



## Review of factors affecting the abundance of toheroa (*Paphies ventricosa*)

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## EXECUTIVE SUMMARY

**Williams, J.; Sim-Smith, C.; Paterson, C. (2013). Review of factors affecting the abundance of toheroa (*Paphies ventricosa*).**

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Toheroa (*Paphies ventricosa*) are a species of large intertidal surf clam endemic to New Zealand, and extensive populations were once present on exposed surf beaches in the regions of Northland, Wellington, and Southland. Commercial and recreational harvesting of the shellfish was intense during the early to mid-20th century, and populations declined to levels where harvesting was no longer viable. With the exception of limited customary take, harvesting of toheroa has been prohibited for over 40 years in some parts of the country, yet most toheroa populations have failed to recover. The reasons for this are not clear. The aim of this project was to review factors that might influence the abundance of toheroa, focusing specifically on sources of mortality and factors affecting recruitment. This report presents the existing time series of toheroa abundance estimates from surveys of the six main toheroa populations, and reviews the current knowledge available regarding toheroa, including local perspectives gathered from a case study in Northland. Possible factors influencing toheroa abundance were identified, and, where sufficient data were available, these were investigated further. Gaps in our knowledge were highlighted and suggestions made for future work to improve our understanding of the processes affecting toheroa.

From the time series data, it is evident that there has been a general decline in the abundance of toheroa recorded over time, with the exception of the Oreti Beach population which has increased since the 1990s. There is a great deal of variation in the abundance estimates, and not all populations have followed the same fluctuations over time. This indicates that there may be different local influences acting on the populations rather than a major overriding influence at a national level. The overall downturn observed has not been as marked in some populations as others, with Dargaville Beach (and Oreti Beach) appearing to have greater densities of juveniles than the other beaches suggesting that recruitment is better in some areas than others. Stock depletion and collapse can result from recruitment overfishing. While it is not possible to determine whether the continued low abundance of toheroa at some beaches is the result of recruitment overfishing, it is unlikely that this is the main factor. High recruitment has been observed at times when the abundance of the spawning stock was low.

From the review of literature, the main factors identified that potentially affect toheroa abundance were food availability, climate and weather, sand smothering/sediment instability, toxic algal blooms, predation, harvesting, vehicle impacts, and land use change. Of these, the available data on climate and weather, toxic algal blooms, vehicle impacts, and land use change were sufficient for further investigation. An association was found between toheroa mass mortality events and negative values of the Trenberth climate index  $Z$  at the time of the event, indicative of easterly zonal flow. This corroborates anecdotal observations that these events often coincide with easterly winds. There is strong evidence that the use of vehicles on beaches can be damaging to toheroa. Most vehicles drive on the mid to high tide area of the beach, where the densest beds of adult and juvenile toheroa are found, respectively, and both adults and juveniles appear vulnerable to vehicle traffic. Toheroa beds are usually associated with areas of the beach wet from freshwater seepage and it is possible that changes in land use adjacent to the beach could affect the availability of suitably wet beach habitat. Land use change was explored by comparing modern and historic land use adjacent to Ninety Mile and Dargaville beaches, which historically supported two of the largest populations of toheroa in New Zealand. Forests now dominate in contrast to dunes at Ninety Mile Beach. This increase in forestation is likely to have altered the hydrology of the area, reducing freshwater input to the beach, but it is unknown how important such changes may have been for toheroa. During recent surveys, very low numbers of toheroa were encountered at Ninety Mile Beach, while at Dargaville Beach, where land use has not been altered in the same way, toheroa were more abundant. The number of watercourses

annotated on topographic maps has also shown a larger decrease over time at Ninety Mile than at Dargaville.

From the case study on local perspectives, interviews carried out with iwi and others closely associated with toheroa identified six themes that grouped the factors thought to influence toheroa abundance. These themes were the deleterious effects of vehicles on beaches, negative features of the customary permit system, the loss of a stewardship ethic among Maori, adverse effects from land use, effects of cyclical weather patterns, and negative effects from the preferential harvest of large toheroa. Natural processes were considered to have a major influence on toheroa mortality and recruitment, but the cumulative effects of anthropogenic influences were thought likely to severely limit the ability of toheroa populations to recover from large scale natural mortality events or periods of poor recruitment.

This review has highlighted a number of factors likely to influence toheroa abundance. To investigate the causal mechanisms operating, a combination of monitoring, experimental, and modelling studies may be necessary. Undertaking zoning work on toheroa beaches by restricting vehicle access to permit comparisons of populations living under the same environmental conditions, but without vehicle stress, may provide detail on how influential vehicle stress is on toheroa survival. Investigating options for land use change in some areas whilst performing monitoring may provide indications of the relationship between land usage and toheroa abundance. Characterising the environmental conditions on beaches where toheroa populations have not reduced in number as significantly as at others may permit the habitat variables that promote the maintenance of healthy toheroa populations to be elucidated.

## 1. INTRODUCTION

Toheroa (*Paphies ventricosa*) are a species of large intertidal surf clam endemic to New Zealand. Extensive populations of toheroa were once present in large numbers on exposed surf beaches in the regions of 'Northland' (i.e. Northland and Auckland regions), 'Wellington' (i.e. Wellington and Manawatu-Wanganui regions), and Southland (Figure 1). Commercial and recreational harvesting of the shellfish was intense during the early to mid 20th century, and populations declined to levels where harvesting was no longer viable. With the exception of limited customary take, harvesting of toheroa has been prohibited for over 40 years in some parts of the country, yet most toheroa populations have failed to recover. The reasons for this are not clear. The aim of this project was to investigate factors that might influence the abundance of toheroa, focusing specifically on sources of mortality and factors affecting recruitment, by collating and reviewing the available information on toheroa.

Surveys of toheroa have been carried out at the following six beaches where major toheroa populations were found: Ninety Mile Beach and Dargaville Beach in Northland (Figure 2); Muriwai Beach near Auckland, and the 'Wellington' region beaches (Figure 3); and Oreti Beach and Bluecliffs Beach (Figure 4) in Southland. This report presents the existing time series of toheroa abundance estimates generated from those surveys, and reviews the current knowledge available regarding toheroa, including local perspectives gathered from a case study in Northland. Possible factors influencing toheroa abundance were identified, and, where sufficient data were available, these were investigated further. Gaps in our knowledge were outlined and suggestions made for future work to improve our understanding of the processes affecting toheroa.

The overall objective of this project was to investigate variations in the abundance of toheroa. The specific objective was to investigate sources of mortality of toheroa and factors affecting the recruitment of toheroa.

## 2. METHODS

Data on the abundance and size structure of toheroa for the six main toheroa populations, located at Ninety Mile Beach, Dargaville Beach, Muriwai Beach, the Wellington region beaches, Bluecliffs Beach, and Oreti Beach (Figures 1–4), were collated and entered into a database to create individual time series for the different beaches. Details of the various survey methodologies undertaken and reported are provided in Appendices 1–6.

