 1960s, the number of large adult toheroa remains low.

OBJECTIVES

This work achieved the following objectives of projects TOH200901 and TOH201001. Note that because of the high importance of toheroa resources to customary fishers, both survey projects were undertaken by consulting with and involving tangata whenua in the conduct of the research.

<u>TOH200901</u>

Overall Objective:

1. To determine the distribution of toheroa (*Paphies ventricosa*) beds, and the abundance and size structure of toheroa on Ninety Mile Beach.

Specific Objectives:

1. To review the survey design for estimating the abundance of toheroa on Ninety Mile Beach.

2. To estimate the size structure and absolute abundance of toheroa on Ninety Mile Beach, during February–May 2010. The target c.v. for the estimate of absolute abundance of legal sized toheroa (≥100 mm shell length) is 20%.

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

<u>TOH201001</u>

Overall Objective:

1. To determine the distribution of toheroa and tuatua (*Paphies ventricosa* and *Paphies subtriangulata*) beds, and the abundance and size structure of toheroa on Dargaville beach.

Specific Objectives:

1. To complete the first phase of a two-phase stratified survey to determine the distribution of toheroa and tuatua beds, and the abundance and size structure of toheroa and tuatua on Dargaville beach.

2. A brief comparison between phase 1 survey results and historical data needs to be compiled and submitted. The results of this phase need to be discussed with the Ministry of Fisheries Science group before permission is given to undertake phase 2 of this survey.

3. To determine the distribution of toheroa and tuatua beds, and the abundance and size structure of toheroa and tuatua on Dargaville beach. The target coefficient of variation for the estimates of absolute abundance is 20%.

4. Compare the results of the full survey with historical data on abundance of these shellfish on this beach.

1 INTRODUCTION

1.1 Toheroa and tuatua

The toheroa (*Paphies ventricosa*) is a large endemic surf clam of the family Mesodesmatidae, the marine bivalve mollusc wedge clams; congeneric species are the pipi (*P. australis*), tuatua (*P. subtriangulata*), and deep water tuatua (*P. donacina*). Toheroa grow the largest in size out of this group of species (Powell 1979). Examination of survey data suggests that toheroa maximum size varies from about 130 mm shell length in Northland (Morrison & Parkinson 2008) to about 150 mm shell length in Southland (Beentjes 2010a, b). They are strong and adept burrowers, a necessary adaptation to their pounding surf zone environment, and are usually found buried up to 20–30 cm below the surface of the sand; toheroa feed by extending their pair of long siphons up through the sand to access microalgae suspended in the water column (Morton & Miller 1968).

Toheroa occur only on particular beaches fully exposed to surf, with fine sand, with sufficient residual moisture to prevent desiccation at low tide, and with abundant phytoplankton (Rapson 1952, Cassie 1955). The main toheroa populations are found along the west coast of Northland, the west coast north of Wellington, and the south coast of Southland. High density beds of toheroa are patchily distributed along the beach, and are often associated with wetter areas associated with streams or freshwater seepage usually found in lower lying, small embayments along the beach (Morton & Miller 1968, Powell 1979). Greenway & Allen (1962) reported “it would appear that toheroa do well generally in an area where there is freshwater seepage, but that distribution within those areas may be random or else upset by the shifting nature of the sand and seepages. Just as many beds appeared to lie in the drier ridges between seepages as lay in the seepage hollows themselves”.

Toheroa life history and factors affecting their abundance were reviewed by Williams et al (submitted 2012). Like many marine invertebrates, toheroa reproduce by broadcast spawning, synchronously releasing their gametes into the seawater for external fertilisation. The microscopic larvae develop in the plankton over a period of about three weeks, before they settle out of the water column and metamorphose into juvenile toheroa (spat). Spat settlement occurs in the high intertidal zone on the beach, and larger juveniles and adults are often found aggregated in dense beds at the mean tide level in the middle of the beach. Initial growth can be very fast, with North Island toheroa reaching sexual maturity at a length of about 40 mm after 1 year, and 75 mm after about 2 years, and 100 mm after 4–5 years. Growth slows substantially in larger animals. Mortality (susceptibility to death) and recruitment (addition of new individuals to the population) are highly variable.

The tuatua (*P. subtriangulata*) is a far more common species of surf clam than the toheroa. Tuatua are extensively distributed around New Zealand in localised abundant populations, but mainly occur in the North Island (particularly the east coast) and at more scattered locations in the northern South Island, Stewart Island, and the Chatham Islands (Morton & Miller 1968, Powell 1979, Morley 2004). They are ecological markers of fine, clean, fluid sands on ocean beaches with moderate wave exposure (Powell 1979). Sometimes tuatua have apparently replaced toheroa on the North Island west coast, but the two species seldom coexist (Morton & Miller 1968). Akin with toheroa, tuatua spat also settle high in the intertidal zone and occupy positions further down the shore as they grow in size, but the densest beds of predominantly adult tuatua are found at the lowest part of the shore, in the zone from the low intertidal to the shallow subtidal (to about 4 m depth) (Morton & Miller 1968, Morley 2004). The tuatua is usually wedged only a few centimetres into the sand, with the straight siphonal end often characteristically exposed and discoloured by a green or brown algal film (Morton & Miller 1968). The shell of the tuatua is much thicker and more robust than that of toheroa, and other characteristics of the shell are used to distinguish between the two species (Appendix 1).

1.2 Toheroa fisheries and surveys

Toheroa are an iconic New Zealand shellfish: they are of great importance to Maori as a customary fishery species, and also previously supported regionally important commercial and recreational fisheries (Williams et al. submitted 2012). Once abundant on exposed surf beaches in the regions of Northland, Wellington, and Southland, toheroa were subjected to intensive harvesting during the first half of the twentieth century, and the majority of their populations declined to low levels. All commercial harvesting ceased in 1969, and recreational harvesting was prohibited at Ninety Mile Beach in 1971 and Dargaville Beach in 1980, yet surveys in 2006 showed the population abundance of toheroa at both beaches was low compared to their former levels.

Historically, the largest populations of toheroa in New Zealand were found in west Northland, particularly on Ninety Mile, Dargaville, and Muriwai beaches, and monitoring of these northern beaches has been carried out for more than 70 years . Time series of abundance for toheroa have been required by the Ministry for Primary Industries for all major toheroa beaches: Ninety Mile Beach, Dargaville Beach, Muriwai Beach (west Northland), and Oreti Beach and Bluecliffs Beach (Southland). Dargaville Beach is one of the few remaining beaches to have been subjected to customary harvest of toheroa in recent years, and concerns have been raised about the sustainability of harvests.

1.3 Beach characteristics

Ninety Mile Beach and Dargaville Beach are located on the west coast of New Zealand’s North Island (Figure 1). These hard-packed, fine-sand beaches are exposed to prevailing winds and swell from the southwest; they are fairly flat in profile, measuring about 100–200 m wide at spring low tide, and are intersected at intervals by small creeks and streams flowing down the shore.

Ninety Mile Beach extends almost 90 km along the west coast of the Aupouri Peninsula, from Scott Point in the north to Reef Point at Shipwreck Bay (Ahipara) in the south. The beach is backed by extensive sand dunes, which spread up to 10 km inland and reach heights of up to 150 m. Pine forests are planted behind the majority of the beach (Brook & Carlin 2000, Walker 2007). The southern end of the beach around Ahipara and Shipwreck Bay is more sheltered because the beach curves around to face north.

Dargaville Beach extends around 82 km from Maunganui Bluff in the north to North Head, Kaipara Harbour in the south. This fairly straight beach is exposed along its entire length. North of Glinks Gully the beach is backed by sandstone cliffs, whereas to the south the beach is backed by sand dunes. A small pine plantation exists at North Head (McKelvey 1999).

1.4 Rationale for the surveys

This report documents the findings of two survey projects conducted to determine the distribution, abundance and size structure of toheroa and tuatua populations at Ninety Mile Beach in 2010 and Dargaville Beach 2011. This information should assist in toheroa management and conservation. Both surveys used a two-phase stratified random transect sampling design. Prior to each survey, we used the best available information to review the survey design and produce an appropriate stratification. Stratification at Ninety Mile was based on historical information on toheroa distribution. At Dargaville, where multiple toheroa beds were known to be present, the stratification was based on pre-survey fieldwork at the beach, analysed in comparison with historical data on the abundance and distribution of Dargaville toheroa from previous surveys. Transect allocation was optimised for surveying toheroa, although all toheroa and tuatua found during the survey were sampled. We used a target c.v. of 20% on the abundance of toheroa 40 mm or more in shell length (i.e., the putative spawning stock).

2 REVIEW OF SURVEY DESIGNS

2.1 Surveying bivalve populations

Bivalves such as toheroa and tuatua are well known for their patchy distribution at a range of spatial scales, so estimating their distribution and abundance is problematic. Many early surveys of bivalve populations in New Zealand used systematic sampling designs with transects spaced at regular intervals along the beach, which can lead to complications in estimating the sampling variance, and hence the confidence limits that can be placed around the estimate. Systematic surveys allow for ease of location of sampling sites, good coverage of the entire area, and permit iterative increase in the sampled area during sampling until the periphery of the “population” has been reached. However, for the calculation of variance, a key assumption is that sampling points are randomly distributed. This assumption is clearly erroneous with systematic surveys, although several authors have pointed out that such an assumption is usually reasonable (e.g., Milne 1959, Ripley 1981). Circumstances where the assumption is not reasonable include those where there is spatial correlation of density (where the variance tends to be biased, Wolter 1984) or there is patchiness on a scale “in phase” with the sampling grid (where the biomass estimate itself can be biased). McArdle & Blackwell (1989) describe the possibility of biased estimates arising from periodic patterns in distribution and their interference with the sampling grid. Under these conditions, the level of these biases can be very high (Payandeh 1970, Dunn & Harrison 1993). Several alternative variance estimators have been developed specifically for systematic surveys (e.g., Dunn & Harrison 1993, Millar & Olsen 1995) although there is no consensus as to the most appropriate. All are approximate and pragmatic solutions to a difficult problem.

An alternative might be to consider adaptive sampling (e.g., see Thompson & Seber 1996), in which additional samples can be added when the target species/size is encountered. This can be of particular merit for surveying rare and patchily distributed organisms, but the approach also has its disadvantages. These include the introduction of biases into conventional estimators so new unbiased estimators are needed, and the potentially unending nature of sampling at particular sites where the target is repeatedly detected. The logistics of sampling are also less straightforward than conventional sampling at predetermined positions.

Because of the problems with systematic surveys, and to allow more efficient surveys with fewer transects to be sampled, NIWA generally use a stratified random approach to surveying populations of bivalve shellfish (e.g., toheroa, cockles, pipi, scallops). Conventional simple random sampling would require many more transects to give a good coverage of the target population. Stratified random sampling uses relevant prior information about the nature of the population to divide it into sub-populations (strata) that are internally more homogeneous (Snedecor & Cochran 1980). This stratification approach has been used by NIWA for many years to survey toheroa populations for the

Ministry of Fisheries (e.g., see Carbines & Breen 1999, Morrison & Parkinson 2001, Beentjes & Gilbert 2006a, b, Morrison & Parkinson 2008, Beentjes 2010a, b). In these toheroa surveys, stations (transects) are allocated randomly within strata, and beach infauna are sampled by digging quadrats spaced at intervals down the transect from high to low water.

2.2 Review of Ninety Mile Beach survey design

Surveys of toheroa have been carried out at Ninety Mile Beach since about the 1960s and information from those surveys was used to determine an appropriate stratification for the 2010 survey. We analysed the available data from previous surveys (Greenway & Allen 1962, Greenway 1969, 1972, 1974b) to assess potential patterns in the distribution and abundance of toheroa along the beach. A partial survey in 1961 (Greenway & Allen 1962), covering 30 miles (48 km) of the beach from Wairoa Stream to Hukatere, concluded that “only the northernmost 10 miles [16 km] yielded good dense beds of toheroa”. Full surveys from 1962–67 (Greenway 1969), in which the beach was divided into five sections (Figure 2, labelled I–V), concluded “there was no really consistent pattern of distribution; the sections with the densest population varied from season to season”. Examination of the data from both studies, however, suggests that toheroa appeared to be more abundant in sections II, III and V.

NIWA conducted the most recent surveys of toheroa on Ninety Mile Beach in 2000 (Morrison & Parkinson 2001) and 2006 (Morrison & Parkinson 2008) using two-phase stratified random designs. In each year, the beach was initially stratified before the survey by traversing the beach looking for dense siphon holes (‘pock-marked’ sand, putatively denoting toheroa beds) and by limited exploratory digging. The beach was divided into strata representing different (putative) toheroa densities and/or areas along the beach. Subsequently, two-phase stratified random sampling was undertaken using transects orientated down the beach slope, with 0.25 m^2 quadrats dug at 10-m intervals down each transect.

The results of the 2000 and 2006 surveys suggest a suspected pattern of higher toheroa abundance in the region between Waipapakauri and Ngataki, and north from The Bluff to Scott Point (Figure 3), similar to that apparent from surveys in the 1960s (Greenway & Allen 1962, Greenway 1969).

Toheroa were uncommon in 2006, with only 124 individuals found (Morrison & Parkinson 2008). Most of these were juveniles of 50 mm shell length or smaller, few were in the 50–74 mm range, and only one individual larger than 75 mm was found (surveys at Ninety Mile in the 1960s and 1970s found toheroa up to 115–119 mm). No identifiable beds were encountered, and the distribution of toheroa was described as very variable and patchy. An estimated 8.8 million toheroa (c.v. 31%) were present. Limited additional searching of specific areas of the beach, specifically identified by local iwi as being good gathering spots, failed to find any further concentrations of toheroa.

Some issues were encountered with the 2006 stratification. This was due to the presence of tuatua in very high abundances at much higher tidal heights than considered ‘normal’, resulting in the misinterpretation of beach areas with siphon holes as toheroa beds, together with some unexpected misidentification problems between juvenile toheroa and juvenile tuatua, in the initial stratification survey. While these issues were rectified in the main survey through careful use of identification guides and diagnostics, it meant that the initial stratification of the beach based on the density of siphon holes was not optimal. We suspect that the siphon holes observed in the 2006 stratification survey were those of tuatua not toheroa. Given the low abundance of toheroa on the beach, the effects of this sub-optimal stratification were unlikely to have significantly impacted on the final conclusions, but probably resulted in some inflation of the c.v.

Stratification based on pre-survey observations of siphon holes was considered useful in the 2000 survey of toheroa at Ninety Mile Beach (Morrison & Parkinson 2001), and in a 1999 survey of toheroa at Dargaville Beach (Akroyd et al. 2002). It appears, however, that the utility of this method is suitable only for surveying beaches that contain dense beds of toheroa which can be positively identified by the nature of the siphon holes on the surface of the sand. The attributes of toheroa and tuatua siphon holes must be easily distinguished, and, equally importantly, the pre-survey stratification should immediately precede the main survey sampling to avoid problems of toheroa movement over time (e.g., with wave and storm action). Stratification using this approach is problematic because the presence of surface siphon holes appears to vary depending on environmental conditions. In the 2006–07 surveys of toheroa at Dargaville Beach and Muriwai Beach, Akroyd et al. (2008) found that the location and density of toheroa beds identified by siphon holes in the pre-survey stratification had changed considerably by the time the full surveys were conducted.

Based on the low abundance of toheroa at Ninety Mile Beach in 2006 (Morrison & Parkinson 2008) and on more recent observations by local iwi, we predicted that the abundance of toheroa in 2010 was likely to be very low, and the existence of dense beds of toheroa was unlikely. Tuatua and toheroa are known to exist in the intertidal zone at Ninety Mile beach, and both species exhibit surface siphon holes under appropriate conditions. We considered that a pre-survey traverse of the beach looking for siphon holes would not be a cost-effective basis for stratification in 2010. We decided that resources allocated to a pre-survey exploration would be better invested in sampling during the full survey.

We considered that stratification of the beach was appropriate for the 2010 survey, but based our stratification on prior information on the historical distribution and abundance of toheroa (and tuatua) at Ninety Mile Beach, rather than on pre-survey observations of siphon holes.

2.3 Review of Dargaville Beach survey design

Stratification based on pre-survey observations of siphon holes and exploratory sampling proved useful in the 1999 and 2007 surveys of toheroa at Dargaville Beach (Akroyd et al. 2002, 2008), in the 2000 survey of toheroa at Ninety Mile Beach (Morrison & Parkinson 2001) and in Southland toheroa surveys (e.g., Carbines & Breen 1999). This method is suitable only for surveying beaches that contain dense beds of toheroa which can be positively identified by the nature of the siphon holes on the surface of the sand, and was, therefore, considered appropriate for the Dargaville 2011 survey. Stratification using this approach is potentially problematic because the presence of surface siphon holes appears to vary depending on environmental conditions, but given that the majority of toheroa in a reasonably abundant population will be found in aggregated beds, it is very important to stratify the beach according to the bed and non-bed areas if possible. The attributes of toheroa and tuatua siphon holes must be easily distinguished, although by all accounts tuatua are not found in great numbers in the intertidal zone at Dargaville Beach, unlike the perhaps unusual situation sometimes observed at Ninety Mile Beach. Equally importantly, the pre-survey stratification should immediately precede the main survey sampling to avoid problems of toheroa movement over time (e.g., with wave and storm action). In the 2007 surveys of toheroa at Dargaville Beach and Muriwai Beach, Akroyd et al (2008) found that the location and density of toheroa beds identified by siphon holes in the pre-survey stratification had changed considerably by the time the full surveys were conducted.

Previously, the most abundant and extensive toheroa beds at Dargaville Beach were found in the southern half of the beach, which was subjected to intensive harvesting during the early to mid twentieth century. Surveys in the last decade have found that the northern half of the beach contained the most toheroa (Akroyd et al. 2002, 2008).

In preparing the research proposal for the TOH201001 project, we undertook some preliminary fieldwork at Dargaville Beach on 26 November 2010. NIWA’s sub-contractor Shade Smith (EAM Ltd.) examined a section of the beach from Glinks Gully to Mahuta Gap (Figure 4) by driving along the beach looking for signs of toheroa and by conducting some preliminary sampling. Several prominent, dense toheroa beds were observed at specific locations along the beach, and these were easily distinguished by the tens to hundreds of conspicuous siphon holes per square metre of sand. Preliminary sampling at one bed, measuring approximately 114 m long by 40 m wide, revealed that in a 0.25 m^2 quadrat, in which 12 siphon holes were apparent, there were a total of 83 toheroa ranging from 10 to 70 mm in shell length. No tuatua were encountered. In addition, hundreds of toheroa spat were found in the higher intertidal zone of the beach, and local observations by tangata whenua (B. Seale and J. Te Tuhi, pers. comm.) suggest there was a good spatfall of toheroa in 2009 and 2010. Results of the 2010 preliminary fieldwork suggested that there may be about 15 to 18 major toheroa beds along Dargaville Beach, and about 20 minor beds. The majority of these were thought to be in the northern half of the beach, but a full 2-phase random stratified survey of Dargaville Beach was considered to be warranted, and we proposed to stratify the beach using a combination of initial (pre-survey) stratification fieldwork and analysis of toheroa distribution patterns using the 1999 and 2007 Dargaville toheroa survey data.

Historical data were examined to determine the optimum quadrat spacing for the survey. The 1999 Dargaville survey used a combination of quadrat spacing within transects, dependent on whether a quadrat was within an identifiable toheroa bed or not (Akroyd et al. 2002). That approach complicated the subsequent analysis, and was abandoned for the next survey in 2007, where quadrat spacing was consistent within transects and strata, but varied between strata (5 m spacing for toheroa bed strata, and 10 m spacing for non-bed strata) (Akroyd et al. 2008). When operating with a finite budget, this additional sampling within a transect comes at the cost of reducing the number of transects that can be sampled along the beach, so we have reanalysed the 2007 survey data to examine the implications of 5 m and 10 m quadrat spacing.

The 2007 survey was stratified on the basis of four toheroa bed strata (strata 1 to 4), and one non-bed stratum (stratum 5) (Akroyd et al. 2008). In our reanalysis of those survey data, for each stratum, the original transect data were resampled with replacement 1000 times (generating a new set of data with the same number of transects as the original survey), and the mean number of adult toheroa calculated. In addition, similar resampling with replacement was conducted with the same sample size, but randomly selecting quadrats at 10 m intervals (starting at the first or second quadrat from the high water mark), and repeating this approach with 1.75 times the original 5 m transects per stratum (roughly the equivalent sampling effort, allowing for travel time). The distribution of estimates of mean toheroa per transect, median, and 5^{th} to 95^{th} percentile range for each of our three resampling approaches are shown in Figure 5. For stratum 3 in particular (which had the highest density in 2007 at approximately 1100 toheroa per transect) there was a marked decrease in precision (increase in the 5^{th} to 95^{th} percentile range) with 10 m quadrat spacing, even with increased numbers of transects sampled. Strata 1, 2, and 4 all had similar mean numbers of toheroa per transect (approximately 500) but gave contrasting results, with a drop in precision with 10 m spacing in stratum 2 versus no real difference in precision with 5 m or 10 m spacing in strata 1 and 4. Our simulation suggested that sampling at 5 m spacing of quadrats may be of real benefit (in terms of increased precision) for transects that traverse high density toheroa beds (more than 500 toheroa per transect).

Examining the distribution of toheroa down the beach from previous surveys (Figure 6), it can be seen that the larger (mature) toheroa are found further down the beach than the juveniles, with the main density of adults occurring in the lower half of the beach. Plots of the proportion of adult toheroa per transect against proportion of distance down the beach (Figure 7) suggested that although the adults tended to be lower down the beach, the full beach profile should still be sampled.

3 SURVEY METHODS

3.1 Ninety Mile Beach, 2010

3.1.1 Survey design

The Ninety Mile 2010 survey used a two-phase stratified random sampling design. The survey extent was defined as the intertidal area of the beach from the headland of Reef Point at Shipwreck Bay (Ahipara) in the south, to Scott Point in the north (Figure 1). The beach was divided along its length into four strata (Figure 3) with strata size inversely proportional to assumed density. This split the beach up into four regions that made sense geographically as well as with the historical toheroa distribution. Although primarily produced to survey toheroa, the design also suited the estimation of tuatua abundance.