The available published and unpublished literature on toheroa was reviewed, including scientific research papers, Ministry of Fisheries reports, New Zealand Marine Department annual reports, fisheries technical reports, and newspaper and magazine articles. In addition, historical qualitative and anecdotal information on toheroa from Northland beaches was gathered from interviews of local community members that are closely associated with the Northland beaches. This case study is detailed in Appendix 8.

Potential pressures on toheroa were identified from the literature review and several of these were investigated further where data allowed. Methods are detailed separately where this has been undertaken.

## 3. TIME SERIES OF ABUNDANCE

Estimates of toheroa population abundance derived from surveys conducted at the six main toheroa beaches are presented in Figures 5–7. Two categories of shell length were used: ‘pre-recruits’ (40–74 mm) and ‘recruits’ (75 mm or larger). On the whole, comprehensive surveys were not conducted until the 1960s at most beaches. Surveys before 1998 did not use sieves as part of the sampling protocol, so estimates of putative ‘juvenile’ toheroa (less than 40 mm) are not presented because they are considered unreliable.

### 3.1 Northland region beaches

Ninety Mile Beach, also known as Te Oneroa a Tohe (‘the long beach of Tohe’), extends from Scott Point to Ahipara Bay (88.5 km, Figure 2) in the Far North district of Northland. This exposed, open coast beach has a low gradient and is backed by extensive sand dunes, which extend up to 10 km inland and reach heights of up to 150 m. Pine forest plantations occupy the majority of the land adjacent to the beach (Brook & Carlin 2000, Walker 2007).

Dargaville Beach, also known as Ripiro Beach, is bounded by Maunganui Bluff in the north to Kaipara North Head in the south (72 km, Figure 2) in the Kaipara district of Northland. The beach is long and straight with fine sand, and fresh water seepage between mid and low tide is a common feature of parts of the beach. North of Glinks Gully the beach is backed by sandstone cliffs, while south of Glinks Gully the beach is backed by sand dunes. The littoral width of the beach varies from 180–300 m (Redfearn 1974). A small pine plantation exists at North Head (McKelvey 1999).

Muriwai Beach, also known as Te Oneone Rangatira Beach, spreads from the southern side of the Kaipara Harbour entrance to Muriwai village in the south (42 km, Figure 3). It is backed by low sand dunes and pine forests are found behind the entire length of the beach. Technically, Muriwai Beach is in the Auckland region, but for the purposes of this report we have grouped it in the Northland region.

The earliest estimates of toheroa abundance for the Northland region were made by several different observers based on observations and limited surveys, and these were summarised by Cassie (1955) and Rapson (1954). The first record was for Ninety Mile Beach in 1920, where there were reportedly 54.5 miles of good toheroa beds, roughly the majority of the beach. A description of part of the stock at Ninety Mile in 1926 suggested that there was an almost inexhaustible supply of toheroa at that time. Mass mortality events were observed in 1930 and 1932, and by 1933 the abundance of large

toheroa (over 3 inches in length, equivalent to 76 mm) at Ninety Mile was an estimated 11–12 million (which is probably an underestimate because only about 60% of the beach was sampled). In 1938 a heavy and widespread toheroa mortality event was observed along the entire west coast of the North Island, and in 1939 the abundance of large toheroa at Ninety Mile was an estimated 1.4 million, about an order of magnitude lower than in 1933. Following an apparently rapid initial recovery, the toheroa population at Ninety Mile declined in the 1940s to the extent that in 1946 it was ‘considered that the beach had never before been so barren’ and by 1948 toheroa were so scarce that it was difficult to find even a single specimen. By the late 1950s, however, toheroa stocks at Ninety Mile were reportedly improving (O’Halloran 1958, 1959, 1960). At Dargaville Beach, where early estimates of toheroa abundance are very limited, the total abundance of toheroa was reportedly 9 million in 1938 (of which 4.1 million were over 3 inches in length) and about 5 million in 1948. At Muriwai Beach, which has a more complete set of early estimates, the total abundance of toheroa was reported to be fairly consistent between 1937 and 1952, ranging between about 5 and 15 million, except after the heavy mortality event in 1938 when it was less than 1 million. The abundance of large toheroa (over 3 inches in length) at Muriwai was an estimated 6.7 million in 1937 and 5 million in 1942.

Estimates of abundance that are available from the more comprehensive surveys that followed from the 1960s onwards show that the populations at Ninety Mile, Dargaville, and Muriwai beaches underwent large fluctuations in abundance in the 1960s and 1970s (Figure 5). For example, two main peaks in abundance are evident at Ninety Mile around 1962 and 1970, each followed by declines over several years. During this period, the estimates of small and large toheroa appear to follow a similar trend. Since around 1980 surveys were conducted only sporadically, but the abundance of large toheroa appears to have remained low, despite occasional high abundances of small toheroa (spat). The most recent surveys at Ninety Mile in 2010 and Dargaville in 2011 were described by Williams et al. (2013).

### **3.2 Wellington region beaches**

The ‘Wellington’ region (i.e. Wellington and Manawatu-Wanganui regions) west coast toheroa population surveys were encompassed in the area between Koitiata Stream and Waikanae Beach (74 km, Figure 3). The area was divided into various sections, but the boundaries of the sections were not always consistent between surveys and the entire area was not surveyed in every survey. The structure of all the Wellington toheroa beaches south of Himatangi is similar; the beaches have fine uniform sands with occasional patches of shell and shingle, a gentle gradient, and are backed by sand dunes. North of Himatangi the beaches generally consist of shell grit interspersed with patches of sand. Fresh water seepage between mid and low tide is common on many of the beaches (Tunbridge 1967, Williamson 1969b).

Estimates of toheroa abundance for the Wellington region beaches are available for the mid 1960s to mid 1970s period only, except for at Waitarere and Hokio beaches which were also surveyed in 1940 (Figure 6). Toheroa populations were observed to be poor in 1958 and 1959 (O’Halloran 1959, 1960), and stocks were low in 1960, with poor phytoplankton noted that season (O’Halloran 1961). Peaks in abundance followed by declines occurred at all beaches in the mid to late 1960s.

### **3.3 Southland region beaches**

Oreti Beach is 29 km long, stretching from the New River entrance to west Riverton. Toheroa surveys usually covered 15.4 km of the beach from 1.8 km south of the south beach entrance to Waimatuku stream (Figure 4). The southernmost 1.8 km of the beach is a designated reserve that is permanently closed to toheroa harvesting (Millar & Olsen 1995). Surveys before 1990 are poorly documented and the methodology is assumed to have remained consistent between years (Beentjes et al. 2003).

Bluecliffs Beach is situated in Te Waewae Bay, which stretches from Sandhill Point to Pahia Point (Figure 4). It is a shallow shelving exposed beach backed by sandstone or mudstone cliffs. Toheroa



surveys cover the area between Grove Burn and Waikoau River (11.3 km). East of Grove Burn the sediment grades from sand to gravel (Street 1971).

Toheroa abundance estimates are available from surveys conducted at Oreti Beach and Bluecliffs Beach since 1969 and 1966, respectively (Figure 7). Abundance estimates, size, and spatial distribution of toheroa at these beaches were reviewed in detail by Beentjes (Beentjes 2010a, b).

At Bluecliffs Beach, there has been an overall decline in the abundance of small and large toheroa. The steepest downturn occurred over a ten year period between the mid 1960s and mid 1970s, followed by a more gradual decline since then, albeit with spikes in the abundance estimates in 1997 and 2005. In 2009, abundance at Bluecliffs was very low. Erosion of the beach has meant the area surveyed at Bluecliffs has been reduced since the mid 1980s; the area outside the surveyed area is assumed to be unsuitable for toheroa.

At Oreti Beach, the abundance of large toheroa increased in the early 1970s and subsequently fluctuated at a relatively high level until after 1985, when the population almost halved over two years. Abundance decreased further over the next ten years until 1996, when the population reached the lowest level recorded at Oreti. However, estimates since 1998 suggest the Oreti population has markedly increased, with the most recent survey in 2009 indicating abundance is at levels comparable to those observed in the early 1970s and 1980s.

## 4. REVIEW OF CURRENT KNOWLEDGE

### 4.1 Overview

Toheroa (*Paphies ventricosa*) are intertidal, suspension-feeding surf clams belonging to the family Mesodesmatidae, which also includes other New Zealand species in the same *Paphies* genus: pipi (*P. australis*), tuatua (*P. subtriangulata*), and deep water tuatua (*P. donacina*). Toheroa are the largest of these species, growing up to about 150 mm at some beaches. Toheroa inhabit exposed, open coast, fine sand ocean beaches, and are primarily found in the middle of the eulittoral (foreshore) zone, buried up to 20–30 cm below the surface. The bivalve has two long extendable siphons that protrude from the sand when feeding, and a large muscular foot, which enables the shellfish to rapidly burrow into the sand (Morton & Miller 1968).

Toheroa are broadcast spawners with separate sexes. Gametogenesis occurs in late autumn and winter, with peak spawning following in early spring (Redfearn 1974). A secondary spawning event may take place in summer, and occasionally a third spawning event may occur in autumn (Redfearn 1974). The larvae are planktonic, spending around three weeks in the water column before settling out of the water column onto the beach, metamorphosing into juvenile toheroa (spat) (Redfearn 1974, 1982, 1997). Growth in the first couple of years is rapid, with toheroa predicted to reach 70–80 mm length in one year and 100 mm in three to five years and estimated to attain a maximum size of 153 mm length and live for up to 20 years (Beentjes & Gilbert 2006b).

Toheroa are endemic to New Zealand and were once abundant on Northland west coast beaches (Ninety Mile Beach, Dargaville Beach and Muriwai Beach), Wellington west coast beaches (from Rangitikei River to Waikanae Beach), and Southland beaches (Oreti Beach, and Bluecliffs Beach and Orepuke Beach within Te Waewae Bay) (

Figure 1). Small populations also existed in the North Island at Spirits Bay, Tom Bowling Bay, Tokerau, Te Arai, Mitimiti, Whangape, Pollok, Piha, Ohope, Opotiki, and in the South Island at Hampden Beach, Waikouiti Beach and Long Beach, although only single specimens have been found at the latter two beaches (Hoby 1933, Cassie 1955, Street 1971, Redfearn 1974).

Toheroa were a much sought after delicacy by both Maori and New Zealand Europeans. Commercial harvesting of the shellfish began in the late 1800s; harvesting mainly occurred on the Northland

beaches, and the vast majority of the harvest was canned (Stace 1991). Total commercial production for Northland beaches from 1928 to 1969 was typically around 20 tonne of canned product per annum, with a record production of 77 tonnes in 1940 (Redfearn 1974). Toheroa were also canned at the Wellington beaches and in Te Waewae Bay at various times, for very short durations (Redfearn 1974). By 1969 toheroa populations around the country had declined to such an extent that commercial harvesting was no longer economically viable, and all commercial harvesting ceased in 1969 (Redfearn 1974).

Recreational harvesting pressure on toheroa populations was intense from the early 1900s onwards, though little quantitative data is available. Harvesting regulations were introduced in 1932 and became progressively more restrictive, in an attempt to control the nationwide population decline in toheroa stocks. However, toheroa populations continued to decline and recreational toheroa harvesting has been prohibited from Ninety Mile Beach since 1971, from Muriwai since 1976, from the Wellington beaches since 1978, from Dargaville and Te Waewae Bay since 1980, and from Oreti Beach since 1993.

Adult populations have still not recovered to a level that would allow commercial or recreational harvesting, and no toheroa harvesting is currently permitted within New Zealand, with the exception of limited customary harvests (Greenway 1972, Redfearn 1974, McKinnon & Olsen 1994, Akroyd 2002, Beentjes & Gilbert 2006a).

Given that large toheroa were once abundant on several exposed New Zealand beaches, it appears that certain aspects of the population dynamics or supporting habitat have changed, so that these areas can no longer support large adult toheroa populations. Over the last 40 years, toheroa populations appear to have received erratic (and occasionally quite substantial) recruitment pulses, followed by large scale mortality that prevents increases in adult abundance (Morrison & Parkinson 2001, 2008). The specific processes that influence recruitment and mortality of toheroa have been speculated upon, but have not been methodically studied. By reviewing the factors that might influence the recruitment and mortality of toheroa, using the available scientific, customary, and historical information, we aim to provide a better understanding of the processes that might be driving the decline of this iconic New Zealand shellfish.

## **4.2 Recruitment process**

Recruitment, in an ecological sense, is defined as the addition of new individuals to the population. In the context of this report, recruitment is defined as the successful settlement of juvenile toheroa (spat) on the beach.

### **4.2.1 Reproduction**

Toheroa are gonochoristic (the sexes are separate in different individuals, and sex does not change over an individual's lifetime), with a 1:1 male to female sex ratio, though very occasionally hermaphrodite individuals are found (Hoby 1933, Smith 2003). It has been estimated that the majority of toheroa reach sexual maturity at 32 mm in length, at an age of 9 to 15 months (Redfearn 1974), though recent growth estimates of South Island toheroa suggest that toheroa could reach sexual maturity in well under one year (Beentjes & Gilbert 2006b). In a study by Redfearn (1974), all toheroa were found to be mature by 47 mm in length.