The specified target c.v. of 20% on the estimated abundance of toheroa 100 mm or larger was deemed inappropriate given that less than 0.1% of the population sampled in the 2000 survey were 100 mm or larger (Morrison & Parkinson 2001), and no toheroa of that size were encountered in the 2006 survey (Morrison & Parkinson 2008). Instead, we adopted a target c.v. of 20% on the estimated abundance of toheroa 40 mm or larger (i.e., the putative spawning stock). Based on previous surveys, a total of 50 transects were considered sufficient to meet the target c.v.

Our preferred design was presented to and approved by the SFWG in December 2009 and the Te Hiku o Te Ika Iwi Forum in March 2010. The Forum agreed that our stratification was sensible in relation to historical and recent local knowledge of the distribution and abundance of toheroa at the beach.

3.1.2 Transect allocation

For optimal (in the sense of minimum variance) allocation of sampling effort among strata, the number of stations in any stratum should be proportional to the product of stratum area and some intuitive weighting factor derived from existing data (Francis 1984). This allows good coverage of the target population with the stations allocated, and assigns more sampling effort to the strata where most of the individuals are expected to be found. In this way, the sampled population is a good representation of the true population targeted. The adaptive two-phase strategy is more efficient than conventional stratified sampling, reducing the skew and expected error in the abundance estimates, as well as allowing for greater flexibility in the field (Francis 1984).

For each survey, 75% of the total number of stations (transects) expected to be sampled over the 4-day survey period was allocated to phase 1 (i.e., 3 days of sampling) and 25% to phase 2 (i.e., 1 day of sampling).

Phase 1 transects were allocated to each stratum proportional to the area of the stratum and its likely toheroa density. A minimum of three transects per stratum were assigned initially. The remainder of phase 1 transects were allocated based on the expected mean abundance of toheroa per transect in each stratum, and optimised using the ‘area mean squared’ allocation method of Francis (1984). Sampling of phase 1 transects was completed over the first three days of each survey. Allocation of phase 2 transects to strata was conducted on the fourth day, after completion of the third day’s sampling, on the basis of maximising reductions in the variance estimates, again using the mean squared allocation method. This was achieved by adding a transect iteratively to each stratum, and using the existing density and variance information to predict the likely improvement in the c.v. for each possible stratum allocation. The transect was assigned to the stratum giving the greatest reduction in the overall c.v., and the process repeated until all available phase 2 transects had been allocated. The positions of transects within strata were randomised using computer software, and were constrained to keep all transects at least 20 m apart.

3.1.3 Sampling methodology

The survey was timed to coincide with four days of spring low tides during daylight hours to allow the maximum possible intertidal slope of the beach to be sampled using transects with quadrats spaced at 10 m intervals in all strata. Transect positions along the beach were located using differential GPS. At each transect, the following procedure was undertaken.

Each transect was pre-assigned a random starting point (0–9 m) below the high tide water mark. As in previous surveys, each transect was aligned at right angles to the beach, running down the beach slope from high (edge of dunes) to low water. Down each transect, quadrats of 0.25 m^2 (0.5 × 0.5 m) spaced at regular intervals were excavated to a depth of 30 cm with a spade or fork, minimising damage to toheroa as far as possible.

Quadrats were positioned every 10 m down each transect using a rope knotted at the sampling interval (as opposed to using tape measures), minimising potential wind and passing vehicle problems. To allow for potential edge effects, animals encountered on the seaward edge of the quadrat or the left edge of the quadrat facing up the beach were included in the sample; any animals encountered on the landward edge or the right edge facing up the beach were excluded. All sand excavated was sieved using a 5-mm mesh screen agitated in seawater, leaving behind any shellfish present. Toheroa and tuatua were identified through the careful use of identification guides (e.g. Morley 2004) and diagnostics (Appendix 1).

All toheroa and tuatua from each quadrat were counted, and the shell length (maximum anterior-posterior dimension) of each was measured to the nearest whole millimetre down, unless damage to the shell prevented measuring or the catch of tuatua was very large (in which case a subsample of the tuatua catch was measured for shell length). Whenever possible, shellfish were reburied in the beach as quickly as possible after measuring, but to save time while sampling it was sometimes necessary to retain them for measurement at a later time. Samples of toheroa from some transects were retained overnight for shell length measurements and to obtain length-weight data, but were replanted alive in the beds the next day; large samples of tuatua were frozen and processed later in the laboratory. Toheroa damaged during sampling were also retained and frozen for later analysis in the laboratory for related research on toheroa genetics, age, and growth.

3.1.4 Estimation procedure

At each beach, the target population of toheroa to be surveyed lies within the intertidal area of the entire beach length, and it is assumed that this is a finite population. So, the beach can be divided into a finite number (*N*) of non-overlapping rectangles, each being the area that could be searched in a 0.5 m wide transect from high to low tide. The possible number of 0.5 m wide transects in each stratum is essentially the length of the stratum (distance along the beach) multiplied by 2 (this slightly overestimates the total number of potential transects because of the curvature of the beach). From the statistical point of view, the sampling unit for analysis is the transect, rather than either the quadrats or the toheroa individuals themselves. The value for each sampling unit (transect) is the total number of toheroa that would have been found if the entire transect had been searched.

We estimate the total number of toheroa in transect i, y_i, as

$$y_i = \frac{2T_i}{m_i} \sum_j A_{ij}$$

where T_i is the length of transect i (in metres), m_i is the number of quadrats in transect i, and A_{ij} is the number of toheroa found in quadrat j in transect i. The factor of 2 is required because quadrats sampled only 0.5 m every 10 m down the transect.

The sample mean for stratum h is calculated as

$$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$$

where i denotes the sampling unit (transect) within the stratum, y_{hi} is the value (abundance of toheroa) for the ith transect within stratum h, and n_h is the sample size (number of transects within stratum h).

The sample variance for stratum h is calculated as

$$s_h^{\,2} = \frac{\sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2}{n_h - 1}$$

To combine all strata and estimate the overall mean abundance of the population, the stratified estimator is

$$\bar{y} = \sum_{h=1}^{L} W_h \bar{y}_h$$

where W_h is the relative weight attached to stratum h (where $W_h = N_h/N$, with N being the total potential number of transects on the beach, and N_h being the potential number in stratum h) and L is the number of strata.

The variance estimator is

$$\mathrm{var}(\bar{y}) = \sum_{h=1}^{L} W_h^2 \frac{s_h^{\,2}}{n_h}$$

No finite correction term was applied because the sampling fraction was negligible (Snedecor & Cochran 1980).

For stratified random sampling, the sample mean and variance are unbiased estimates of the population mean and variance. The overall estimated population abundance, Y, is simply

$$Y = \bar{y}N$$

The coefficient of variation for the overall population is

$$c.v. = \frac{\sqrt{\mathrm{var}(\bar{y})}}{\bar{y}}$$

Quadrat length frequency distributions are estimated by scaling the recorded length frequency distributions by the inverse of the sampled fraction (number of toheroa measured divided by the total number counted) and to a square metre of sand. Transect length frequency distributions are estimated by scaling the quadrat length frequency distributions to the transect length. Stratum length frequency distributions are estimated as the mean transect length frequency distribution for that stratum scaled by the stratum length (distance along the beach, in metres). We estimate the population length frequency by adding the stratum length frequency distributions.

The same estimation procedure applies for the analysis of data on tuatua abundance.

The spatial distribution, abundance, and size of toheroa and tuatua were examined in relation to position along the beach (geographic location between Scott Point and Ahipara) and distance down the beach slope from the high water mark.

3.2 Dargaville Beach, 2011

3.2.1 Survey design

The Dargaville Beach 2011 survey also used a two-phase stratified random sampling design. The survey extent was defined as the intertidal area of the beach from the headland of Maunganui Bluff in the north to North Head in the south (Figure 4). A preliminary check of a section of Dargaville Beach in November 2010, and observations by local toheroa experts, revealed that multiple major toheroa beds were present, suggesting that stratification of the beach based on pre-survey fieldwork was warranted (see section 2.3).

Stratification fieldwork for this project was carried out over a 6-day period around the time of low tide from 14–19 March 2011. Using a four-wheel drive vehicle, experienced toheroa researchers travelled the entire length of Dargaville beach, from Maunganui Bluff in the north to North Head in the south, searching for signs of toheroa and toheroa beds. This method of identifying toheroa beds has been used successfully in previous toheroa surveys and relies on the observers noting subtle shading changes in the colour of the sand (i.e., darker or mottled appearance of beach), investigating areas of the beach where freshwater streams and seeps occur, and areas where double siphon holes occur. Where a bed, or signs of toheroa presence were encountered, a handheld GPS was used to record the location, approximate dimensions of the bed were paced out, and a $0.25 m^2$ quadrat was haphazardly sampled at the approximate centre of the bed at the mid tide level. Total numbers of toheroa and tuatua found within the quadrat were recorded as well as maximum, minimum, and modal shell lengths. A further test to gauge the density of juveniles in the upper intertidal 'Juvenile Settlement Band' (JSB) was also conducted which involved rapidly tipping a two litre volume of seawater onto the beach surface and noting the numbers and sizes of small juveniles 'floated' out of the pooling sand/water mix. In addition to investigations of beach areas where signs of toheroa were evident, exploratory diggings and searches in the JSB for toheroa were also made every 2 km along the beach. Each bed or 2 km exploratory site was allocated to a stratum (High, Medium, Low, Non-bed) on the basis of estimated toheroa abundance observations at the site. Limited time constraints on the last day of the stratification fieldwork prevented exploratory digging south of Roundhill (to North Head), and this area was therefore allocated to a fifth stratum, "South".

The distribution of toheroa beds identified from our stratification fieldwork in March 2011 was compared with historical data from the previous two surveys at Dargaville Beach (Figure 8). In 1999, virtually all toheroa beds were recorded north of Glinks Gully, with most beds in the central region of the beach (Baylys Beach to Glinks Gully), and a few identified to the north of the beach. In 2007, overall abundance of toheroa was lower, but the beds appeared to be distributed along a greater proportion of the beach. Notably, the proliferation of beds in the central region of the beach observed in 1999 was significantly reduced in 2007. The 2011 stratification fieldwork identified toheroa beds along the full length of the surveyed beach (although the area to the south of Roundhill was not examined in the same detail as areas to the north), with a concentration of high and medium density beds recorded in the central region of the beach.

The total length of the beach (Maunganui Bluff to North Head) examined during the stratification fieldwork was 82 km. From our stratification fieldwork estimations of bed dimensions, we divided this distance into five strata. The mean number of adult toheroa per transect was estimated for each stratum on the basis of scaled counts from the middle of the bed where quadrat sampling had been conducted, and from the estimated bed dimensions. Mean density within a bed was assumed to be one eighth of the density in the middle of the bed, on the basis of our analysis of data from the 1999 and 2007 surveys.

Given the potential high abundance and variable nature of spat on the beach, the specified target c.v. of 20% on the estimated absolute abundance of toheroa was deemed to be fairly ambitious. Instead, and in line with the Ninety Mile survey target, we adopted a target c.v. of 20% on the estimated abundance of toheroa 40 mm or larger (i.e., the putative spawning stock) at Dargaville Beach. A total of 60 transects (45 in phase 1 sampled over the first 3 days, and 15 in phase 2 on the fourth day) were considered sufficient to meet the target c.v. We allocated phase 1 transects to strata on the basis of the relative size of the strata and the estimated mean number of mature toheroa (40 mm or more shell length) per transect. Phase 2 transects were allocated on the basis of maximising reductions in the variance estimates using the mean squared allocation method (Francis 1984)

Our review work and the proposed survey design for the Dargaville 2011 survey were documented in a Research Progress Report submitted to the Ministry of Fisheries on 4 April 2011.

3.2.2 Transect allocation

The same method of allocating transects to strata was used as for Ninety Mile Beach (see section 3.1.2).

3.2.3 Sampling methodology

The same sampling procedure as was used for the Ninety Mile survey was used for the Dargaville survey (see section 3.1.3), with the exception that for the Dargaville survey quadrats were spaced at 5 m intervals in the High and Medium density strata and at 10 m spacing in all other strata. This decision was based on the results of our simulation analysis using data from the 2007 survey of Dargaville beach to determine the optimum quadrat spacing for different toheroa densities (see section 2.3). These results and the March 2011 stratification fieldwork at Dargaville beach suggested that our High and Medium density strata had sufficiently high numbers of toheroa to benefit from quadrat sampling at 5 m spacing.

In addition, for the Dargaville survey, upon arrival at the transect position (located using GPS) a photograph was taken of the dune system directly above the transect, and also down the beach along the line of the transect. These images were examined to characterise dune flora, land use behind the dunes, and the nature of any water features (e.g., streams, seeps) present at the beach. In addition, at each quadrat position, the distance from the beach surface to the water level observed in the bottom of the quadrat (to a maximum of 30 cm) was measured with a ruler, and the time recorded.

3.2.4 Estimation procedure

The same estimation procedure as was used for the Ninety Mile survey was used for the Dargaville survey, where the spatial distribution, abundance, and size of toheroa and tuatua were examined in relation to position along the beach (geographic location between Maunganui Bluff and Kaipara North Head) and distance down the beach slope from the high water mark.

4 SURVEY RESULTS

4.1 Sampling and catch details

4.1.1 Ninety Mile Beach, 2010

The Ninety Mile survey was conducted over four days from 26 to 29 April 2010. Sampling and catch details are shown in Table 1 and summarised below. A total of 744 quadrats were sampled, spaced every 10 m along 50 transects positioned between Scott Point and Ahipara (Figure 9). Transects ranged in length from 90 to 210 m (mean 140 m). Phase 1 transects (n = 38) were completed during the first three days of the survey, and phase 2 transects (n = 12) were completed on the fourth day. Phase 2 transects were allocated to strata 1, 2, and 4 (Figure 3); overall, 24% of the total number of transects sampled were allocated to phase 2.

No toheroa beds were observed during the Ninety Mile survey; only 38 individual toheroa were encountered. All of these were measured, including two individuals (5% of the total) that incurred shell damage. Toheroa ranged in size from 7 to 62 mm shell length, with 34% of the catch categorised as juveniles (40 mm or smaller) and 66% as small adults (40–74 mm). No large adults (75 mm or larger) were observed. Toheroa were present in 22 (44%) transects, with 0–7 individuals found in the quadrats sampled per transect. Most of the toheroa were from strata 2 and 4 (Figure 3).

In stark contrast, large and dense beds of tuatua were present at Ninety Mile, which in some areas extended for kilometres along the beach. A total of 13 982 tuatua were found in the same quadrats as those sampled for toheroa during the survey, of which 9330 (67%) were measured. Shell damage was not observed for tuatua. Tuatua ranged in size from 5 to 61 mm shell length. Tuatua were present in 41 (82%) transects, with 0–1241 individuals per transect. Most of the tuatua catch was also from strata 2 and 4 (Figure 3).

4.1.2 Dargaville Beach, 2011

The Dargaville survey was conducted over four days from 14 to 17 April 2011. Sampling and catch details are shown in Table 1 and summarised below. A total of 942 quadrats were sampled, spaced every 5 m (in medium and high density bed strata) or 10 m (in all other strata) along 62 transects positioned between Maunganui Bluff and North Head (Figure 9). One other transect ‘N31’ was sampled but excluded from the analysis because it was an accidental repeat sampling of transect ‘N16’. Transects ranged in length from 50 to 220 m (mean 103 m). Phase 1 transects (n = 45) were completed during the first three days of the survey, and phase 2 transects (n = 17) were completed on the fourth day (Table 1). Phase 2 transects were allocated mainly to stratum N, but also to strata H, M, and S; overall, 27% of the total number of transects sampled were allocated to phase 2.

Forty-five toheroa beds of variable size and density were identified during the pre-survey stratification fieldwork, and these were grouped as three bed strata (H, M, and L) that were sampled during the survey, together with non-bed stretches of the beach (stratum N), and the southern part of the beach (stratum S). The total catch of toheroa was 7891 toheroa, of which 7573 (96%) were measured; the remaining 318 (4%) were unable to be measured because of damage to the shell. Toheroa ranged in size from 3 to 120 mm shell length, with 56% of the catch categorised as juveniles (40 mm or smaller), 42% as small adults (40–74 mm), and 3% as large adults (75 mm or larger). Toheroa were present in 60 (97%) of the transects, with 0–992 individuals found in the quadrats sampled per transect. Most of the toheroa were from strata H and M.

Tuatua were uncommon at Dargaville. The total catch of tuatua was 1191, of which 1188 (99.7%) were measured. Shell damage was not observed for tuatua. Tuatua ranged in size from 6 to 61 mm shell length. Tuatua were present in 55 (89%) of the transects, with 0–370 individuals found per transect. Most of the tuatua catch was also from strata H and M.

4.2 Density and abundance estimates

Estimates of toheroa and tuatua mean density (number per transect) and population abundance (millions) at Ninety Mile and Dargaville beaches in 2010 and 2011 are given in Table 2. The target c.v. of 20% on the abundance of toheroa 40 mm or more was met for the Dargaville survey (c.v. 15%), and was close to being met on the Ninety Mile survey (c.v. 24%). Similar levels of precision were obtained for the estimates of tuatua absolute abundance (c.v. of 14% at Ninety Mile, and 25% at Dargaville).

At Ninety Mile, toheroa densities were very low, with an estimated population mean density of 14 toheroa (all sizes) per transect (range 4–19 by stratum). Scaled up to the total length of the beach, the estimated population abundance of toheroa (all sizes) was 2.4 million with a c.v. of 23%, of which about 1.6 million (c.v. 24%) were 40 mm or more shell length; there were no large toheroa (75 mm or more) found. In contrast, tuatua densities were very high, particularly in strata 2 and 4; the estimated population mean density was 4875 tuatua (all sizes) per transect (range 199–7076). This equates to an estimated population abundance of tuatua (all sizes) of 854 million with a c.v. of 14%. This estimate does not include tuatua in the subtidal zone because it was not surveyed.

At Dargaville, toheroa densities were far higher by comparison. The estimated population mean density was 461 toheroa (all sizes) per transect (range 182–3164 by stratum). The mean density of toheroa (all sizes) in the high and medium bed strata H and M was 2874 and 3164 toheroa per transect, respectively, about 16–17 times higher than in the non-bed stratum N which had the lowest density (mean density 182 toheroa per transect). Scaled up to the total length of the beach, the estimated population abundance of toheroa (all sizes) was 75.6 million with a c.v. of 43%, of which 12.8 million (c.v. 15%) were 40 mm or more shell length; about 1 million of these (c.v. 26%) were 75 mm or more. Tuatua densities were much lower than at Ninety Mile: the estimated mean density was 93 tuatua per transect at Dargaville (range 51–490), and the estimated population abundance was 15.3 million tuatua (all sizes) with a c.v. of 25% in the intertidal area of the beach surveyed.

4.3 Length frequency distributions

The estimated length frequency distribution of the toheroa and tuatua populations at each beach are shown in Figure 10. Patterns in length frequencies were also examined by stratum for both toheroa (Figure 11) and tuatua (Figure 12).

At Ninety Mile, the population length distribution of toheroa was not well defined because few toheroa were found, although a bimodal distribution was still apparent, with juvenile and small adult modes centred at about 10 mm and 50 mm respectively. This bimodal distribution was observed in all strata except stratum 3, where only 1 individual (42 mm) was found. A mode at around 10 mm was observed in strata 1, 2, and 4; larger modes were apparent at 40 mm in strata 2 and 3, and at around 55 mm in strata 1 and 4.

At Dargaville, two modes were also evident in the toheroa length frequency distribution, characterised by a primary mode of juveniles at about 15 mm and a secondary mode of small adults centred around 50 mm. However, there were also signs of a third mode of larger adults (at about 70–80 mm) with the distribution skewed towards the largest sizes (up to 120 mm). This was clearest in the high and medium bed strata H and M length distributions, although those were dominated by the modes of juveniles (20 mm) and small adults (50 mm). The low density bed stratum L showed a clear juvenile mode at about 10 mm and low frequencies of larger toheroa, but not as large as those found in strata M and H. A similar juvenile mode was also evident in the southern stratum S. The pattern in the length structure of the few toheroa found in the non-bed stratum N was not strong, with a range of sizes found.

The length distribution of tuatua at Ninety Mile was dominated by a strong mode at about 20 to 45 mm. When examined at the stratum level, there was a clear mode at about 30 mm in strata 2 and 3, whereas in stratum 4 the mode was at about 38 mm. A few larger (55 mm or larger) were found, usually at the lowest part of the intertidal zone.

At Dargaville the majority of the tuatua population was less than 20 mm shell length, a smaller mode was present around 25 mm, and a moderate number of individuals were in the 30 to 50 mm length range.

4.4 Alongshore spatial distributions

At Ninety Mile, there was no obvious pattern in the distribution of toheroa along the length of the beach from Scott Point to Reef Point (Figure 13). Tuatua were found in great numbers along most of the Ninety Mile beach length, but particularly in the central and northern parts of the beach (Figure 14).

At Dargaville, the pre-survey stratification fieldwork in March 2011 suggested that high and medium density toheroa beds were mainly distributed in the central and northernmost areas of the beach, and the toheroa densities detected during the full survey in April 2011 reflected that pattern (Figure 13), although occasional high density patches were also detected in the south. There were relatively low densities of tuatua compared with those of toheroa, but the highest tuatua densities were found within toheroa beds (Figures 13 and 14).

Toheroa abundance was generally higher in or near to freshwater seeps and streams compared to drier beach areas; no such pattern was observed for tuatua (Figure 15).