Toheroa reproduce by broadcast-spawning, releasing their gametes into the seawater for external fertilisation. They have a semi-continuous reproductive strategy, with spawning and subsequent recovery through the maturation of gametes potentially occurring several times from late winter to early autumn. In northern populations, gametogenesis occurs over late autumn and winter, with toheroa reaching maximum reproductive condition in late winter (July–September). A major spawning peak occurs in late winter–spring (July–November), with up to 80% of the population spawning. Histological studies show that gonads may rapidly redevelop within one month of

spawning, and a second spawning event often occurs in summer (December–January). In some years toheroa may spawn a third time in autumn (March), and partial (‘trickle’) spawning can occur at any time during the year (Redfearn 1974, 1982, 1997, Smith 2003). No reproductive studies have been conducted on southern toheroa populations. Like many other temperate bivalves, it is thought that environmental conditions, such as an abundance of food and changes in water temperature, primarily determine the onset and duration of spawning in toheroa (e.g., Muranaka & Lannan 1984, Devauchelle & Mingant 1991, Utting & Millican 1997).

Toheroa have been observed spawning *in situ* on Dargaville Beach. In one instance, spawning occurred for a period of 10 minutes at night on an incoming tide where 80–100 adults emerged from the sand with their siphons extended. Gametes were released in a stream from their exhalent siphon on the incoming waves (Akroyd 2002, Smith 2003).

Mature eggs are 60–90 µm in diameter and adult females can release 15 to 20 million eggs during a single spawning period of 2–3 hours (Hoby 1933, Redfearn 1982). Fecundity of female toheroa increases with length, though the exact size-fecundity relationship is unknown. Hoby (1933) estimated that a 56 mm (shell length) toheroa contained about 2 million eggs, whereas a 106 mm toheroa contained between 11 and 23 million eggs.

Oocyte diameter was found to vary significantly within an individual, and toheroa only release a portion of their gametes during a spawning event (Smith 2003). Small to medium toheroa (less than 80 mm shell length) had a larger variation in oocyte diameter and condition index during the spawning season compared to large toheroa (greater than 80 mm). This suggests that smaller toheroa release the majority of their eggs during a spawning event providing a short pulse of gametes, whereas large toheroa spawn more frequently but release a smaller percentage of their eggs at any one time, providing a more sustained supply of gametes (Redfearn 1974, Smith 2003).

Smith (2003) found a high level of gametogenic synchrony between male and female toheroa. Such reproductive synchrony is often observed in broadcast spawning marine invertebrates, and is widely thought to be an adaptation to maximise fertilisation success. For toheroa in particular, specific cues may be important to synchronise spawning, otherwise the chance of fertilisation occurring in such a turbulent environment is likely to be very small. Kaitiaki (a Maori word meaning ‘guardian with an obligation’) of Dargaville Beach believe that toheroa spawn around the time of the full moon (Smith 2003), and Akroyd (2002) reported several observations of toheroa spawning during the days leading up to the full moon. Smith (2003) studied the relationship between toheroa spawning and the lunar cycle, and suggested that spawning events may be correlated to a semi-lunar rhythm, with spawning occurring around the time of either a new moon or a full moon. However, a more frequent and regular sampling regime conducted over the entire year is required to confirm this.

#### **4.2.2 Fertilisation and larval development**

Toheroa larvae have been reared to settlement stage under hatchery conditions (Redfearn 1982). Mature adults collected from the field were induced to spawn by scrubbing them with a brush and then subjecting them to temperature fluctuations between 20 and 28°C, as well as adding a sperm suspension to the water. Eggs and sperm were collected separately and artificially fertilised. Toheroa sperm rapidly cluster around the unfertilised eggs and fertilisation occurs within 30 minutes. Sperm remain active for up to seven hours if no eggs are present (Hoby 1933).

Fertilised eggs produce two small polar bodies shortly after fertilisation has occurred, and within 2–4 hours the eggs show the first and second cleavages (Smith 2003). Ciliated blastulae appear 15–24 hours after fertilisation, and straight-hinge veligers develop 24–48 hours after fertilisation (Smith 2003). The veligers progress to umbo stage larvae at lengths of 109–140 µm, and pediveliger larvae were observed at lengths greater than 250 µm (Smith 2003). The majority of larvae settled at 270–300 µm in length, after approximately 22 days culture at 25°C (Smith 2003). The timing of settlement varied considerably, and it is likely that toheroa larvae, like many other bivalves, have the ability to

delay settlement if a suitable settlement substrate cannot be found (Hoby 1933, Redfearn 1982, Smith 2003).

### **4.2.3 Settlement**

In ecology, settlement is defined as the transition from a pelagic to a benthic life phase. The process begins with the onset of a behavioural search for a suitable settlement substratum and ends with metamorphosis of the individual. Certain bivalves also exhibit secondary settlement behaviour, where young spat may detach and re-settle a number of times by producing a long mucus thread that increases the viscous drag on the animal, allowing it to drift in the currents. Known as bysso-pelagic drifting, the occurrence of this behaviour has not been investigated for toheroa, but has been found to occur in certain closely-related Mactrid clams (Sigurdsson 1976).

Toheroa spat are washed ashore and the majority settle on the beach just below the high water mark. Peak settlement of spat (2 mm or more shell length) occurs in summer (December–January), one to two months after the peak spawning period (Redfearn 1974). In years when settlement is high, spat can be found as a continuous band along the beach. It is thought that this distribution is caused by the surf dislodging small toheroa and depositing them near the high water mark. Initially, spat have a limited ability to burrow, and instead anchor themselves to the substrate by attaching a byssus thread to sand grains. At a length of 2 mm spat can burrow to a depth of 1–2 cm below the surface. As the shellfish grow they progressively move lower down the shore to around the mid-tide level, and burrow to greater depths (Redfearn 1974, 1982, McKinnon & Olsen 1994, Redfearn 1997, Beentjes & Gilbert 2006a).

It is not known whether toheroa have any particular physical, chemical, or biological cues for settlement. Beaches that contain toheroa share a number of common features including open exposed surf conditions, a wide shallow gradient (dissipative beach), usually backed by sand dunes or cliffs, fine uniform sand with an average grain size of 0.21–0.33 mm, high levels of fresh water seepage on the beach, and high concentrations of phytoplankton (Rapson 1952).

Anecdotal reports state that toheroa are more common in areas where freshwater runs down the beach or where the water table lies close to the surface. When the tide is out, the sand in these areas remains moist for longer periods of time, and toheroa living there may have a lower risk of desiccation. Toheroa at Dargaville Beach were found to be living just above the water table, which was 100–300 mm below the surface (Akroyd 2002). In some areas, toheroa have also been associated within small embayments along the beach, where eddy currents may concentrate phytoplankton and toheroa larvae (Rapson 1952, Cassie 1955, Redfearn 1974, Akroyd et al. 2002, Smith 2003, Akroyd et al. 2008).

Toheroa spat are seldom found in adult beds, and occasionally separate juvenile beds are found (Cassie 1955), indicating that spat do not settle directly in the adult beds. Smith (2003) found that densities of juvenile toheroa (less than 32 mm) on the upper shore were significantly higher in areas directly above adult beds, compared to areas where no adult beds were present. This putative juvenile-adult association could be the result of: 1) larval attraction to adult toheroa (e.g., by chemical cues); 2) onshore water currents that regularly deposit planktonic larvae at the same locations along the beach; or 3) favourable environmental conditions that lead to higher survival rates in certain locations. In contrast, juveniles on Oreti Beach are spread along the entire length of the beach and do not appear to be clearly associated with any of the main beds (Beentjes & Gilbert 2006a).

## **4.3 Post-settlement feeding, growth, and movement**

### **4.3.1 Feeding**

The surf zone of exposed sandy beaches is a highly productive environment, capable of supporting a large infaunal biomass. The strong wave action on surf beaches pumps sea water through the sand, releasing trapped algae, organic detritus, and inorganic nutrients into the water column. These

regenerated nutrients are capable of supporting a high production of diatoms, which in turn support numerous filter-feeding organisms, including toheroa, which live in the surf zone (McLachlan & Brown 2006). Cassie (1955) observed that dense phytoplankton blooms were a common occurrence on all beaches where toheroa are present, and he hypothesised that toheroa relied on these blooms to obtain sufficient nutrients. The occurrence of phytoplankton blooms on toheroa beaches is dependent on the availability of nutrients (both from the interstitial water and beach run-off), the occurrence of onshore winds to drive the phytoplankton onto the beach, and favourable environmental conditions. Anecdotal reports suggest that toheroa condition markedly improves after the autumn rains commence, coincident with the dense phytoplankton blooms, visible as a 'greenish-brown scum on the beach and in the water' (Hefford 1931).

Toheroa are generalist filter feeders, consuming phytoplankton and organic debris up to 25 µm in size. Diatoms of the genus *Chaetoceros* are some of the most predominant phytoplankton in exposed inshore coastal waters (Rapson 1954, Street 1971), with *Chaetoceros armatum* accounting for up to 96% of the phytoplankton in the water at Dargaville Beach during May (Rapson 1954). The same study indicated that the plankton cycle on the west coast of the North Island was influenced by westerly winds blowing for most of the year which permit the inshore phytoplankton flora to build up; zooplankton did not generally thrive until easterly winds occurred, around October, allowing zooplankton to dominate inshore. On a fairly regular basis, tropical and subtropical genera were added to the plankton from the north. The average quantity of phytoplankton at each of four west coast beaches (Ninety Mile, North Kaipara, Muriwai and Wellington) was calculated as ranging from 1.4 (Ninety Mile Beach) to 59.9 g per cubic metre dry weight (North Kaipara).

Toheroa have a slightly different feeding mechanism from the closely related tuatua. Both shellfish are filter feeders, but toheroa ingest both organic and inorganic material, which is sorted in the alimentary canal, whereas tuatua have an efficient sorting mechanism that operates before ingestion. Cassie (1955) proposed that the difference in feeding mechanism between the two species gives tuatua a greater ability to survive in low food conditions. When phytoplankton concentrations are low, the diet of toheroa includes a greater proportion of inorganic material than that of the tuatua, the latter being able to sort and discard inorganic material before ingestion.

### 4.3.2 Growth

Growth rates of toheroa have been estimated by combining length-frequency cohort analysis with the measurement of macroscopic shell rings. Assuming these shell rings are laid down annually, North Island toheroa have been estimated to reach 43 mm after one year, 71 mm after two years, and 100 mm after 4–5 years (Redfearn 1974). Cassie (1955) reported that South Island toheroa from Oreti Beach had a much slower growth rate, with toheroa reaching 32 mm after one year, 44 mm after two years, and 100 mm after 9 years. It should be noted, however, that shell rings of toheroa may not be laid down on an annual basis and that shell reading of toheroa remains to be validated before growth and longevity could be confidently estimated (Naylor et al. 2010).

Beentjes & Gilbert (2006b, a) more accurately predicted the growth rates of South Island toheroa from mark and recapture data (41 out of 600 marked toheroa were recaptured at Te Waewae Bay after a release period of up to 26 months, and 98 out of 930 marked toheroa were recaptured at Oreti Beach after up to 4 years). Predicted growth rates were much faster than those of Cassie (1955) and Redfearn (1974), with toheroa at Te Waewae Bay predicted to reach 80 mm in one year and 100 mm in three years. The predicted growth rate for toheroa at Oreti Beach was slightly slower, with toheroa predicted to reach 70 mm in the first year and 100 mm in four to five years. Growth slows substantially in larger animals, with adults reaching a maximum size of about 150 mm and a maximum age of 20 years (Cassie 1955, Brunton 1978, McLachlan et al. 1996, Beentjes & Gilbert 2006b, a).

The maximum size of toheroa differs between populations, with toheroa from Te Waewae Bay attaining the greatest recorded maximum size of 153 mm. Based on an examination of historical

survey data, the maximum size of toheroa recorded from Wellington and Oreti Beaches is about 145 and 136 mm respectively (Beentjes & Gilbert 2006a), and Northland toheroa appear to grow to a maximum size of about 130 mm.

No growth estimates based on mark and recapture data are available for northern toheroa populations, and it is unknown whether: 1) the growth rate of northern populations varies from that of southern populations, 2) growth rates vary between years, and/or 3) the difference in growth rate estimates is caused by the different methodologies used. Beentjes & Gilbert (2006b) suggested that the lower maximum size and lack of large toheroa (over 100 mm) in current Northland populations may be because of a slower growth rate and/or higher mortality rate in Northland populations.

### **4.3.3 Movement**

Movement of toheroa may be active or passive. Tagging experiments have shown that while the majority of animals are sedentary, some tagged individuals actively move several miles from their release point (Greenway & Allen 1962). Vertical distribution of toheroa on the shore varies with size of the shellfish. Newly settled spat are most abundant just below the high tide mark, juvenile toheroa (under 40 mm) are most numerous on the upper shore, though they occupy a wide vertical range of the intertidal zone, and adult toheroa are generally concentrated in a narrow band around mid-tide level (Cassie 1955, Beentjes et al. 2003, Williams et al. 2013). This segregation by size suggests that active movement is occurring as toheroa grow in size.

Toheroa use the swash of waves to actively move up and down the beach, with movement mainly occurring at night. The shellfish emerge out of the sand with their siphons extended just before a wave break. As the swash wave passes over the shellfish they release their foot and are carried away in the direction of the flow. Once the wave recedes the toheroa rapidly burrow back into the sediment, completely burying themselves within one minute (Mestayer 1921, Cassie 1955, Smith 2003). Thousands of toheroa have been observed to emerge at one time and entire beds are reported to move both along the beach, and up and down the shore, with beds moving 30 m or more during a night (Redfearn 1974, Akroyd 2002). The factors that trigger a mass migration of toheroa are not known, but local kaitiaki report that on a number of occasions entire toheroa beds have shifted location after a storm (Akroyd 2002).