4.5 Downshore spatial distributions

Patterns in the downshore (high to low water) distribution of toheroa and tuatua at each beach were assessed using plots of density versus distance from high water. At both Ninety Mile and Dargaville beaches, toheroa occupied a similar position on the beach slope, mainly from 0 to about 100 m down from high water. Two modes were apparent in their downshore population distribution: in the high intertidal (0 to 60 m) and mid-tidal (80 to 120 m) areas (Figure 16). When examined at the stratum level, it was clear that the mid-tide position of toheroa was strongest in the high-density bed stratum at Dargaville beach only (Figure 17).

High densities of tuatua occurred in the mid to low tide area at Ninety Mile; in contrast, tuatua densities were very low in that same zone at Dargaville and highest near to the high water mark (Figure 16). The downshore distribution of tuatua varied among strata at both beaches (Figure 18). At Ninety Mile, tuatua in strata 2 and 4 had a broad downshore distribution (from about 50 to over 150 m from high water) whereas those in stratum 3 were found mainly around just around 150 m from high water. At Dargaville, tuatua were restricted mainly to the high intertidal, with the highest densities observed in the high and medium density toheroa bed strata.

There was a pattern of increasing toheroa size with distance from high water. This was seen best at Dargaville beach where large numbers of toheroa were encountered. Although small juveniles were spread across most of the intertidal beach slope, the highest densities were found close to the high water mark. Larger juveniles and adults occupied areas further down the beach slope, in the mid to low areas of the intertidal zone (Figure 19). A similar pattern of increasing size with distance down the shore was observed for tuatua (Figure 20).

4.6 Length weight relationships

Length weight data were recorded for Ninety Mile tuatua in 2010, and for Dargaville toheroa in 2011; these data were analysed using least squares linear regression (Figure 21). Length weight data for the few toheroa found at Ninety Mile in 2010 were recorded, but were not included in the analysis. No length weight data were collected for tuatua at Dargaville in 2011. Length weight regression coefficients for each species sampled are shown in Table 3. The linear model fitted the data well for both species. Note that the length weight regression for tuatua applied only to tuatua found in the intertidal zone, and may not be suitable for predicting weight from the length of larger tuatua which normally occupy a lower position on the shore, in the lowest part of the intertidal into the shallow subtidal.

4.7 Time series of toheroa abundance

Estimates of toheroa population abundance collated by Williams et al (submitted 2012) were plotted to assess trends at Ninety Mile (Figure 22) and Dargaville (Figure 23) beaches since the 1930s. Estimates are shown for three size categories: juveniles (less than 40 mm shell length), small adults (40–74 mm), and large adults (75 mm or larger). Surveys before 1999 did not use sieves, so estimates of juvenile toheroa before 1998 are likely to be conservative. Substantial uncertainty is associated with most of the estimates before 1999 because of differences in the areas surveyed and methods employed over time.

The earliest estimates of abundance were from occasional informal surveys dating back to the 1930s, conducted primarily to locate the main beds for commercial harvesting. More formal surveys were undertaken annually or biennially from 1962 to 1986, although because those surveys sampled only the mean tide level of the beach, it is likely that abundance was underestimated. Brief inspections carried out in 1990 and 1993 suggested there were very few toheroa, but no estimates are available for those years. Surveys since 1999 covered the entire alongshore length of the beach and the full downshore extent (intertidal zone) and used sieves as part of the sampling protocol. Details of the various survey methodologies undertaken and reported are provided in Appendices 2 and 3.

At Ninety Mile, the estimated population abundance of toheroa has undergone major fluctuations over the available time series (Figure 22). The estimated abundance of large adult toheroa was high in 1933 with about 12 million, low in 1939 with just over 1 million, and high again in 1941 with about 10 million. No estimates are available for the 20 years that followed but it was documented that toheroa were scarce during the 1940s. The 1961 survey covered only just over half of the beach length, so the estimate of about 4 million large toheroa in that year is potentially biased low. Estimates for 1962 and 1963 were high at about 10 million large adults, but there was a strong decreasing trend that followed, and there were only about 1 million in 1965. Their abundance remained low at about 0.5 million until 1969, then increased to a second peak of about 7 million in 1970, yet the following year the estimate was an order of magnitude lower at about 0.7 million. Estimates from the surveys that followed in the 1970s and 1980s were all low at about only 0.1 million large toheroa. In 2000 their abundance was higher at about 1.5 million, but appears to have declined since, with only about 0.5 million in 2006, and no large toheroa found in 2010. Very similar trends are mirrored in the estimated abundance of small adult toheroa (40–75 mm), with two obvious peaks of about 28 million and 21 million in 1963 and 1970 respectively, both followed by sharp declines, plus a third more gradual decline observed in the last decade from about 10 million in 2000 to less than 2 million in 2010. Estimates of abundance for juvenile toheroa (less than 40 mm) were generally very low and probably unreliable up until 2000 when sieving was introduced in the sampling method. Despite this, there are indications of higher juvenile abundance (notable recruitment events) that match up with the two major peaks in the abundance of both small and large adults in the 1960s and 1970s, and high recruitment in 2000.

At Dargaville, the estimated population abundance of toheroa has also seen large changes over the time series, although the trends are not always as clear (Figure 23). The earliest estimate in 1938 was about

4 million large adult toheroa but no further estimates were made until the 1960s. The estimates of abundance for large toheroa were high in the early 1960s, averaging about 10 million from 1962 to 1964, but showed a declining trend with variability over the next four years to reach about 1 million in 1968. Abundance then increased to reach nearly 4 million in 1970, and declined again to sit at about 1 million in 1972 and 1973. There was a slightly larger peak of about 6 million in 1974, but in the following year the estimates were again at about 2 million. Abundance then rapidly increased through 1976 to reach an even higher peak of about 10 million in 1977, and subsequently declined sharply to about 2 million in 1979. Estimates from 1983 to 1986 were consistently low, averaging about 0.4 million. In 1999 there were about 3 million large adult toheroa, a figure comparable with some estimates in the late 1960s, but the estimates in 2007 and 2011 were both low again at about 1 million. The abundance of small adult toheroa oscillated around 5 million from the early 1960s to 1980s except for a particularly high estimate of about 24 million in 1972. That peak in the abundance of small adults coincides with a small peak in juveniles that same year, and both appear to precede the peak of about 6 million large toheroa observed in 1974. The estimates of abundance from the three surveys over the last decade suggest there were about 12 million small adult toheroa in 1999 and 2011, yet only about 2 million in 2006. Recruitment of juveniles was highest in 1999 at about 100 million, and was similar with about 60 million in 2006 and 2011.

Comparing the estimates for the three size categories between beaches revealed a few similarities (Figure 24). The major peak in the abundance of large adults from around 1962–64 followed by a declining trend was common to both beaches, although the decline at Dargaville was more gradual and not as severe. The second major peak in 1970 and subsequent decline in large adult abundance at Ninety Mile coincided with a minor peak and decline at Dargaville. The declining trend in the abundance of large adults over the last decade (1999–2011) was common to both beaches. Turning to recruitment, however, the noticeable peak of juveniles observed in 1970 at Ninety Mile did not coincide with the weak peak at Dargaville, which occurred in 1972. This apparent lag from 1970–72 is more noticeable in the abundance of small adults, with Dargaville peaking two years later than Ninety Mile. High recruitment of juveniles was evident at Dargaville in 1999 and at Ninety Mile in 2000, although recruitment appears to have been substantially and consistently higher at Dargaville over the last decade. During that period, trends in the abundance of juveniles and small adults between beaches are not consistent overall; whilst at both beaches their abundance was relatively high at the turn of the century (1999–2000) and lower in 2006, Dargaville appears to have received increased recruitment in 2011 whereas recruitment was low at Ninety Mile around the same time (2010).

5 DISCUSSION

5.0 Survey methods

The two phase stratified random transect design used for the Ninety Mile 2010 and Dargaville 2011 toheroa and tuatua surveys provided good data for estimating population abundance and detecting patterns in their spatial and size distributions. Since the highest densities of toheroa are typically found in beds, good knowledge of the alongshore and spatial distribution of the beds is required for sensible stratification. Sampling at greater intensity within beds (e.g., using more closely spaced quadrats) increases the precision of the estimates. If larger toheroa were the primary target in future surveys, greater precision on the estimates could be expected by focusing sampling on the mid tide zone of the beach where the main adult densities usually occur. The full length of the beach may still need to be sampled though, to enable the estimation of juvenile toheroa and intertidal tuatua. For estimates of the tuatua spawning stock, most of which is likely to be found below the low tide mark, other methods suitable for surveying the shallow subtidal would need to be employed.

When examining trends in toheroa abundance, it was difficult to assess the levels of juvenile recruitment for surveys before 1999 because they did not use sieves and it is likely that many of the small toheroa were missed. Although the selectivity of previous surveyors visually searching for toheroa in the sand dug from quadrats is unknown, this could be investigated in future by sampling quadrats using both the visual and sieving methods. The resulting selectivity curve could be used to make an approximate correction to the historical estimates.

5.1 Population patterns

Only a few, mainly small, toheroa were found during the 2010 survey at Ninety Mile Beach, and it is evident that the population status is at a very low ebb. Whilst some of the toheroa may have been capable of spawning, they were detected only at low densities which may not have been sufficient for successful fertilisation of eggs during spawning (Levitan 1995). Small toheroa probably have limited reproductive potential compared with larger toheroa, as fecundity often increases exponentially with size in bivalves. It is possible that the survey may have missed some inconspicuous beds of toheroa, but some locally known “toheroa spots” were searched and no toheroa beds were found. Tangata whenua involved in the Ninety Mile survey also indicated that toheroa numbers have become increasingly rare at other west coast beaches in the Far North that used to hold good beds of toheroa (e.g., Tanutanu and Mitimiti beaches). Limited reproductive output of toheroa in the Far North may be a factor contributing to the consistently lower level of recruitment at Ninety Mile compared to Dargaville beach over the last decade. Given its current status, it seems unlikely the Ninety Mile population would support any form of toheroa harvesting, although this was not investigated in the present study.

In marked contrast, toheroa were locally abundant at Dargaville beach in 2011, found mainly in relatively small but conspicuous beds, but also at lower non-bed densities. Although the abundance of juvenile and small adult toheroa at Dargaville was relatively high in 2011, the number of large adults was low.

Toheroa beds appeared to be associated with wetter areas of the beach, which were numerous in central and northern Dargaville beach, but uncommon at Ninety Mile. The occurrence of toheroa beds in and around freshwater streams was also observed in the 2006 survey (Akroyd et al. 2008), but the association between freshwater seepage and the toheroa has long been recognised. Rapson (1952) produced a diagrammatic plan of toheroa beds at Dargaville Beach, which recognised many of the patterns known to local residents and detected by the recent surveys. Toheroa living in areas of fresh water seepage may have greater protection from desiccation (see Williams et al. submitted 2012).

Despite the marked difference in toheroa abundance between the two beaches surveyed, most of the toheroa were small and belonged to well defined length modes, suggesting that recruitment may be dependent on the reproductive success of only a few year classes. At Dargaville, where sufficient toheroa were present to clearly detect patterns in the length distribution, the two dominant length modes of about 15 mm and 50 mm, and a third weaker mode of about 70–80 mm, were very similar to the population length modes at Dargaville beach in 1999 (Akroyd et al. 2002) and 2006 (Akroyd et al. 2008). Redfearn (1974) tracked the progression of toheroa length modes by sampling length frequencies at bimonthly intervals at Dargaville beach; the results, together with his estimates of toheroa age from shell readings, suggest these three modes are likely to belong to the 0+, 1+, and 2+ year classes.

The patterns observed in the spatial distribution of toheroa at length agree with the patterns described previously by earlier work (e.g., see Redfearn 1974) and by local toheroa observers (J. Te Tuhi, pers. comm.). For example, the pattern in the downshore distribution at length suggests an ontogenetic shift, with the smallest (presumably youngest) shellfish settling in highest densities near the high water mark and gradually occupying positions further down the shore as they grow in size and age. Redfearn (1974) suggested that spat settlement is a passive process dependent on wave action and alongshore currents. These physical forces are likely to have a stronger influence on the settlement and distribution of spat because of their small size and limited burrowing ability, whereas larger toheroa can more actively influence their position on the shore. Large toheroa can be found about 15–20 cm below the surface of the sand, deep enough perhaps to reduce the risk of being washed out of the sand by the surf whilst still being able to extend their long siphons to feed and respire. Positions lower down the shore could be preferable to larger toheroa because they are submerged for longer on each tidal cycle, allowing more time to feed and less time when they may be vulnerable to predation while the tide is out.

5.2 Factors affecting abundance

From the available time series of estimates, it is clear that toheroa abundance at Ninety Mile and Dargaville beaches experienced major fluctuations up until about 1980 when surveys became infrequent. Fluctuations were more severe at Ninety Mile than Dargaville, suggesting that the beach habitat there could be more vulnerable to large environmental changes, whereas Dargaville might be more stable. Differences in the geology of the two areas may be important. To a great extent, the boom and bust nature of toheroa populations is to be expected because of their highly dynamic surf zone habitat and the multiple life history stages that need to coincide with favourable environmental conditions to produce a large biomass of adults. However, this does not explain the lack of a recovery in the numbers of large adult toheroa over the last 30 years despite the absence of commercial and recreational harvesting.

Morrison & Parkinson (2008) suggested that two processes are acting to limit the regeneration of large adult toheroa. First, recruitment is highly variable, potentially driven by large-scale climatic processes (oceanographic forcing). Second, once recruitment does occur, mortality rates are high, potentially associated with unfavourable beach habitat. Consequently, few toheroa survive to reach large sizes.

In a recent toheroa review project, variations in toheroa abundance were investigated by examining factors that influence recruitment and mortality (Williams et al. submitted 2012). A wide range of scientific, customary, and historical information on toheroa was acquired and reviewed. From the review, eight major factors were identified which appeared to have the potential to influence the abundance of toheroa. These factors were food availability, climatic events, sand smothering/sediment instability, toxic algal blooms, predation, harvesting, vehicle impacts, and land use change. These factors probably act in combination. The anthropogenic factors of changes in land use and vehicles driving on the beach may be particularly relevant to toheroa in Northland, and differences in the strength of their putative impacts at Dargaville and Ninety Mile beaches could have contributed to the marked difference in the current status of the two toheroa populations. Future work on these topics would be needed to investigate this. Illegal harvesting (poaching), the signs of which have been observed by local people, may be an additional factor limiting the number of toheroa attaining large sizes in beds with apparently otherwise favourable habitat conditions at Dargaville beach.

Although toheroa were rare at Ninety Mile beach in 2010, tuatua were in great abundance. The inverse pattern was observed at Dargaville beach, with abundant (mainly juvenile and small adult) toheroa and low numbers of tuatua. At Ninety Mile, the tuatua were mainly small individuals (20–40 mm) found in high density beds that extended for up to several kilometres along the beach. Those small tuatua appeared to occupy the mid-tide niche favoured by adult toheroa and they may compete for resources (e.g., food, space). The distribution of adult tuatua was likely to have been missed by these intertidal surveys, because the largest tuatua are typically found in beds just below the low tide mark. The spawning stock of toheroa, therefore, is probably more vulnerable to factors affecting the intertidal habitat than the tuatua spawning stock.

5.3 Future work

Future work on toheroa should aim to better understand factors affecting the species’ population dynamics, protect important beach habitats and mitigate adverse anthropogenic effects.

Dargaville Beach is one of the few remaining beaches to have been subjected to the customary harvest of toheroa in the last decade. However, all harvesting was prohibited in the most recent years, although the current presence of obvious toheroa beds suggests to some that harvesting should be permitted. Others have raised concerns about the sustainability of harvests, and feel that toheroa at Dargaville should be carefully managed given the rarity of toheroa elsewhere and the apparent need for conservation. A project to estimate sustainable yields (e.g., based on yield per recruit modelling) could be beneficial to inform this discussion. Sampling to determine toheroa length at maturity, and mark-recapture studies to investigate growth and mortality, at these northern beaches would refine our estimates of important biological parameters.

Several ideas for future work were suggested in the recent toheroa review by Williams et al. (submitted 2012). These included regular monitoring of key toheroa populations through the involvement of local community members, field studies to characterise the habitat conditions associated with toheroa densities at different life stages, work to further investigate the relationship between toheroa and land usage above the high water mark, and initiatives to mitigate the impacts of vehicles on beach infauna and habitats. Any future work on toheroa is likely to benefit from concerted engagement between the multiple enduser groups interested in toheroa, including iwi, public, industry, central and local government and scientific research providers. An initial step could be to communicate the findings of these survey (present study) and review (Williams et al. submitted 2012) projects more widely to promote enduser engagement and assist in the planning and prioritisation of future work on toheroa.

6 ACKNOWLEDGMENTS

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8 TABLES

Table 1: Sampling summary for the surveys of toheroa and tuatua at Ninety Mile Beach in 2010 and Dargaville Beach in 2011. Note that one additional transect 'N31' was sampled but excluded from the analysis because it was an accidental repeat sampling of transect 'N16'.

Survey	Stratum			Transects			Quadrats		Catch	
	Description	Code	Length (m)	Phase 1	Phase 2	Total	Spacing (m)	Total	Toheroa	Tuatua
Ninety Mile Beach	Reef Point to Waipapakauri	1	16 820	5	3	8	10	127	5	84
26–29 April 2010	Waipapakauri to 'Ngataki'	2	32 600	16	7	23	10	357	18	8 433
	'Ngataki' to The Bluff	3	14 400	5	0	5	10	62	1	558
	The Bluff to Scott Point	4	23 800	12	2	14	10	198	14	4 907
		Total	87 620	38	12	50	–	744	38	13 982
Dargaville Beach	High-density bed	H	574	11	1	12	5	285	3 517	602
14–17 April 2011	Medium-density bed	M	1 219	8	3	11	5	224	3 588	398
	Low-density bed	L	916	4	0	4	10	37	131	31
	Non-bed	N	65 291	18	12	30	10	322	287	146
	South (of Roundhill)	S	14 000	4	1	5	10	74	368	13
		Total	82 000	45	17	62	–	942	7 891	1 190

Table 2: Estimates of toheroa and tuatua mean density (number per transect) and abundance (millions) at Ninety Mile and Dargaville beaches in 2010 and 2011.

Ninety Mile Beach 2010							Dargaville Beach 2011						
Species/size	Stratum	Length (m)	Transects	Density	c.v.	Abundance	Species/size	Stratum	Length (m)	Transects	Density	c.v.	Abundance
Toheroa	1	16 820	8	12	0.67	0.405	Toheroa	H	574	12	2 874	0.32	3.299
All sizes	2	32 600	23	15	0.39	0.982	All sizes	M	1 219	11	3 164	0.24	7.714
	3	14 400	5	4	1.00	0.109		L	916	4	636	0.38	1.164
	4	23 800	14	19	0.28	0.921		N	65 291	30	182	0.24	23.824
								S	14 000	5	1 416	0.81	39.645
	Total	87 620	50	14	0.23	2.417		Total	82 000	62	461	0.43	75.646
Toheroa	1	16 820	8	10	0.65	0.324	Toheroa	H	574	12	1 355	0.39	1.556
≥ 40 mm	2	32 600	23	8	0.32	0.545	≥ 40 mm	M	1 219	11	1 494	0.33	3.643
	3	14 400	5	4	1.00	0.109		L	916	4	131	0.40	0.240
	4	23 800	14	14	0.40	0.660		N	65 291	30	49	0.21	6.443
								S	14 000	5	32	0.51	0.901
	Total	87 620	50	9	0.24	1.639		Total	82 000	62	78	0.15	12.782
Toheroa	1	16 820	8	0	–	0.000	Toheroa	H	574	12	69	0.39	0.079
≥ 75 mm	2	32 600	23	0	–	0.000	≥ 75 mm	M	1 219	11	93	0.39	0.226
	3	14 400	5	0	–	0.000		L	916	4	0	–	0.000
	4	23 800	14	0	–	0.000		N	65 291	30	5	0.36	0.649
								S	14 000	5	0	–	0.000
	Total	87 620	50	0	–	0.000		Total	82 000	62	6	0.26	0.954
Tuatua	1	16 820	8	199	1.00	6.689	Tuatua	H	574	12	490	0.61	0.562
All sizes	2	32 600	23	7 076	0.20	461.362	All sizes	M	1 219	11	350	0.38	0.854
	3	14 400	5	2 152	0.56	61.992		L	916	4	149	0.50	0.272
	4	23 800	14	6 813	0.23	324.322		N	65 291	30	93	0.31	12.161
								S	14 000	5	51	0.29	1.418
	Total	87 620	50	4 875	0.14	854.365		Total	82 000	62	93	0.25	15.267

Table 3: Coefficients from least squares linear regression of log transformed length weight data for intertidal tuatua (TUA) and toheroa (TOH) at Ninety Mile beach in 2010 and Dargaville beach in 2011. Weight in g greenweight, length in mm shell length. *n*, number of individuals. The regression model is log(Weight) = a + log(Length) *b.