Passive movement of juvenile toheroa can be caused by strong winds and waves which have been observed to expose juvenile toheroa, which can be found drifting in the swash zone (Street 1971, Moller et al. 2009). Similarly, strong winds may cause the aggregation of toheroa spat. For example, after a prolonged period of southwesterly gales a very high concentration (over 1200 per 0.5 m<sup>2</sup> quadrat) of juvenile toheroa (under 26 mm) was found in a small isolated patch in the northeast corner of a small bay on Dargaville Beach (Akroyd et al. 2008).

## **4.4 Sources of post-settlement mortality**

Post-settlement mortality of toheroa is likely to be caused by numerous factors, both natural and anthropogenic. The elements that may affect post-settlement mortality can be divided into physical, biological and chemical factors. Mass mortalities of toheroa populations appear to be a relatively common occurrence and usually occur during summer in northern populations, but are more frequent during winter in southern populations. The most likely sources of post-settlement mortality in toheroa are discussed below.

### **4.4.1 Physical factors**

Physical factors are considered here to be those causing physical damage to toheroa or their habitat.

#### **4.4.1.1 Desiccation**

Several summer mass mortality events in northern toheroa populations were observed to have been preceded by calm weather conditions, easterly (offshore) winds, and neap tides, which resulted in the tides not covering toheroa beds for several days. Mass mortalities in northern populations have been reported in the summers of 1932, 1938, 1956–1959, 1970, 1973, and 2001 (Cassie 1951, Redfearn 1974, Akroyd et al. 2002). The causal mechanism for the mass mortality events is, however, unknown. It is possible that certain weather conditions cause toheroa stress, perhaps by changing the temperature or availability of water within their local habitat. It has been suggested that toheroa living in areas of fresh water seepage may have greater protection from desiccation, and they are anecdotally reported to be more common in these areas (Rapson 1952, 1954, Greenway 1972, Stace 1991, Redfearn 1997) and may be more susceptible to desiccation than the closely related tuatua, which occupy a position lower on the shore. Furthermore, adult toheroa cannot completely close their shells, instead, the gaps between the valves are covered by folds of the mantle (Redfearn 1974, 1997).

#### **4.4.1.2 Storms**

Southland toheroa populations appear to be susceptible to cold, stormy weather. Toheroa burrowing speed is reduced at cold temperatures (G. Bremner & A. Frazer, MFish, pers. comm. in Carbines 1997a), making toheroa more vulnerable to exposure by storm conditions. Millions of dead and moribund toheroa have been stranded on Southland beaches after heavy southerly seas in the winters of 1967, 1968, 1970, and 1988 (Street 1971, Eggleston & Hickman 1972, Street 1972, Langston 1990). Toheroa are not the only shellfish affected by winter storms; in September 1970 more than 20 million shellfish, including approximately 5000 toheroa, were stranded at Te Waewae Bay after a period of very cold, gale-force inshore winds (Eggleston & Hickman 1972).

#### **4.4.1.3 Sand smothering and sediment instability**

The sand on surf beaches is highly mobile and strong wind and wave conditions are capable of shifting large quantities of sand in a short period of time. During storms, benthic macrofauna living in the intertidal zone are at risk of either being smothered, or exposed and washed ashore, where they are more vulnerable to desiccation or predation.

Westerly wind and wave conditions prevail on the west coast of New Zealand, which generally facilitate the accrual of sand on the beach. However, easterly winds frequently occur during spring, which blow considerable quantities of sand down from the dunes onto the beach. Juvenile toheroa living near the high water mark are deeply buried during easterly gales and are likely to be smothered to death (Rapson 1952). For example, in April–May 1930 strong easterly gales deposited large quantities of sand (less than 60 cm deep) on the toheroa beds on Ninety Mile Beach. Approximately 15 million shellfish were killed in a section of the beach 40–56 km north of Ahipara (Hefford 1931, Rapson 1954).

Sediment instability is thought to have contributed to the decline of the toheroa population at Bluecliffs Beach, Te Waewae Bay. Aerial photographs taken of the beach in 1947 show that it had a continuous sand coverage, and during the 1960s there was a considerable depth of sand covering the gravel/cobble basement sediment. However, the sand layer has been gradually eroding away and by 2005 exposed cobble and gravel covered much of the beach, with only 54% of the beach surface being sand. Furthermore, up to 50% of the sand patches had an underlying gravel layer within 30 cm of the surface, which is likely to impede toheroa burrowing. This reduction in suitable habitat for toheroa is thought to have contributed to the population decline at Bluecliffs Beach, which has been steadily declining since population surveys began in 1966 (Beentjes et al. 2006).

Sand levels at Bluecliffs Beach are recorded to fluctuate between winter and summer surveys, by up to 40 cm over a three month period. During winter, storms scour the beach and very little sand substrate is available, while during summer sand accrues on the beach. The location of sand patches



on the beach is also documented to shift, forcing any toheroa within to relocate (Beentjes & Gilbert 2006b). Frequent movement of toheroa will increase their mortality risk, as toheroa moving in the surf zone are more susceptible to being preyed upon or stranded high on the shore.

#### 4.4.1.4 Vehicle impacts

Several research studies have shown that vehicle beach traffic has adverse effects on beach flora and fauna including direct crushing of animals and vegetation (Buick & Paton 1989, Van der Merwe & Van der Merwe 1991, Schlacher et al. 2008), disturbance of seabird breeding and feeding behaviour (Buick & Paton 1989), increased erosion of the sand dunes, and changes to the physical characteristics of the beach and dunes (Anders & Leatherman 1987).

Most of New Zealand's toheroa beaches are used by vehicles for recreational purposes, however limited quantitative data are only available for Ninety Mile Beach, Muriwai Beach, and Oreti Beach. Ninety Mile Beach is a designated state highway and is subjected to high vehicle traffic. Currently, around eight commercial tour operators drive along Ninety Mile Beach (S. Harding, DOC, pers. comm.) using vehicles that weigh up to 13 tonnes, and about 2400 commercial bus trips are made along Ninety Mile Beach annually (enquires were made with all commercial Ninety Mile Beach tour operators registered with the Department of Conservation on their trip statistics; seven out of ten operators provided confidential information on their annual trip total). In 1991, Stace (1991) reported that up to 35 tourist buses per day were driving along the beach in summer. No information is available on the number of private vehicle trips made along Ninety Mile each year, but nearly 400 vehicles were counted travelling along the beach during one day of a recreational fishing contest (the 'Snapper Classic' surfcasting fishing competition, an annual five day event held at Ninety Mile Beach that attracts up to 1000 entrants; see <http://www.snapperclassic.co.nz/index.html>) (Hooker & Redfearn 1998). The beach is also used by commercial mussel spat harvesters, who drive tractors and trailers along the lower half of the beach. Similarly, Oreti Beach is a designated road and approximately 374 vehicles drive along the beach per day in summer, though the majority of vehicles stay within 1 km of the main beach entrance at Dunns Rd (Wilson 1999). Oreti Beach is the location of the annual Burt Munro motorbike challenge, which draws approximately 1700 vehicles to the beach for the event. The actual race track covers about a one kilometre stretch of the beach (Moller et al. 2009). Muriwai Beach is a popular recreational beach and approximately 150 vehicles per day visited the beach between December 2008 and April 2009 (Auckland Regional Council, unpublished data).