Survey	Species	Coefficient		*n*	r^2
		a	*b*		
Ninety Mile, 2010	TUA	-7.71320	2.68617	1 771	0.924
Dargaville, 2011	TOH	-9.41409	3.09298	1 153	0.995

9 FIGURES

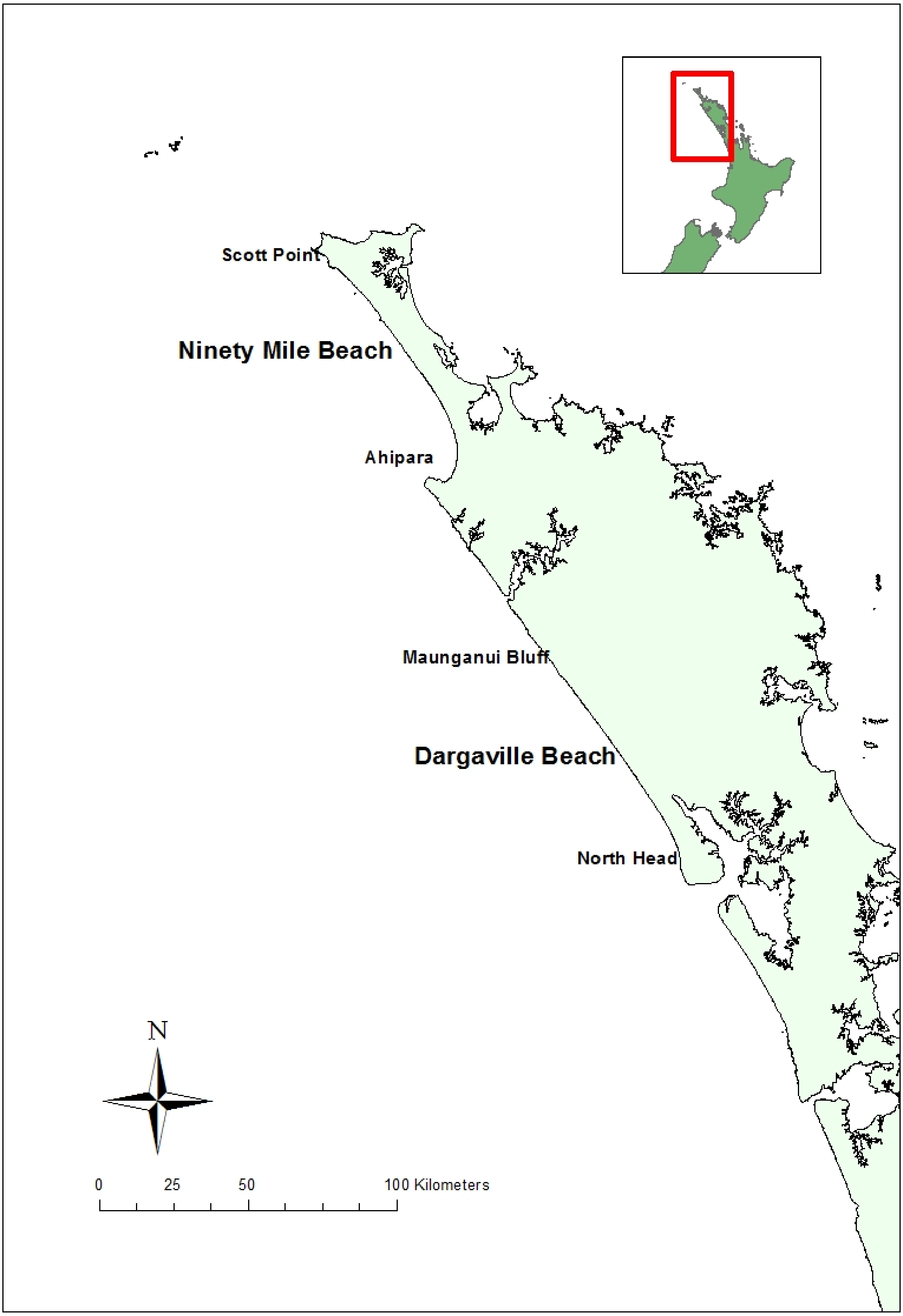


Figure 1: Map showing the location of Ninety Mile Beach and Dargaville Beach in Northland, North Island, New Zealand. Geographical survey limits for each beach are also shown.

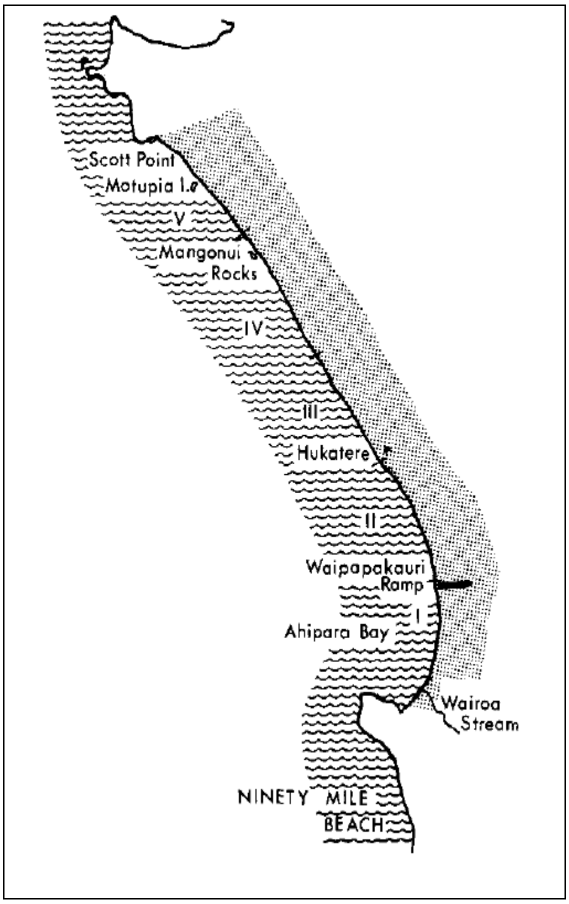


Figure 2: Survey sections (strata) used for the 1962–73 surveys of toheroa at Ninety Mile Beach (from Greenway 1969).

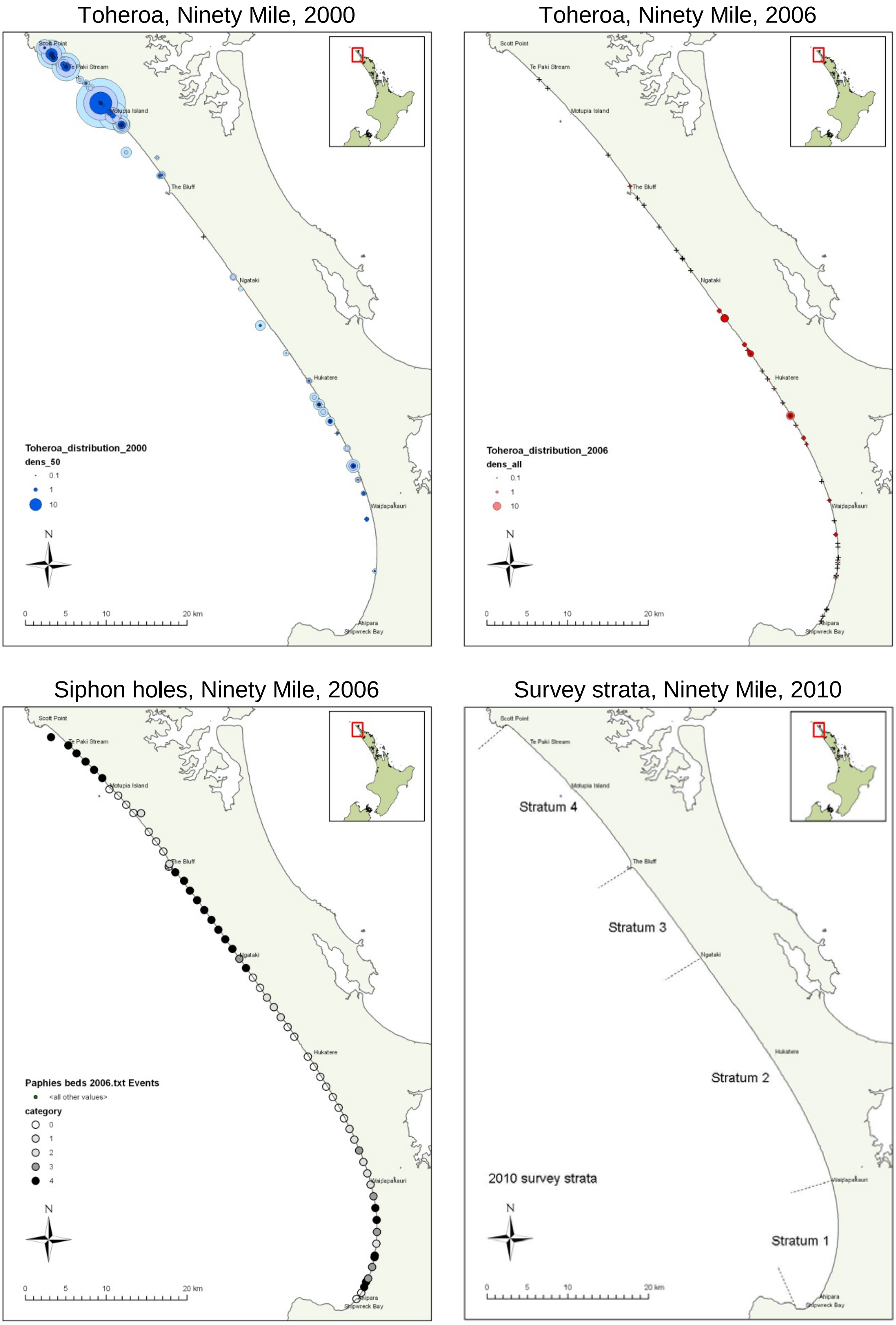


Figure 3: Distribution and abundance of toheroa in 2000 (top left) and 2006 (top right), the distribution of *Paphies* spp. as indicated by categorical observations of surface siphon holes in 2006 (bottom left), and stratification for the 2010 survey of toheroa at Ninety Mile Beach (bottom right). Filled circles in the top two plots indicate toheroa abundance; circle area is proportional to the estimated density (m^{-2}) of toheroa. Crosses denote sites sampled where zero toheroa were found. Filled circles in the bottom left plot indicate the presence of siphon holes; increasing intensity of grey to black shading represents increasing density of siphon holes. We suspect that the siphon holes observed were those of tuatua not toheroa.

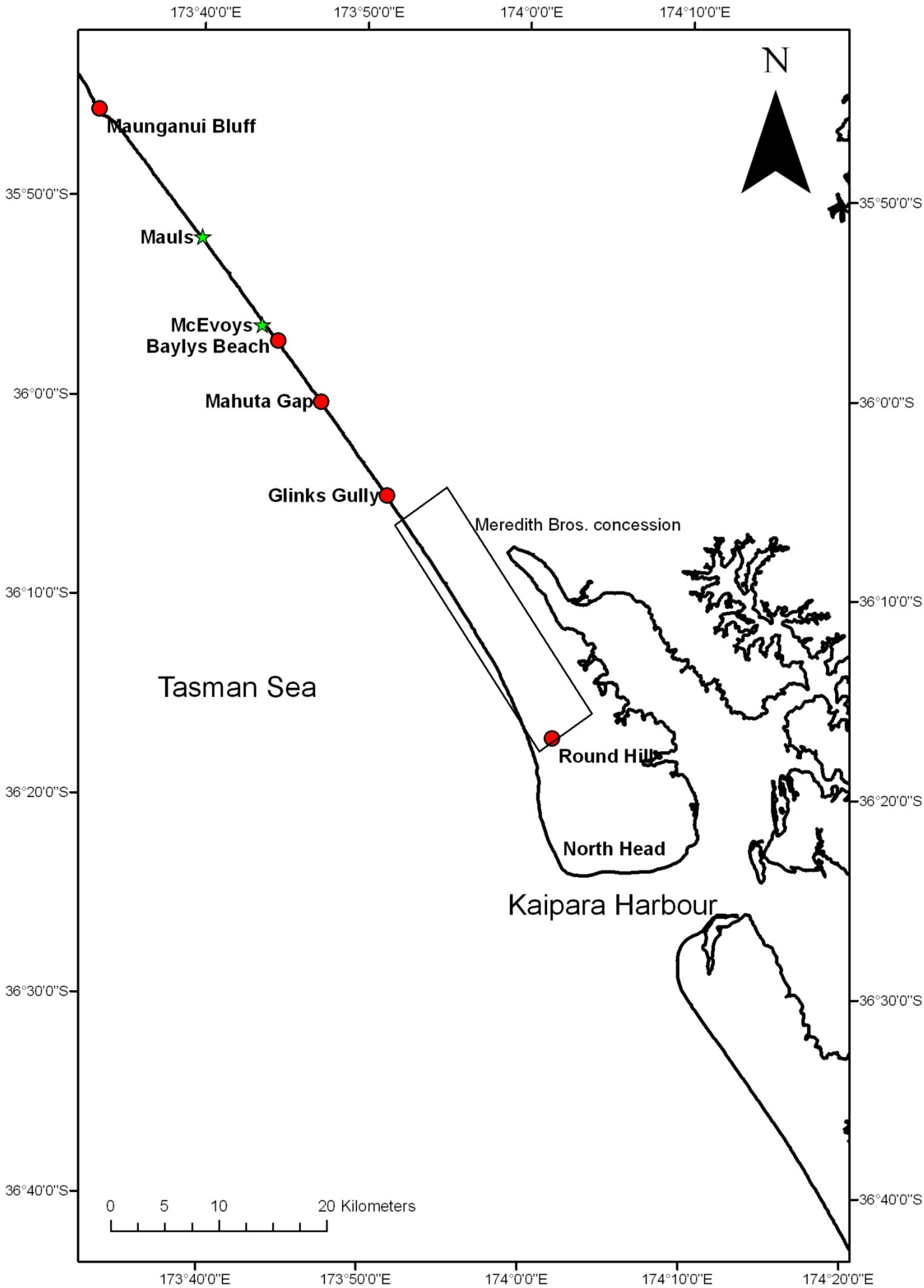


Figure 4: Map of Dargaville Beach, the 72 km stretch of beach between North Head at the entrance to the Kaipara Harbour in the south, to Maunganui Bluff in the north. Local place names are also shown, together with the location of the Meredith Bros. Company Ltd. concession area where commercial toheroa harvesting was conducted during the early to mid twentieth century.

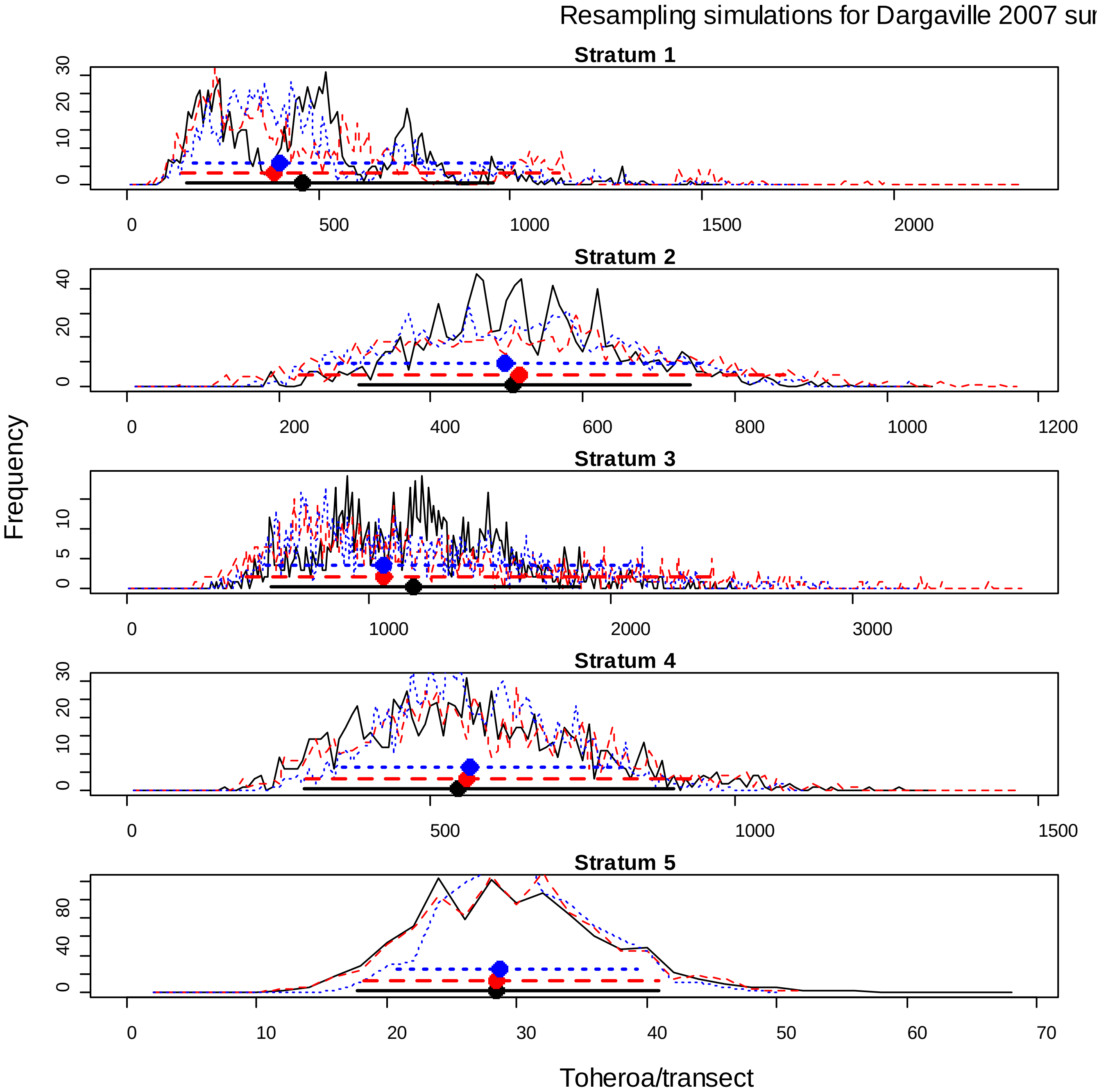


Figure 5: Distribution of mean toheroa per transect, median and 5th to 95th percentile range for resampling simulations for 2007 Dargaville survey data by stratum. Black symbol and lines: resampling of original data; red symbol and lines: resampling with quadrats at 10 m intervals; blue symbol and lines: resampling with quadrats at 10 m intervals and 1.75 times the original transect number per stratum.

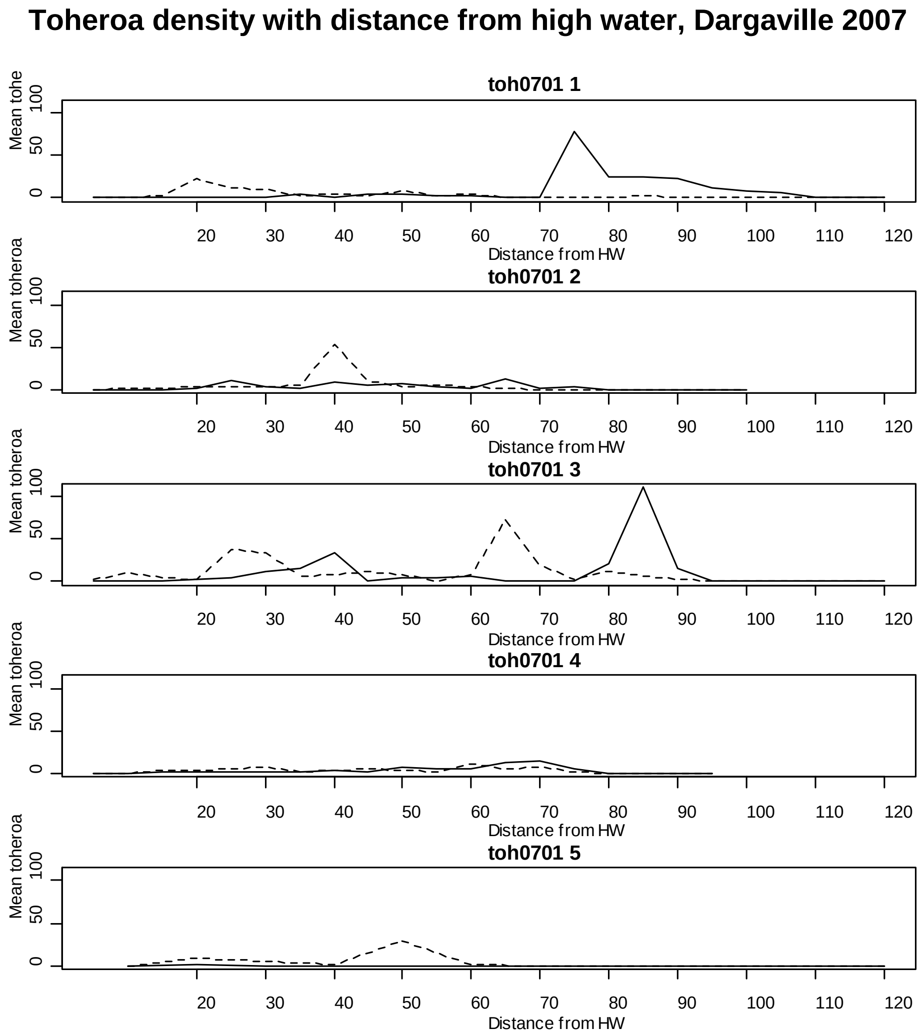


Figure 6: Mean number of toheroa per quadrat against distance down the beach (from high water), by stratum for the 2007 survey at Dargaville Beach. Solid line, toheroa 40mm or more shell length; dashed line toheroa smaller than 40mm.

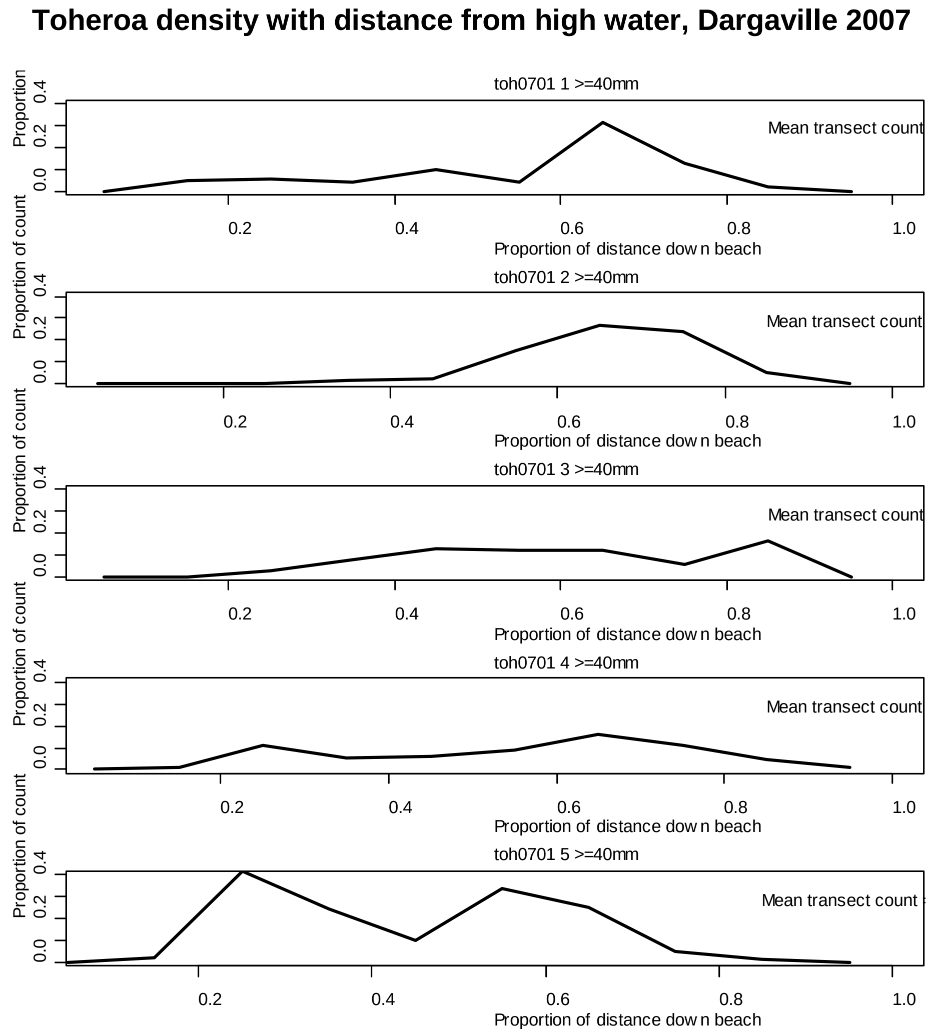


Figure 7: Proportion of adult toheroa count per transect against proportion of distance down the beach (from high water), by stratum for the 2007 survey at Dargaville Beach.

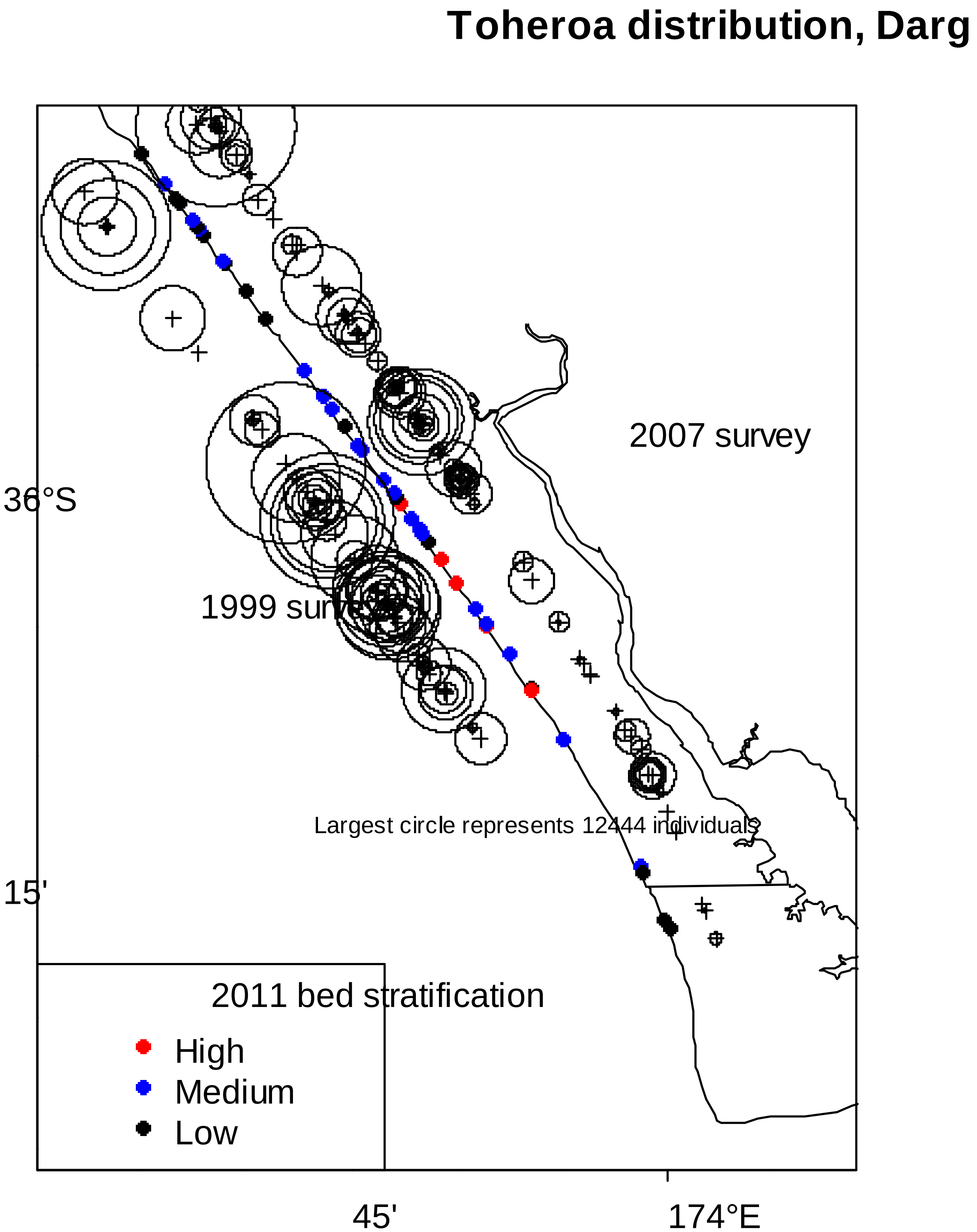


Figure 8: Locations of toheroa beds (categorised as high, medium and low density) in March 2011, compared with survey abundances (estimated numbers per transect down the beach slope) in 1999 and 2007. Previous survey data offset to west and east, plotted at correct latitude for comparison with 2011 data.

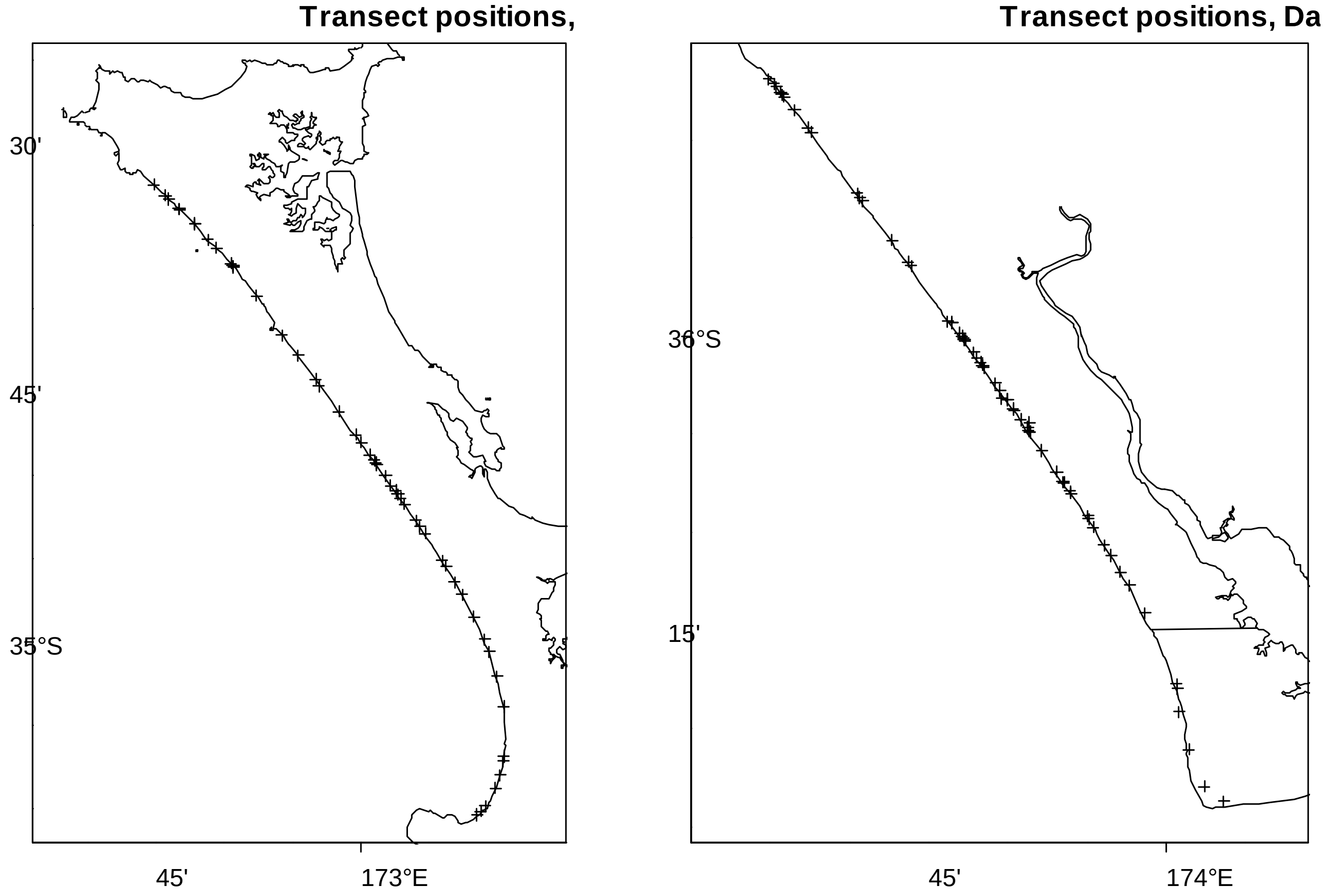


Figure 9: Transect positions for the toheroa/tuatua surveys at Ninety Mile Beach in 2010 and Dargaville Beach in 2011.

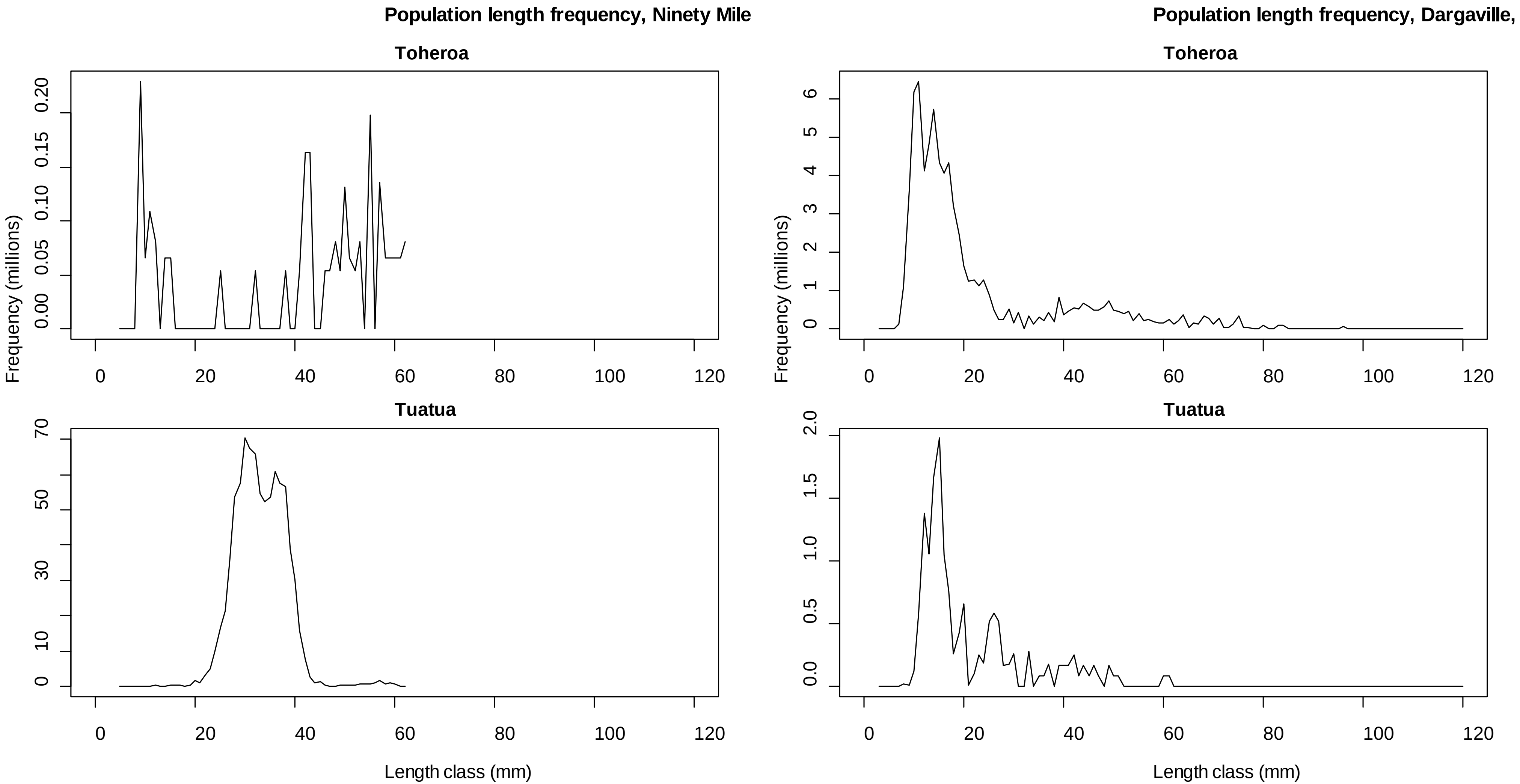


Figure 10: Population length frequency distributions for toheroa (top) and tuatua (bottom) at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.

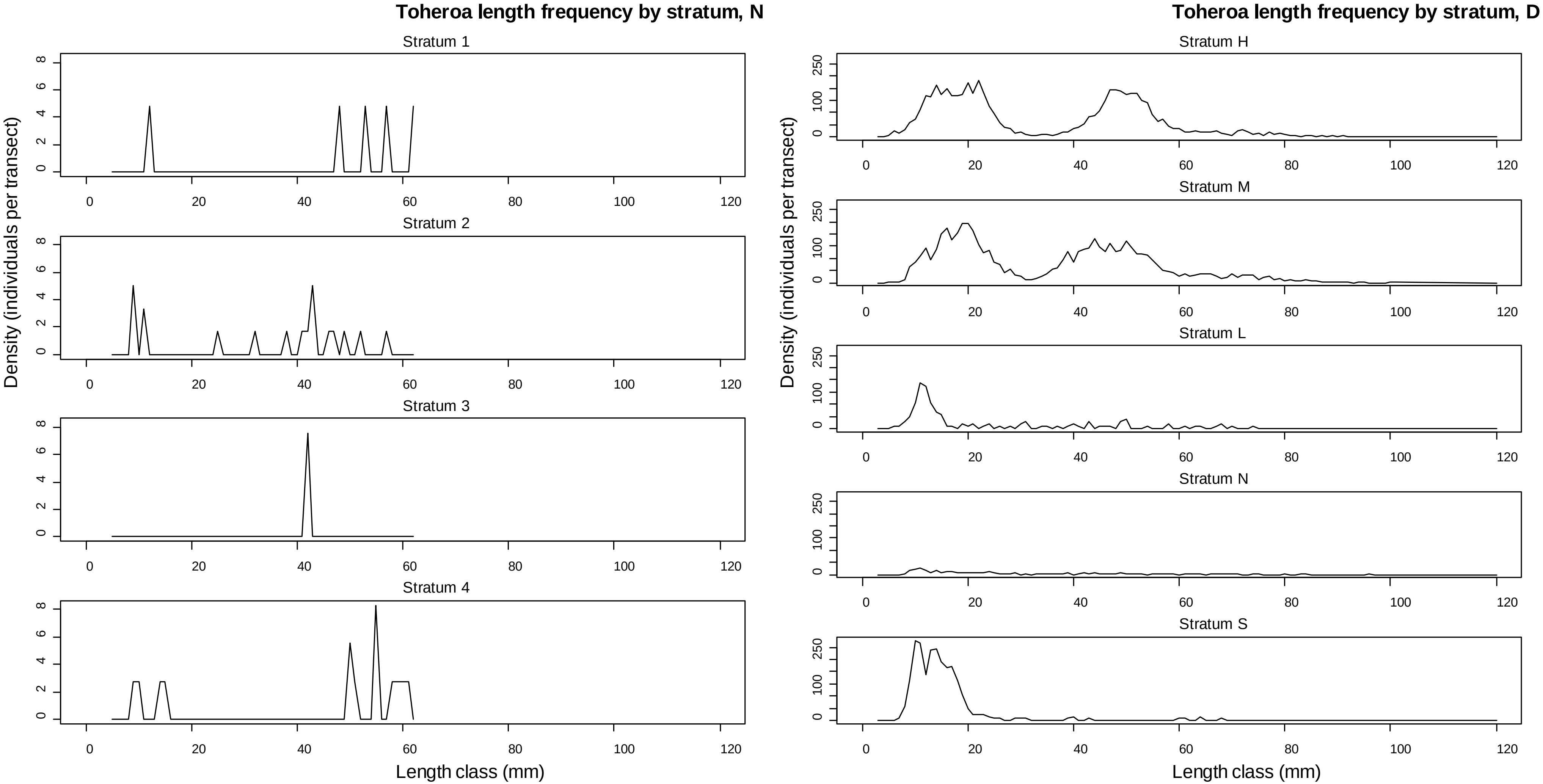


Figure 11: Stratum length frequency distributions for toheroa at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Values plotted as density (number of individuals per transect). Note the different y-axis scales.

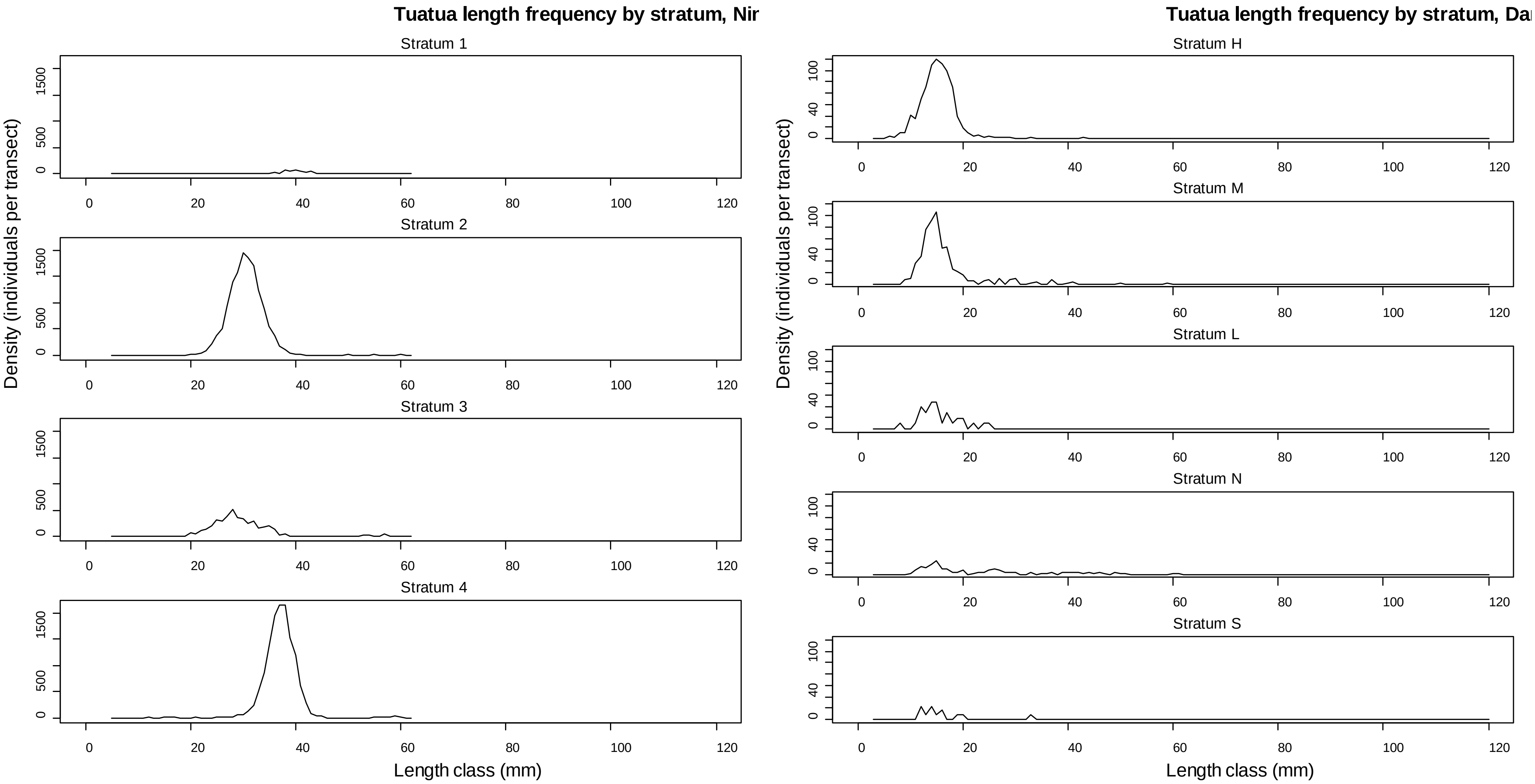


Figure 12: Stratum length frequency distributions for tuatua at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Values plotted as density (number of individuals per transect). Note the different y-axis scales.