There is good evidence that toheroa mortality can be caused by beach vehicle traffic (Redfearn 1974, Brunton 1978, Hooker & Redfearn 1998, Moller et al. 2009). Toheroa may be affected by vehicle pressure in a number of ways including direct crushing, increased desiccation risk, or increased predation risk from birds. Disturbance of buried toheroa by vehicles will cause the toheroa to retract its foot and siphons, leaving it temporarily unanchored below the surface. The compression of the sand by the weight of vehicles also causes the water trapped between the sand to puddle, and the unanchored toheroa will tend to be pulled upwards towards the surface. Repeated compressions by vehicles will cause the animal to emerge out of the sand, forming a distinctive hummock as it emerges, where it may be crushed by other vehicles or preyed upon by birds (Brunton 1978, Hooker & Redfearn 1998).

Moller et al. (2009) conducted an experimental study to investigate the impact of vehicle traffic on toheroa. Preliminary tests on ten buried adult toheroa found that none were damaged by vehicle passes, and therefore, the study focused on juvenile toheroa (5–30 mm). Three hundred and three juvenile toheroa found drifting in the surf zone were allowed to bury themselves either just below the high tide mark or in the mid/lower beach. The toheroa were then driven over one or five times with a motorbike (Honda CRD 250R), car (Toyota Fielder), or utility vehicle (Mazda BT50 Freestyle cab and Isuzu Bighorn). Toheroa mortality was found to vary with location on the beach and type of vehicle. For all vehicles excluding motorbikes, the average mortality incurred was higher on the upper beach (14%) compared to the mid/lower beach (3%); for motorbikes, the average mortality incurred



was high (18%) compared with that from the other vehicles (3%, average mortality across all other vehicles). Driving the test vehicle five times over the toheroa appeared to cause higher mortality than a single pass, but the difference was not statistically significant.

The occurrence of beach events such as fishing contests and off-road vehicle races has the potential to cause significant toheroa mortality. Hooker & Redfearn (1998) found that 14% of (26 out of 160) juvenile toheroa (6–23 mm) in three 1 m<sup>2</sup> quadrats were crushed after particularly heavy vehicle use of Ninety Mile Beach during a large recreational fishing contest. Similarly, Moller et al. (2009) found that an estimated 53 000 (range 31 000–70 000 individuals or 41–90%) juvenile toheroa (72%) were killed on about a one kilometre stretch of Oreti Beach used for the Burt Munro motorbike race. Toheroa mortality along the rest of the beach caused by spectator traffic was not measured.

Thus, it appears that low levels of vehicle traffic on the beach do not cause significant mortality of adult toheroa, but even a single pass can cause significant mortalities in juvenile toheroa, particularly those which live high on the beach in soft sand. High levels of toheroa mortality can be caused by beach events, but mortality is often likely to be localised, and it is unknown what proportion of the overall mortality rate of toheroa is caused by these events.

#### **4.4.1.5 Land revegetation and afforestation**

In Northland, the surrounding land of Ninety Mile beach on the Aupouri Peninsula and Dargaville and Muriwai beaches on the Kaipara coast was originally covered in native broadleaf forest (Smale et al. 1996). Initial Polynesian settlers cleared much of the forest with fire approximately 500–700 years ago (Coster 1989), and early European settlers and their livestock destroyed much of the remaining vegetated areas (Bacon 1976, McKelvey 1999). As a consequence of the removal of coastal vegetation, sand drifting became a large problem on the Aupouri Peninsula and Kaipara coastline in the 1920s, and large areas of coastal farmland and lakes were covered by sand. To stabilise the sand dunes, a large-scale planting programme of marram grass and tree lupin was instigated in the early 1930s by the Ministry of Works. In the early 1950s the government announced that a number of coastal areas around the country were to be converted to state forestry (exotic pine forest, *Pinus radiata*), including most of the area behind Ninety Mile Beach (Aupouri State Forest), Muriwai Beach (Woodhill Forest), and North Kaipara Head (Pouto Forest) in Northland, and Waitarere Beach (Waitarere Forest), and Tangimoana Beach (Tangimoana Forest) on the Kapiti Coast. Planting of Woodhill Forest and Kapiti Coast forests commenced in the early 1950s, planting of Aupouri State Forest commenced in the early 1960s, and planting of Pouto Forest commenced in the early 1970s (McKelvey 1999).

Conversion of the sand dunes to pine forest began with the planting of marram grass to stabilise the dunes. The marram grass was aerially top-dressed with nitrogen fertiliser (at a rate of 20 kg fertiliser/ha) twice a year in spring and autumn. Tree lupins were sown amongst the marram grass a couple of years after the marram grass had been planted, to add nitrogen to the soil and to provide additional shelter. Eventually pine trees were planted four to six years after marram grass was planted. Once the pine trees had become established it was necessary to kill the lupins to prevent them from smothering the pine trees. Initially, the lupins were cut down by hand or mechanically, but during the 1970s they were aerially sprayed with hormones (Tordon or 2,4,5-T Ester) to kill them (Bacon 1976, Sale 1985, McKelvey 1999).

In the late 1980s, fertilisation of the pine forests with urea at a rate of approximately 450 kg/ha was required to compensate for the loss of nitrogen that the lupins provided. As an alternative to urea fertilisation, Waitarere Forest was fertilised with sewage effluent from the local township. Fertilisation of the coastal dune vegetation with urea also occurred at a rate of 100 kg/ha every two years in spring to promote growth of coastal vegetation, which protected the forests (Ogle 1997, McKelvey 1999).

As a consequence of the extensive pine afforestation, soil moisture levels were greatly reduced and the water table has been lowered on the Aupouri and South Kaipara peninsulas (Cromarty & Scott 1996, McKelvey 1999), potentially reducing the amount of freshwater seepage that runs down the beach. Historical groundwater data appear lacking, so that no accurate assessment of this land-use change is available. However, investigations of the Aupouri aquifer implied that the dramatic change to afforestation of the peninsula's western side since the 1970s has reduced groundwater recharge (perhaps by over 50%), groundwater levels and, thus, through-flow and stream flow to the coast and beach (HydroGeo Solutions 2000, Cameron et al. 2001). Reduced freshwater seepage is one possible reason for reduced toheroa numbers in the area, which are anecdotally reported to be more common in areas of freshwater seepage (Rapson 1952, Cassie 1955, Smith 2003). In a recent survey of Dargaville Beach, toheroa abundance was found to be higher in or near to freshwater seeps and streams compared to drier beach areas which contained fewer toheroa (Williams et al. 2013).