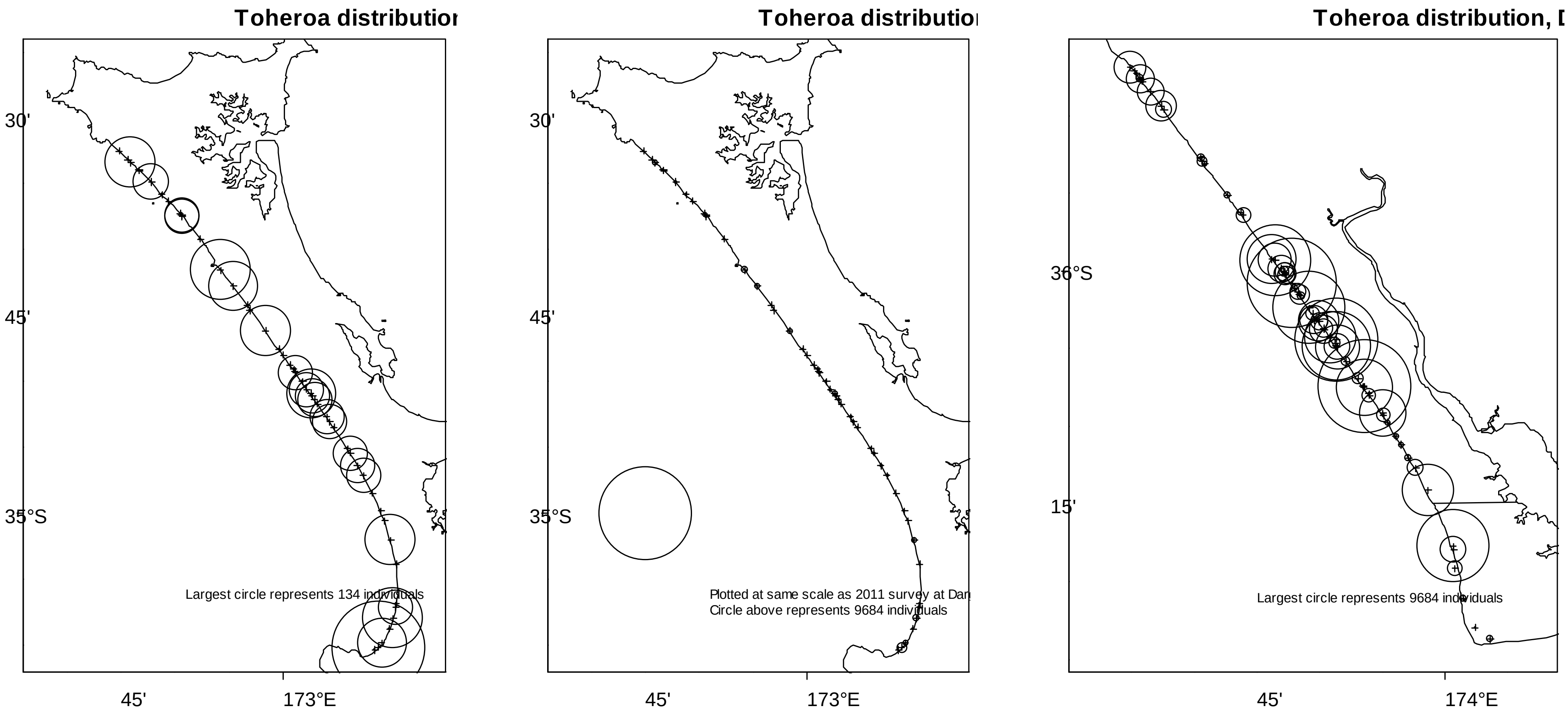


Figure 13: Alongshore distribution of toheroa at Ninety Mile Beach in 2010 (left and centre panels) and Dargaville Beach in 2011 (right panel). Circle area is proportional to the number of toheroa per 0.5 m wide transect down the beach slope (from the high to low water marks). To aid comparison, the centre panel shows the abundance of toheroa at Ninety Mile in 2010 plotted at the same scale as that shown in the right panel for Dargaville in 2011.

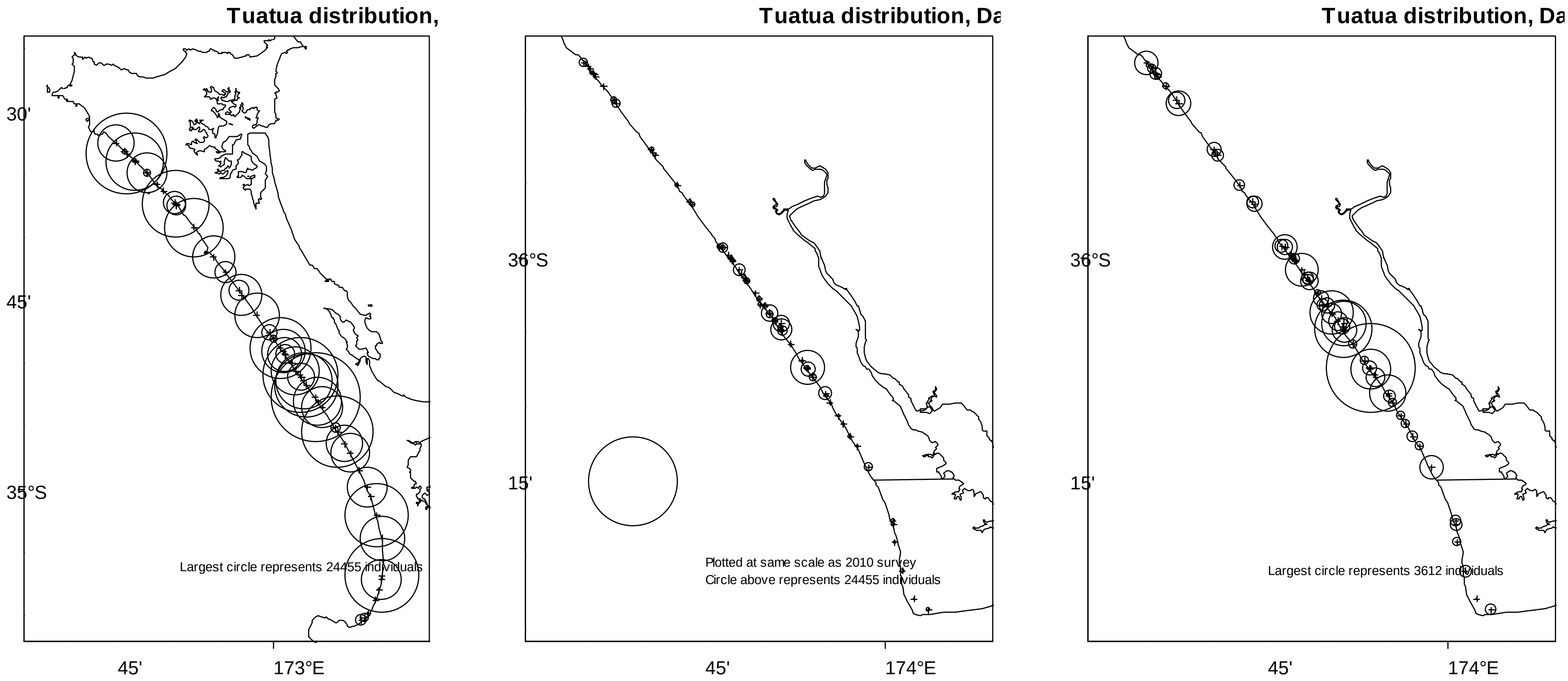


Figure 14: Alongshore distribution of tuatua at Ninety Mile Beach in 2010 (left panel) and Dargaville beach in 2011 (centre and right panel). Circle area is proportional to the number of toheroa per 0.5 m wide transect down the beach slope (from the high to low water marks). To aid comparison, the centre panel shows the abundance of tuatua at Dargaville in 2011 plotted at the same scale as that shown in the left panel for Ninety Mile in 2010.

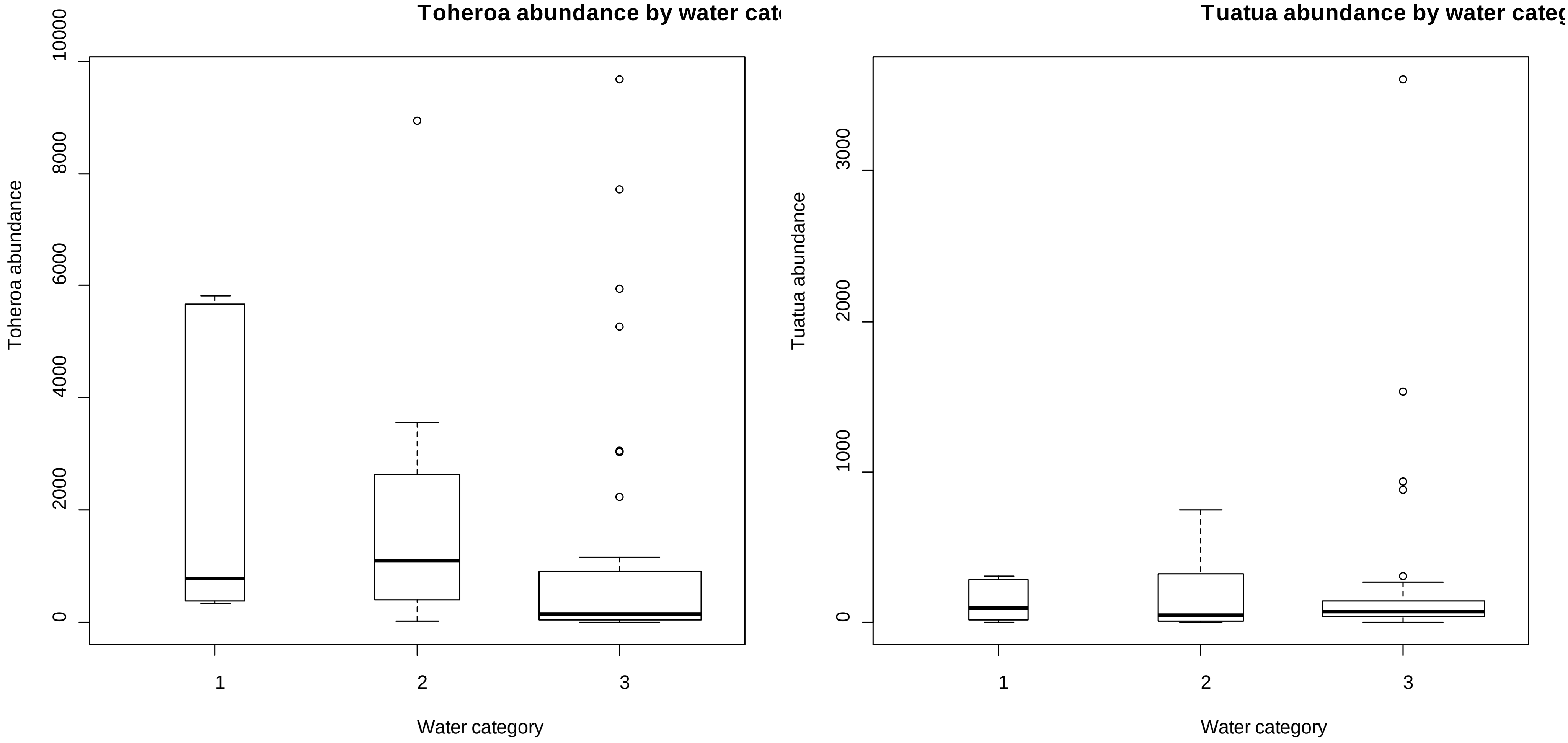


Figure 15: Boxplots of estimated abundance of toheroa (left panel) and tuatua (right panel) at Dargaville beach in 2011, by water category (i.e. proximity to freshwater stream/seep: 1, located within a freshwater stream/seep; 2, 1–50 m from a freshwater stream/seep; 3, over 50 m from a freshwater stream/seep). The solid line in the middle of the box represents the median, and the lower and upper ends of the box are the 25% and 75% quartiles respectively. The dashed lines extending beyond the box in either direction indicate 1.5 times the size of the box. Points beyond these lines are often considered to be outliers.

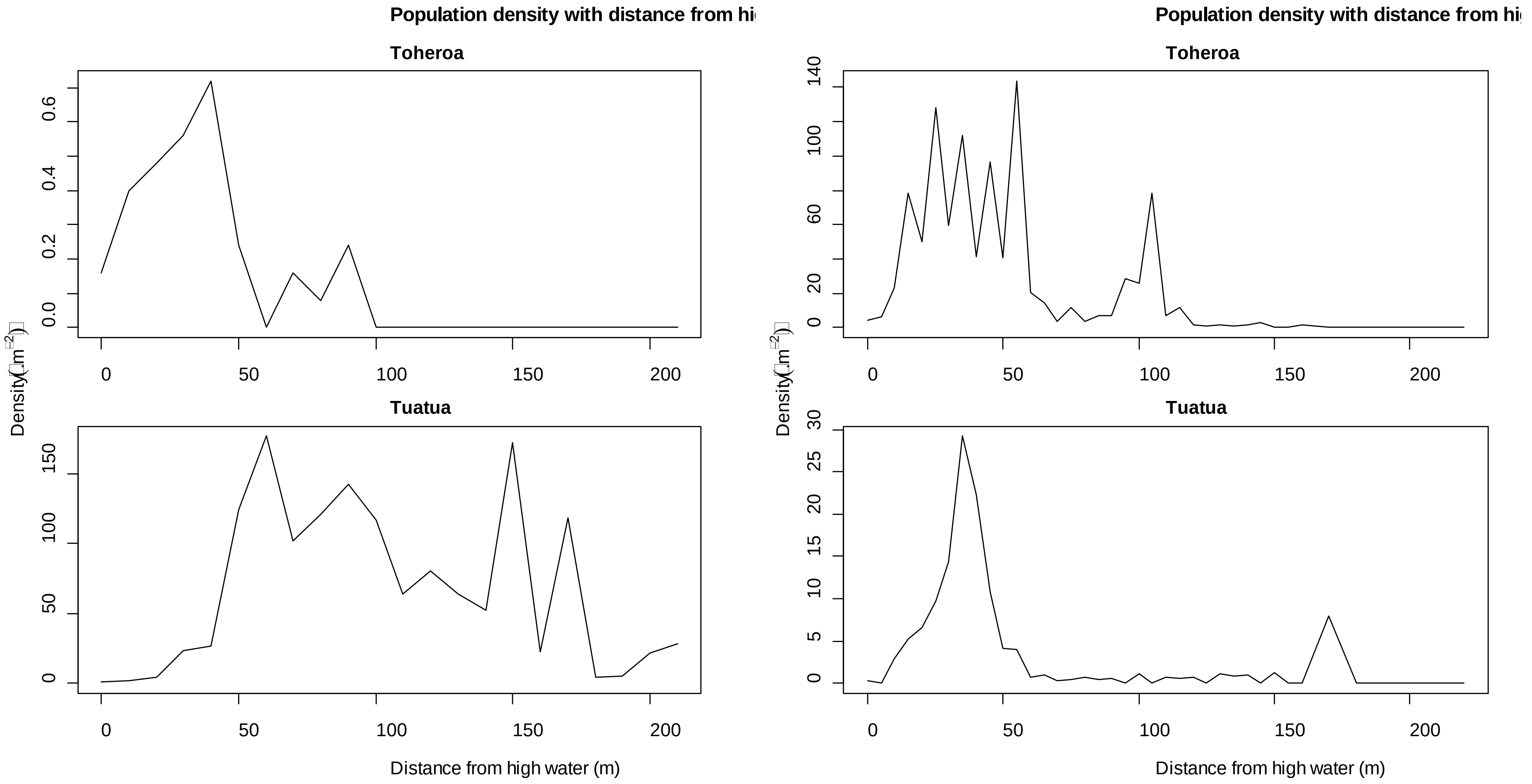
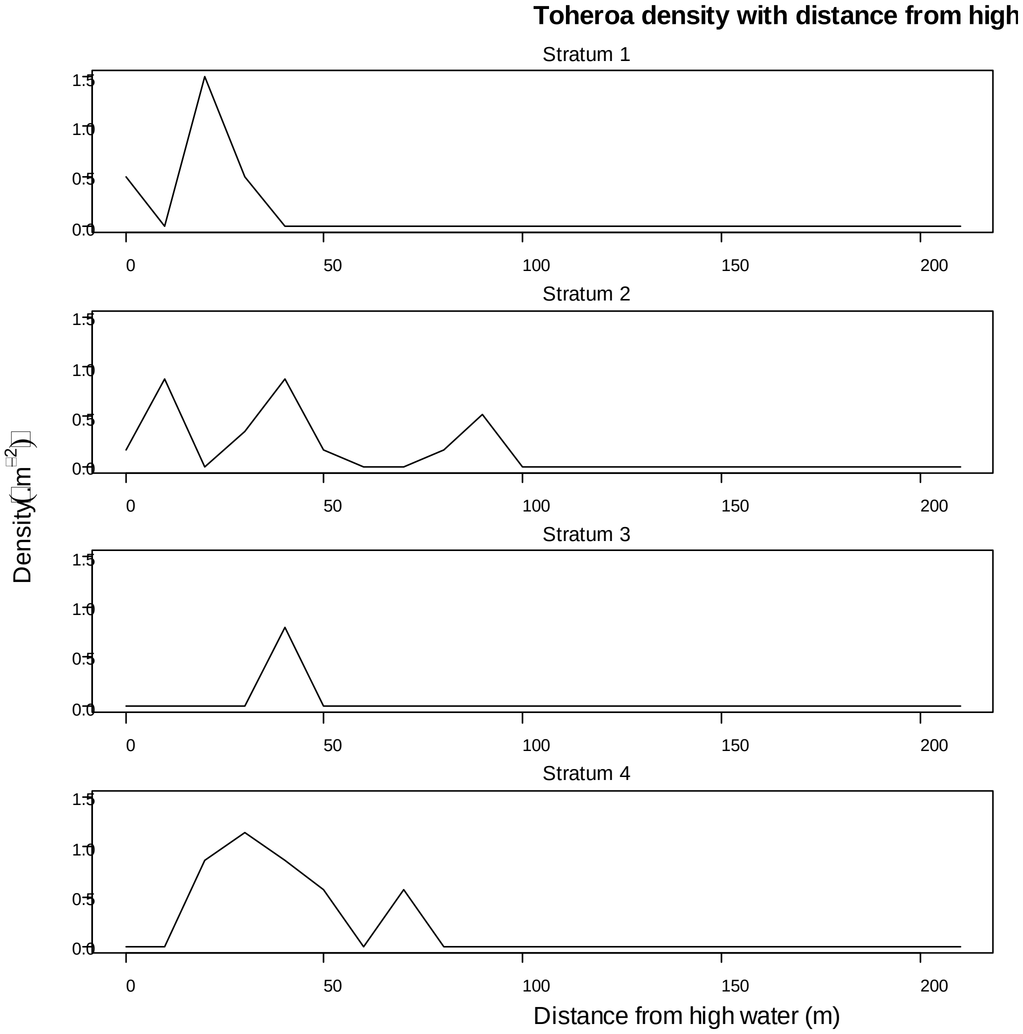


Figure 16: Population density (individuals.m^{-2}) with distance from high water (i.e., down the beach slope) for toheroa (top) and tuatua (bottom) at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.



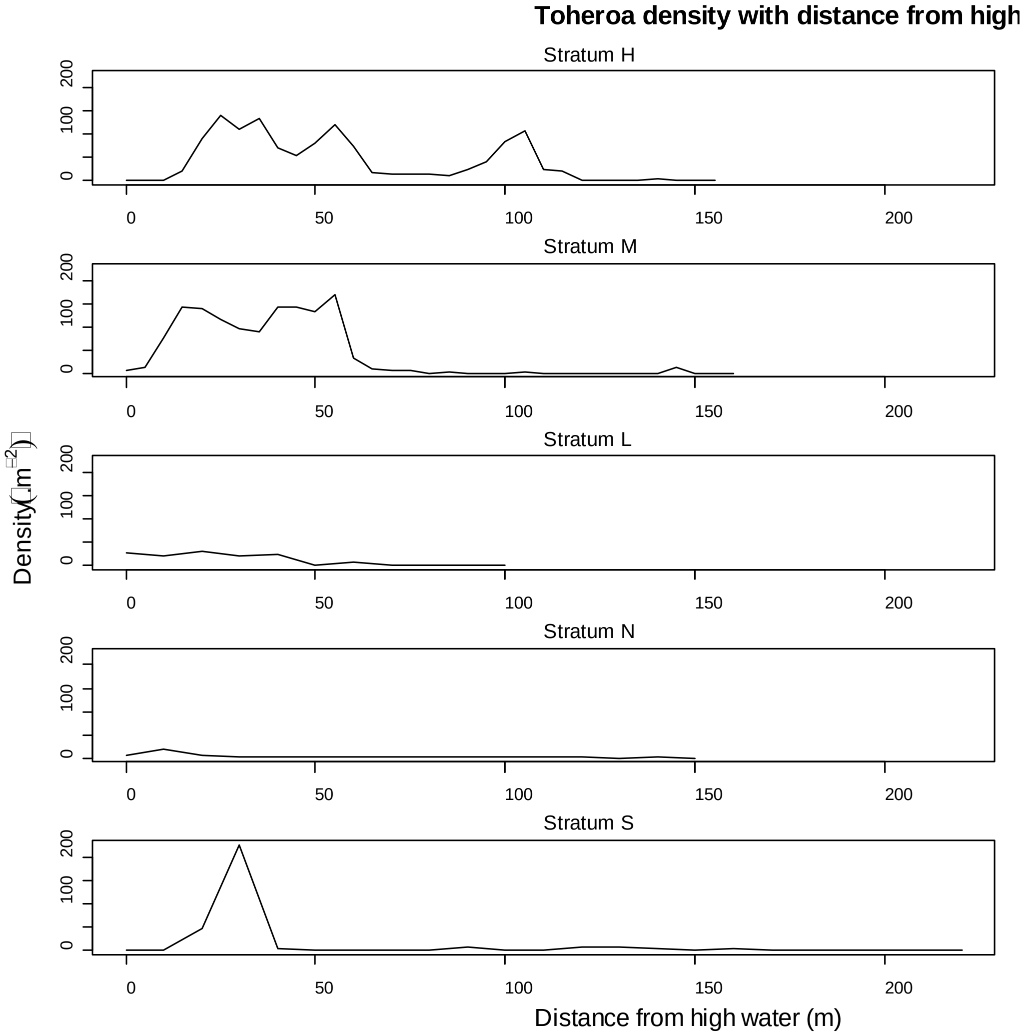


Figure 17: Toheroa density (m^{-2}) with distance from high water (i.e., down the beach slope) by survey stratum at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.

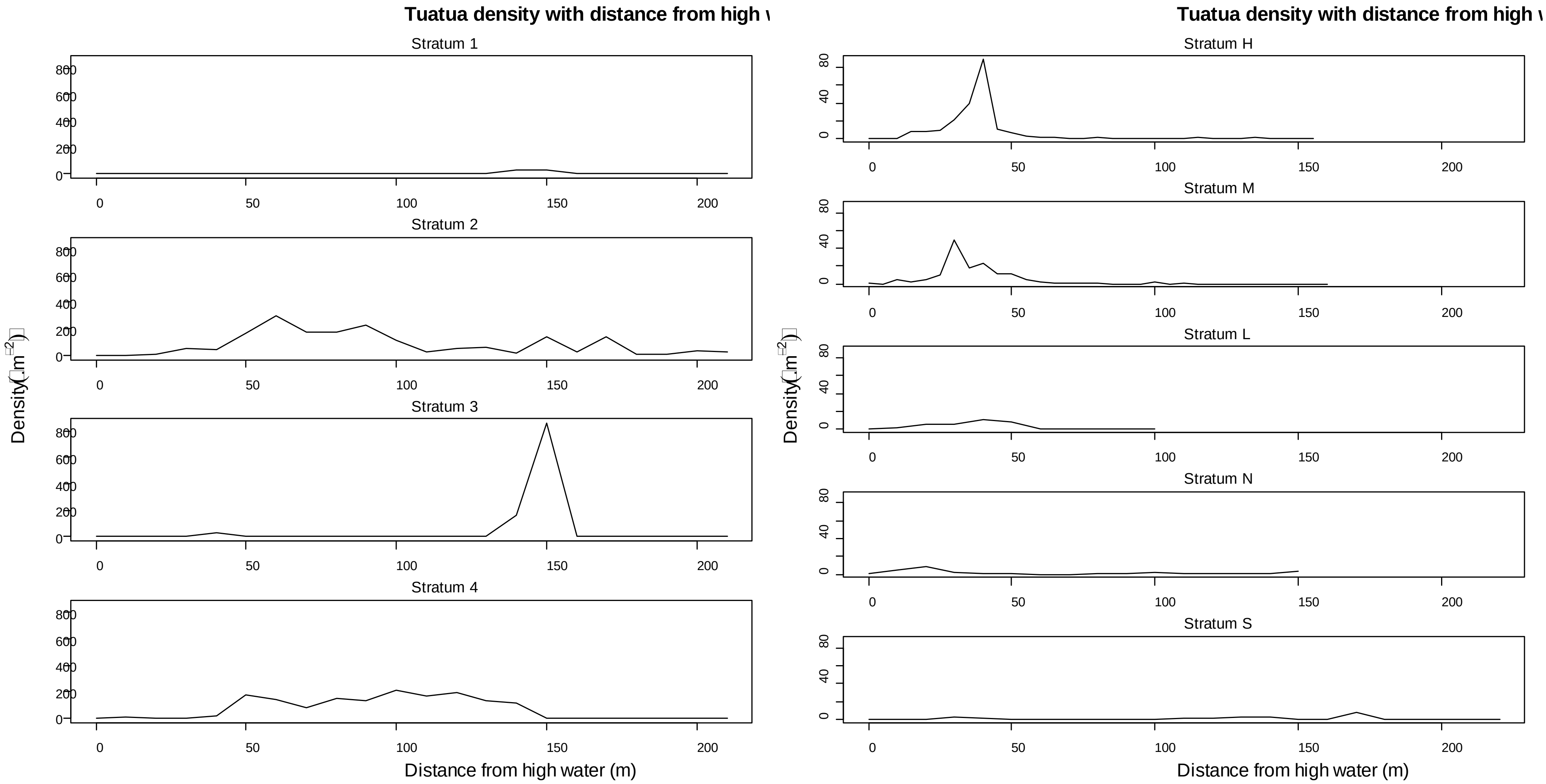


Figure 18: Tuatua density (m^{-2}) with distance from high water (i.e., down the beach slope) by survey stratum at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.

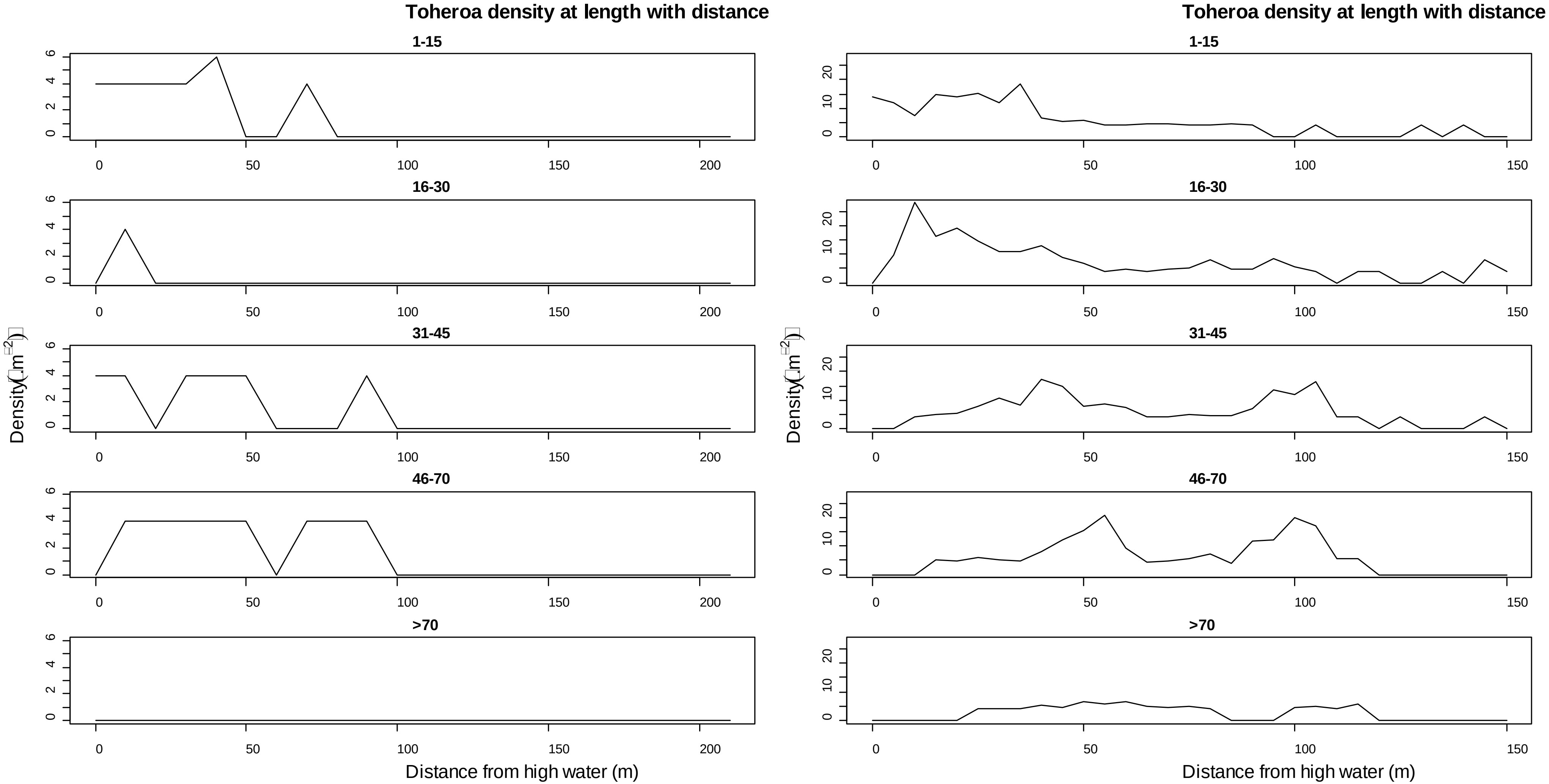


Figure 19: Toheroa population density at length (individuals.m^{-2} in different 15 mm length bins, all strata combined) with distance from high water (i.e., down the beach slope) at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.

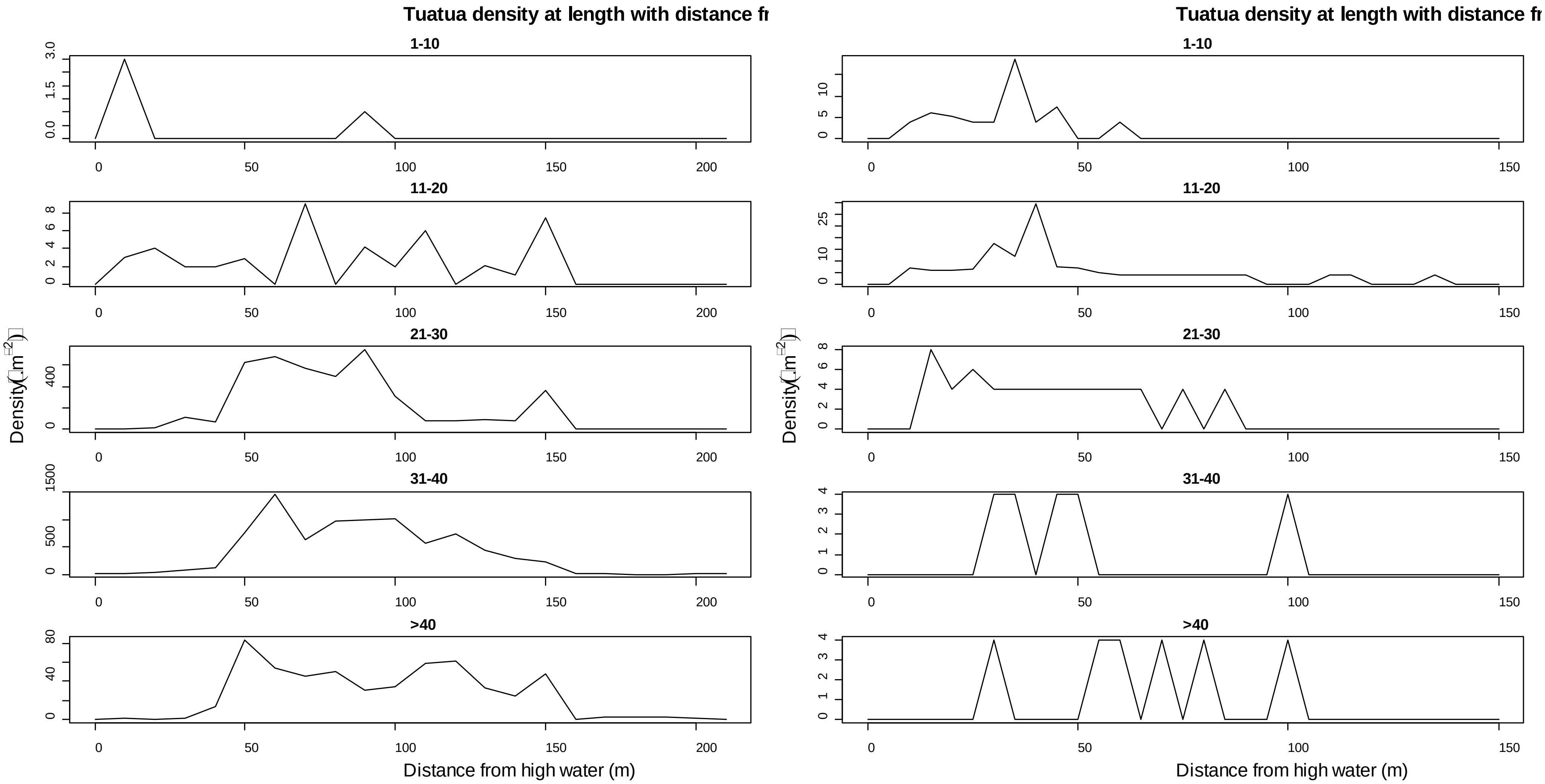


Figure 20: Tuatua population density at length (individuals.m^{-2} in different 15 mm length bins, all strata combined) with distance from high water (i.e., down the beach slope) at Ninety Mile Beach in 2010 (left panels) and Dargaville Beach in 2011 (right panels). Note the different y-axis scales.

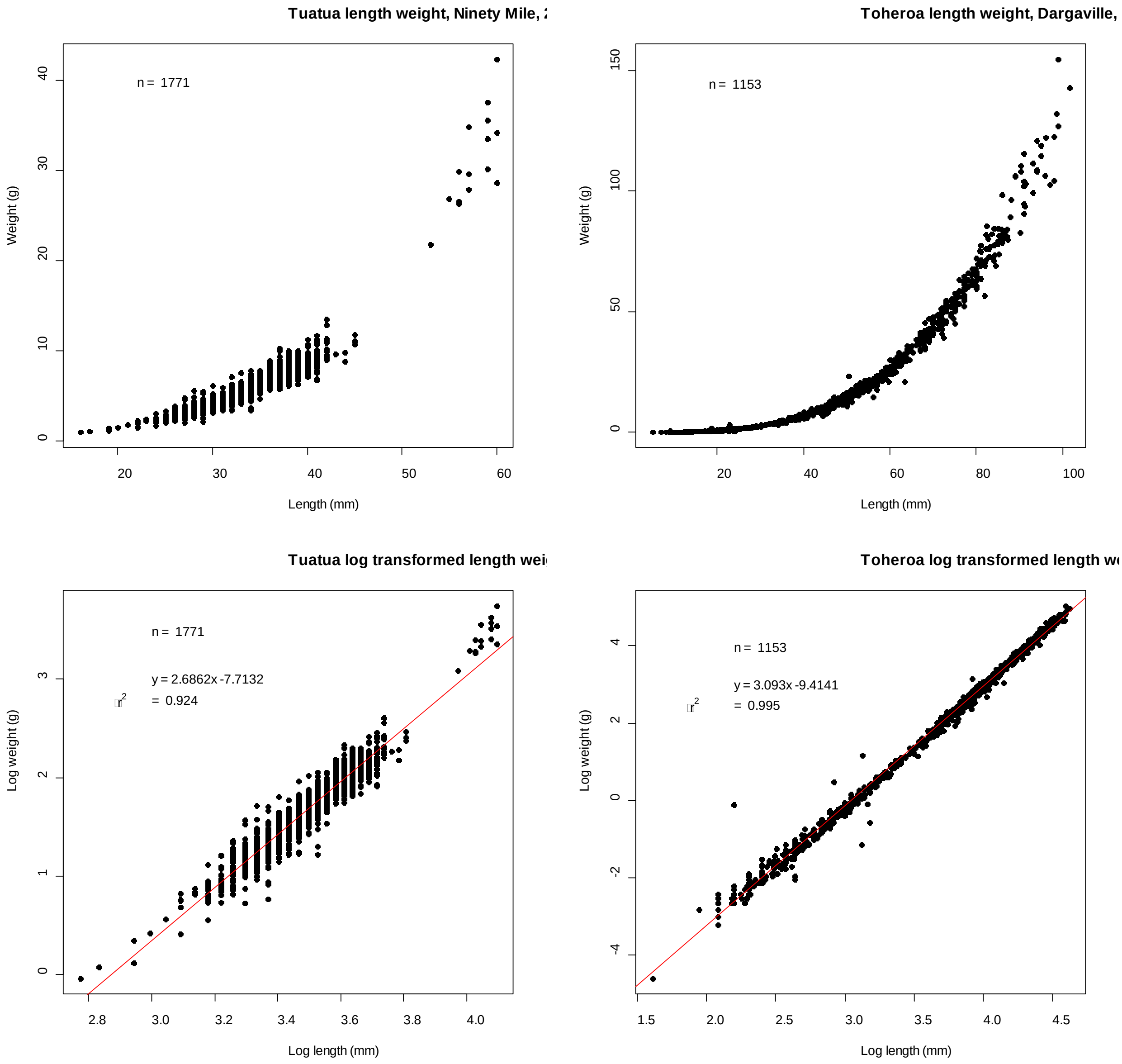


Figure 21: Length weight data for intertidal tuatua at Ninety Mile Beach in 2010 (left panels) and toheroa at Dargaville Beach in 2011 (right panels). The few length weight data recorded for toheroa at Ninety Mile in 2010 are not shown here. No length weight data were collected for tuatua at Dargaville in 2011. Bottom panels show the fits of a least squares linear regression to the log transformed length and weight data for each species. n, number of observations.

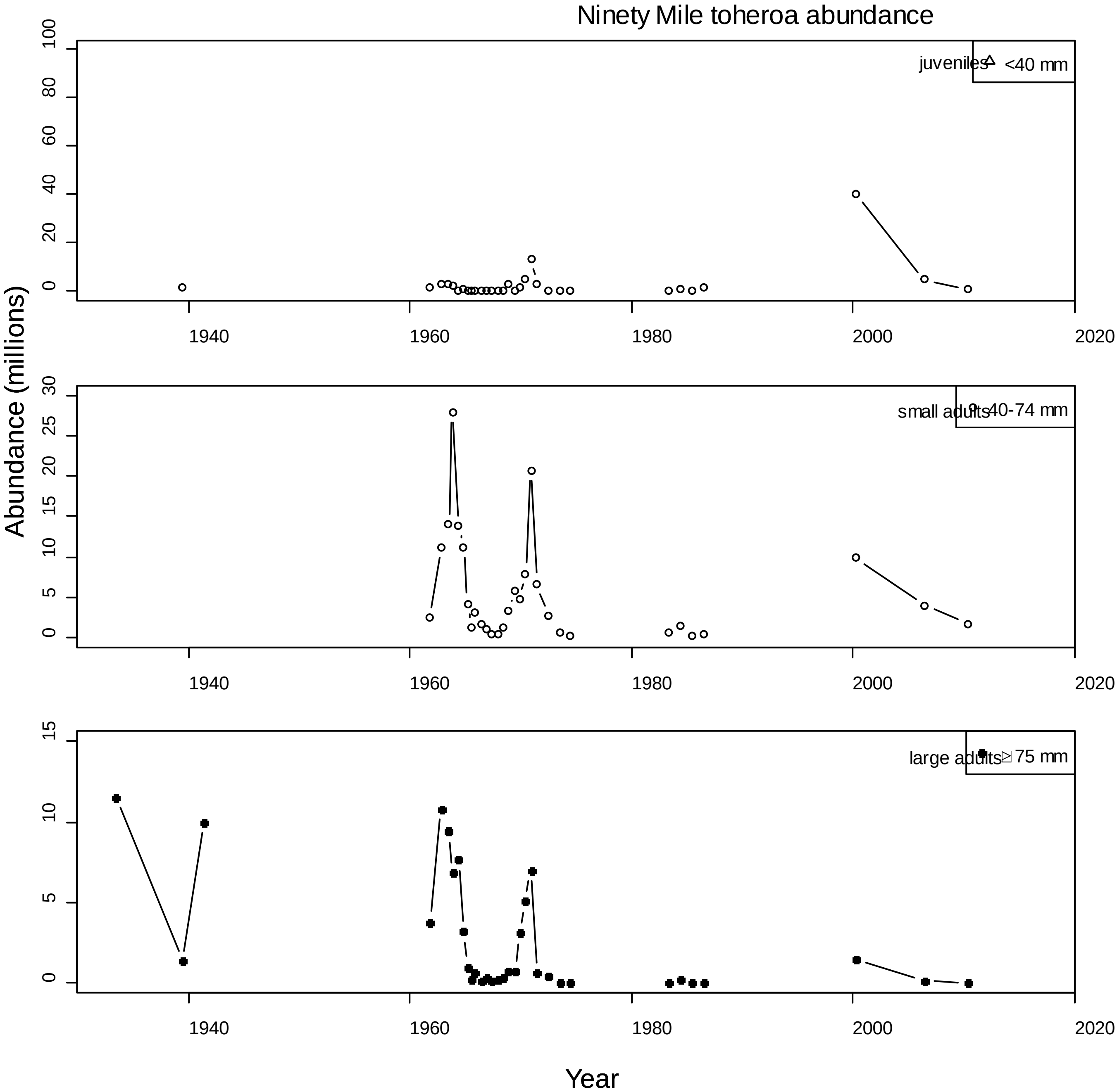


Figure 22: Time series of abundance for toheroa at Ninety Mile beach from 1933 to 2010. Note the different y-axis scales for the three different size categories.

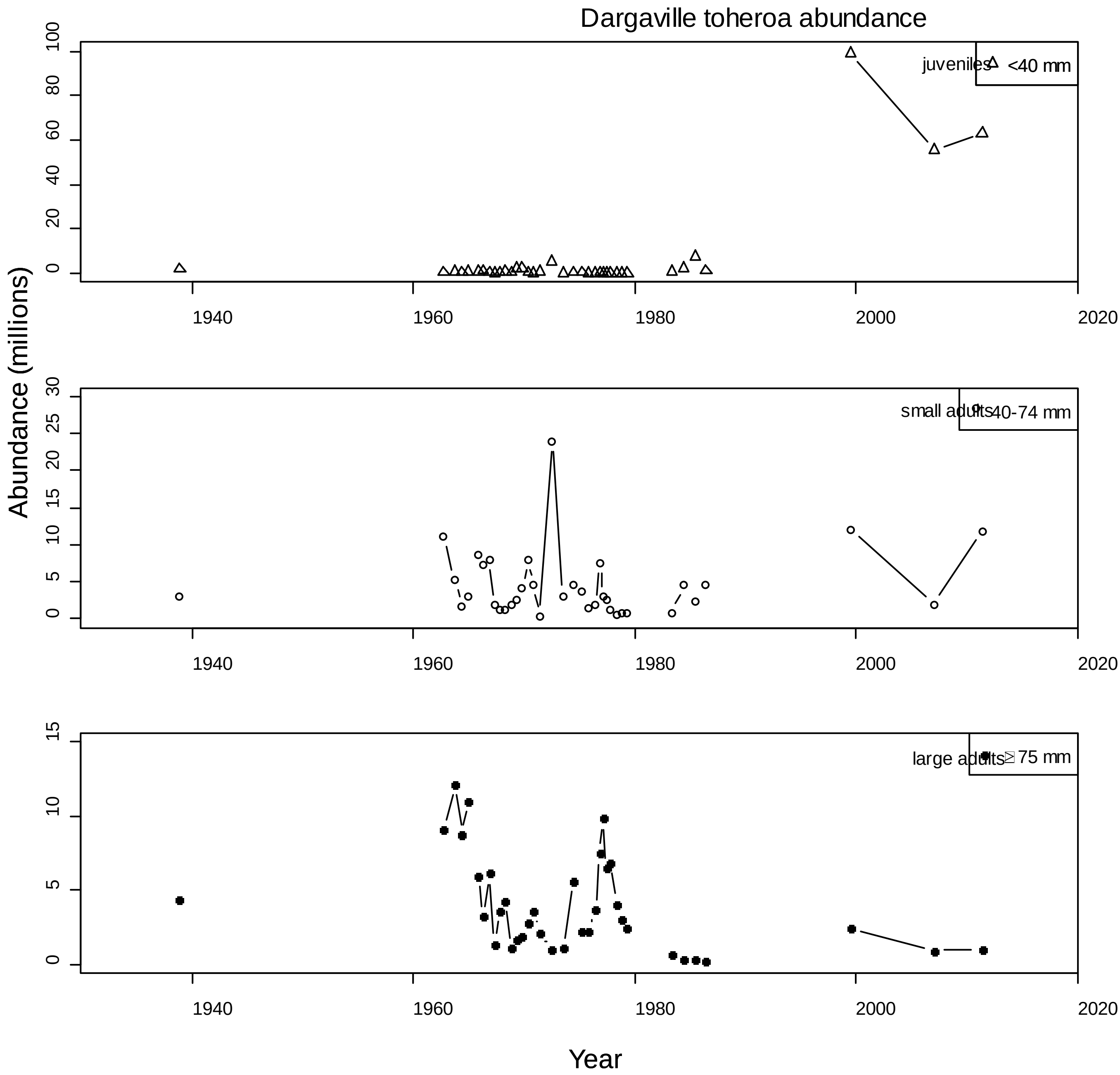


Figure 23: Time series of abundance for toheroa at Dargaville beach from 1938 to 2011. Note the different y-axis scales for the three different size categories.

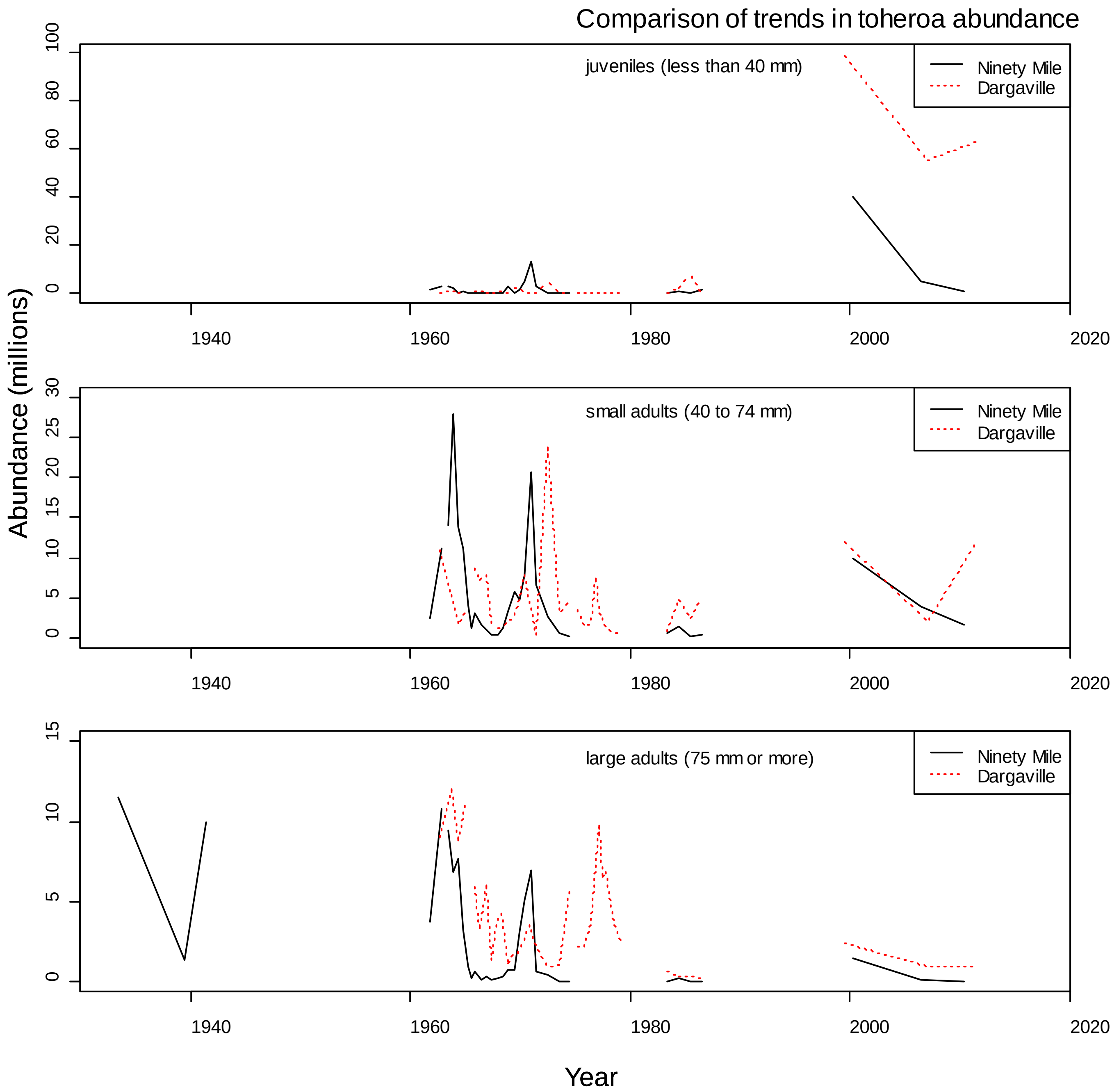


Figure 24: Comparison between estimates of abundance for juvenile (less than 40 mm shell length), small adult (40–74 mm) and large adult (75 mm or more) toheroa at Ninety Mile beach (solid black lines) and Dargaville beach (dotted red lines) from 1933 to 2011. The estimates are the same as those shown in Figure 22 and Figure 23, but the two beaches are shown overlaid here to aid the comparison of trends in abundance.

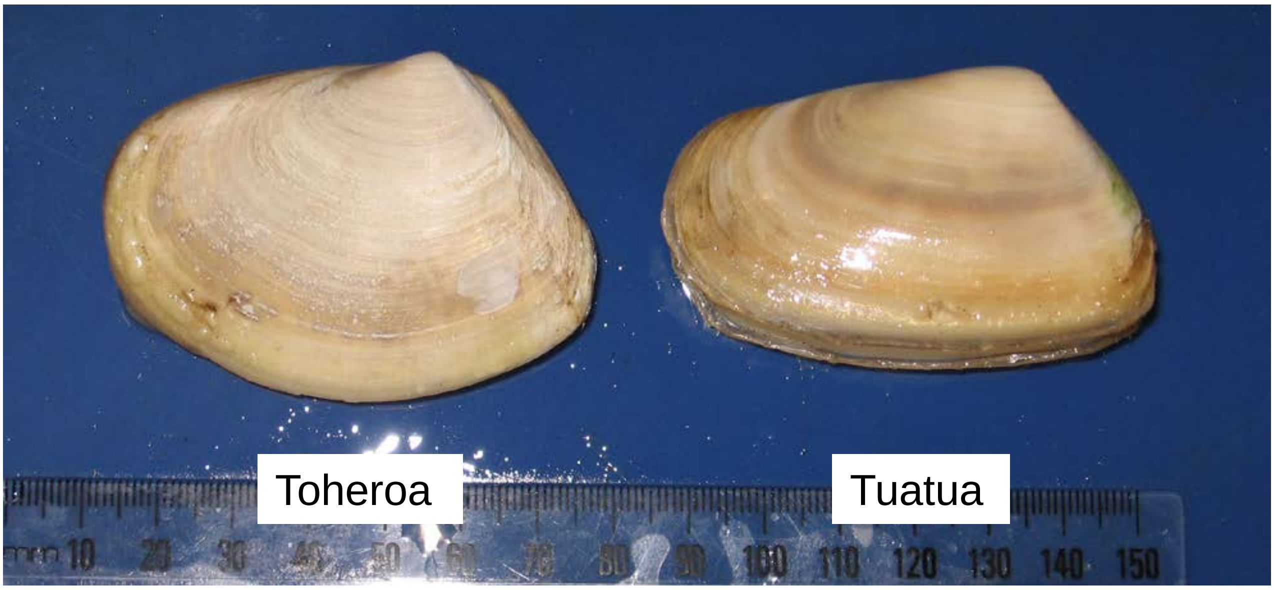
10 APPENDICES

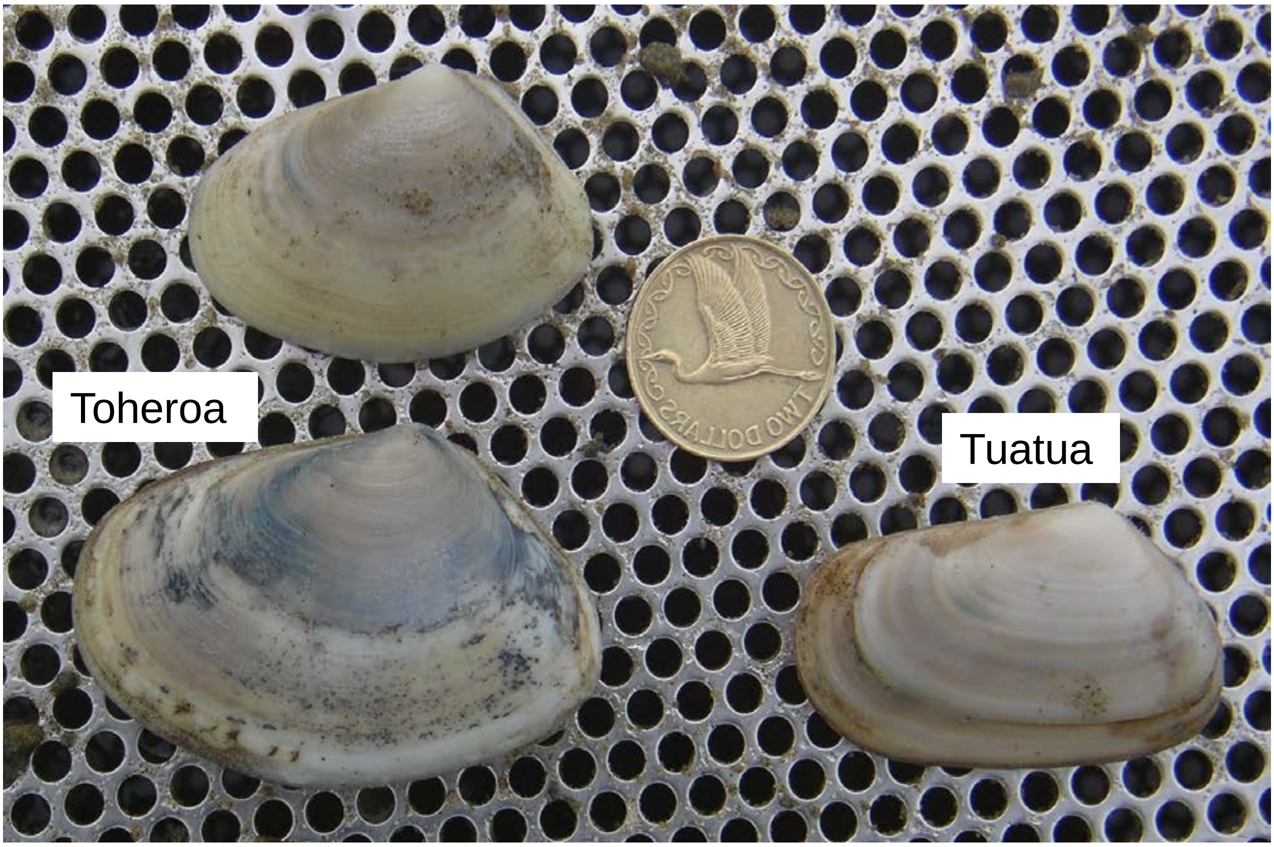
Appendix 1. Toheroa and tuatua identification diagnostics used for the surveys

Toheroa (*Paphies ventricosa*) and tuatua (*P. subtriangulata*) ID

Toheroa:

- **shell thinner than tuatua, gapes at one end** (compared to tuatua closely fitting valves)
- **shell is light, chalky, very fragile, easily cracked, particularly for juveniles** (tuatua shells are thick, hard, and difficult to break)
- **when put on flat surface, toheroa valve rocks longitudinally** (tuatua valve doesn't)
- **angle of shell sides at umbo more obtuse, wide angle** (tuatua closer to a right angle)
- **double posterior ridge** (compared to single strong posterior ridge in tuatua)
- **periostracum seldom covers whole shell** (tuatua more coverage, periostracum shiny)
- **[large pallial sinus, deep indentation** (tuatua have small pallial sinus, short indentation)**]**





Appendix 2. Survey methodology for Ninety Mile Beach (1961–2010)

1961	60 trenches at random locations were dug in the 48 km section of Ninety Mile Beach between Wairoa Stream and Hukatere (Figure 2). The trenches were centred at mid-tide level and ran perpendicular to the beach, 18–25 m long and 45 cm wide (Greenway & Allen 1962).
1962–63	Biannual surveys were conducted before and after the open season. The entire beach was surveyed by digging 27 m long trenches that ran perpendicular to the beach, centred at mid-tide level, and 18 cm wide. Trenches were randomly located, giving an approximate coverage of 1.125 m per km of beach. All toheroa present in the trenches were counted (Greenway 1969).
1965–74	Biannual surveys were conducted before and after the open season between 1965 and 1970; thereafter, surveys were conducted annually. Trenches were replaced with ten 0.21 m^2 quadrats at regular intervals along a 27 m transect that ran perpendicular to the beach and was centred at mid-tide level. The quadrats were dug out with a potato fork and the number of toheroa in all ten quadrats was multiplied by six to give an estimate of the number of toheroa for the whole transect. Transects were randomly located to give an approximate coverage of 1.125 m per km of beach.
1975–86	No specific information is available on the survey methodology from 1975 to 1986 but it is known that surveys were undertaken annually. It is presumed that the methodology remained the same.
1990	A brief survey was undertaken, although no data or methodology is available for this survey.
1993	A 1-day survey was reportedly undertaken, but no methodology is available.
2000	A two-phase stratified random survey design was used to survey Ninety Mile beach. Initially, the beach was visually surveyed for signs of toheroa beds, and preliminary excavations were conducted down the full slope of the beach at 1 km intervals. Based on the preliminary survey the beach was divided into seven density strata. In phase 1, 3–5 transects were allocated to each stratum depending on the estimated area of the stratum and its likely toheroa density. In phase 2, an additional 0–5 transects were sampled in each stratum; the number of additional transects was calculated by maximising the reduction of variance estimates. A total of 40 transects was sampled. Each transect was assigned a random starting point 0–9 m below the high water mark (HWM) and laid out down the shore perpendicular to the beach. Quadrats (0.5 m^2) were dug to a depth of 30 cm at 10-m intervals along each transect to the low water mark. For three transects per stratum the contents of the quadrats were sieved through a 5-mm mesh sieve to ensure that all toheroa (i.e. 5 mm or larger) present in the quadrats were collected. For the remaining transects, the sand within each quadrat was scattered onto the beach and all visible toheroa were collected and measured (Morrison & Parkinson 2001).
2006	The methodology used in this survey was consistent with the 2000 survey, except that the beach was divided into six density strata (high 1, high 2, medium, very low, none 1, and none 2) and the contents of all quadrats were sieved through a 5 mm mesh sieve (Morrison & Parkinson 2008); a total of 42 transects was sampled.
2010	A two-phase stratified random survey of toheroa was conducted from 26 to 29 April 2010 (present study); data on tuatua were also collected during the survey. Phase 1 transects were allocated to each stratum proportional to the area of the stratum and its likely toheroa density and were completed during the first three days of the survey. Phase 2 transects were sampled on the fourth day on the basis of maximising reductions in the variance estimates, again using the mean squared allocation method. This was achieved by adding a transect iteratively to each stratum, and using the existing density and variance information to predict the likely improvement in the c.v. for each possible stratum allocation. All transects were a minimum of 20 m apart. The survey team, comprised of four NIWA staff and 8–10 local iwi representatives, sampled a total of 744 quadrats, which were spaced every 10 m along 50 transects positioned between Scott Point and Ahipara. Transects ranged in length from 90 to 210 m (mean 140 m). The quadrats were excavated to a depth of 30 cm and the contents sieved with a 5 mm mesh sieve. Count and shell length data were recorded for all toheroa and tuatua present.

Appendix 3. Survey methodology for Dargaville Beach (1962–2011)

1962 A survey of the Meredith Bros. concession area on Dargaville Beach (between Glinks Gully and Round Hill) was conducted by Meredith Bros. and Co. Ltd. The beach was divided into 800 m sections and in each section 0.37 m^2 quadrats were dug parallel to the beach at the mid-tide level. The quadrats were dug at 43–76 m intervals until a bed was reached. Beds were surveyed by digging quadrats at 4 m intervals along a transect that ran perpendicular to the beach. Transects were repeated every 24–36 m along the bed, depending on the size of the bed (Greenway 1969, Redfearn 1974).

1962–63 Biannual surveys were conducted by the Marine Department before and after the open season. The 40 km section north of Glinks Gully was surveyed by digging 27 m long trenches that ran perpendicular to the beach, centred at mid-tide level, and 18 cm wide. Trenches were randomly located to give an approximate coverage of 0.9 m per 800 m of beach. All toheroa present in the trenches were counted (Greenway 1969).

1965–74 Biannual surveys were conducted before and after the open season between 1965 and 1970; thereafter, surveys were conducted annually. Trenches were replaced with ten 0.21 m^2 quadrats that were dug at regular intervals along a 27 m transect that ran perpendicular to the beach and was centred at mid-tide level. The quadrats were dug out with a potato fork and the number of toheroa in all ten quadrats was multiplied by six to give an estimate of the number of toheroa for the whole transect. Transects were randomly located to give an approximate coverage of 0.9 m per 800 m of beach (Greenway 1969, 1974b). In 1974, an additional survey was undertaken in the 16 km stretch between Glinks Gully and Chases Gap, in which the transect coverage was three times the usual coverage (Greenway 1969, 1974b, a).

1975–86 No specific information is available on survey methodology from 1975 to 1986 but it is known that surveys were undertaken annually. It is presumed that the methodology remained the same.

1990 A brief survey was undertaken, although no data or methodology is available for this survey.

1993 A 1-day survey was reportedly undertaken, but no methodology is available.

1999 Toheroa beds were located by visual inspection of the beach for siphon holes, and based on this information the beach was divided into three strata: high density bed, low density bed, and non-bed. Beds were surveyed by digging 0.5 m^2 quadrats at 5-m intervals along a transect that ran perpendicular to the beach from the high water mark to the low water mark. Non-bed areas, including the areas above and below defined beds, were surveyed by digging quadrats at 10-m intervals along each transect. The quadrats were excavated to a depth of 30 cm and the contents sieved with a 5-mm mesh sieve. All toheroa present were counted and measured. A total of 53 transects was sampled, with 45 transects passing through toheroa beds (Akroyd et al. 2002).

2007 A two-phase stratified random survey design was used similar to that used by Morrison & Parkinson (2001). Initially, the beach was visually surveyed for signs of toheroa beds, and preliminary excavations were conducted down the full slope of the beach at 1 km intervals. Based on the preliminary survey the beach was divided into five density strata: very high, high, medium, low, and other (non-bed). In phase 1, 5–24 transects were allocated to each stratum depending on the estimated area of the stratum and its likely toheroa density. In phase 2, an additional 0–30 transects were sampled in each stratum; the number of additional transects was calculated by maximising the reduction of variance estimates. A total of 93 transects was sampled. Strata containing toheroa were surveyed by digging 0.5 m^2 quadrats at 5 m intervals along a transect that ran perpendicular to the beach from high water mark to the lowest point possible. The 'other' stratum was surveyed by digging quadrats at 10 m intervals along each transect. The quadrats were excavated to a depth of 30 cm and the contents sieved with a 5 mm mesh sieve. All toheroa present were counted and measured (Akroyd et al. 2008).

2011 A two-phase stratified random survey of toheroa and tuatua was conducted from 14 to 17 April 2011 (present study). Phase 1 transects were allocated to each stratum proportional to the area of the stratum and its likely toheroa density and were completed during the first three days of the survey. Phase 2 transects were sampled on the fourth day on the basis of maximising reductions in the variance estimates, again using the mean squared allocation method. This was achieved by adding a transect iteratively to each stratum, and using the existing density and variance information to predict the likely improvement in the c.v. for each possible stratum allocation. All transects were a minimum of 20 m apart. Phase 1 transects were completed during the first three days of the survey, and Phase 2 transects were sampled on the fourth day. The survey team, comprised of four NIWA staff, a sub-contractor, and numerous local iwi representatives, sampled a total of 942 quadrats, which were spaced every 5 m (in medium and high density bed strata) or 10 m (other strata) along 62 transects positioned between Maunganui Bluff and North Head. Transects ranged in length from 50 to 220 m (mean 103 m). The quadrats were excavated to a depth of 30 cm and the contents sieved with a 5 mm mesh sieve. Count and shell length data were recorded for all toheroa and tuatua present.