Generally total water yield tends to decrease as a catchment is planted with trees because of the higher wet and dry canopy evaporation rates for forest (Fahey & Rowe 1992). Afforesting close to 100% of small to medium size catchments that were previously in pasture or tussock grassland may reduce water yields by up to 55% and low flows by at least 20%. The full effects will not be seen until the canopy closes. With pine forests, canopy closure occurs 5–10 years after planting (Fahey et al. 2004). In large catchments, the effects of afforestation on water yields are likely to be less pronounced, as the plantings will be in different stages of development throughout the catchment. After forest harvesting, water yields may increase by as much as 70% but if replanting of pine is undertaken straight away, yields should return to pre-harvest levels within 6–8 years. A brief but substantial increase in water yield can be expected after thinning.

#### **4.4.2 Biological factors**

Biological factors in this report are those considered to directly alter the biological processes of toheroa or cause mortality.

##### **4.4.2.1 Toxic algal blooms**

Toxic algal blooms are capable of causing mortality in bivalves via smothering and anoxia as a result of the biological oxygen demand of senescent cells (Whyte 1999, Rhodes et al. 2001, Wear & Gardner 2001). Mass mortality of toheroa on Dargaville Beach in January 2001 coincided with very high concentrations (276 000 cells/L) of the toxic alga, *Gymnodinium catenatum*, in the water samples collected from Glinks Gully. Thousands of stressed toheroa had surfaced from the sand and could not close their valves, making them extremely vulnerable to predation and desiccation (Akroyd 2002). Similarly, an estimated 40 000 toheroa and 1.5 million other clams were reportedly killed at Oreti Beach in January 1996 as a result of a *Gymnodinium mikimotoi* bloom (G. Bremner & A Frazer, MFish, pers. comm. in Carbines 1997a).

##### **4.4.2.2 Disease**

No specific diseases or parasites are known to affect toheroa, but this could be because of a lack of knowledge, rather than a lack of diseases. Small DNA-negative virus-like particles were found to be associated with moribund toheroa but it is not known whether they were the cause of mortality; the location where the moribund toheroa were collected from was not reported (Hine & Wesney 1997).

##### **4.4.2.3 Predation**

Toheroa are preyed upon by a number of common animals. Black-backed gulls (*Larus dominicanus*) and red-billed gulls (*L. novaehollandiae*) consume juvenile toheroa whole, and are capable of excavating and consuming adult toheroa up to 130 mm long (Redfearn 1974, Brunton 1978). The gulls repeatedly drop the shellfish from heights of around 80 m until the shell cracks. Brunton (1978) estimated that black-backed gulls could consume up to 20 toheroa per day. Akroyd (2002) observed

black-backed gulls consuming 6–10 adult toheroa per day at Dargaville Beach. Gulls also readily eat tuatua, which are sometimes extremely abundant on Ninety Mile Beach. Oystercatchers (*Haematopus* spp.) have been observed preying on juvenile toheroa less than 30 mm by inserting their bill into the sand and twisting open the toheroa's shell (Street 1971).

Fish, particularly snapper (*Pagrus auratus*) and flounder (*Rhombosolea* spp.), consume juvenile toheroa whole, but can also bite the siphons off adult toheroa (Stace 1991, Futter & Moller 2009). Siphon nipping may not necessarily kill toheroa but it is likely to increase the risk of subsequent predation as the toheroa are forced to live closer to the surface, owing to their shorter siphon length (Grant 1994, Goeij et al. 2001).

Paddle crabs (*Ovalipes catharus*) also prey on toheroa; crabs primarily eat bivalve spat less than 4 mm in length (Wear 1987), but are capable of eating juvenile toheroa up to at least 40 mm long (Haddon et al. 1987). Foregut analysis of paddle crabs caught from Dargaville Beach during summer found that toheroa comprised 16% and 2% of the foregut contents of crabs from Bayleys Beach and Glinks Gully, respectively (Wear & Haddon 1987). Adult crabs were found to be able to consume a maximum of 100 bivalve spat every 6 hours during summer, and every 18 hours during winter (Haddon 1988). Adult toheroa are likely to be less vulnerable to predation by crabs as they have thicker shells and are capable of burying deeper. Levels of toheroa predation by *O. catharus* was found to decrease with increasing burial depth from 0–25 cm (toheroa used in the experiment were 30–40 mm long and the crabs had carapace widths of 95–107 mm) (Haddon et al. 1987, Haddon 1988).

#### 4.4.2.4 Commercial harvesting

Commercial harvesting of toheroa began in the late 1800s but harvest levels remained low until canning of toheroa commenced in the early 1900s. Very little fresh toheroa was sold, as the shellfish cannot survive for long out of water owing to its inability to completely close its valves (Mestayer 1921). The first toheroa cannery opened on North Kaipara Beach, Dargaville in 1904, and a second cannery opened on the beach in 1911. In 1923 the northern Dargaville cannery closed down because access to the toheroa beds on the northern section of the beach was difficult and had become uneconomic. In the same year a new cannery opened on Ninety Mile Beach that operated for three months of the year and processed around 576 000 toheroa per annum (9 600 toheroa per day). The cannery closed in 1945 because poor harvest levels made production uneconomic, but it reopened briefly between 1962 and 1964. The combined commercial production of toheroa by the Ninety Mile and Dargaville canneries increased in the 1930s to reach peak levels in the early 1940s, followed by a consistent decline to 1957; production briefly resumed in 1960 to a smaller peak in 1963, but had decreased to low levels by the late 1960s (Figure 8). Toheroa was also canned at Muriwai Beach, the Wellington beaches, and at Te Waewae Bay at various times, for short durations (Rapson 1952, Redfearn 1974, 1997). Total commercial production was typically around 20 tonne per annum of canned product (about 20 toheroa equated to one kilogram of canned product) (McLachlan et al. 1996), with a record production of 77 tonnes in 1940.

Commercial harvest of toheroa was initially managed by licences issued by the Minister of the Marine Department. Commercial harvesting was only permitted in licensed areas, and the maximum allowable commercial catch was determined by the size and condition of the toheroa population in the licensed area. In 1962 the licence system was replaced by commercial quotas and restricted harvesting seasons, based on annual population surveys. The majority of toheroa commercially harvested were greater than 80 mm in length (McKinnon & Olsen 1994).

On Dargaville Beach and Muriwai Beach, toheroa were harvested with potato forks by digging 1–2 m wide trenches across the bed, perpendicular to the shore. Trenches were spaced at approximately 1 m intervals to ensure that there was a sufficient breeding population left for subsequent years. However, the public were not banned from licensed areas, and would frequently dig over the intervening strips of beach to gather the remaining toheroa. Toheroa were collected in kerosene tins and transported to

the cannery where they were shucked and canned. In contrast, toheroa beds on Ninety Mile Beach were completely dug up from end to end. There was often a large distance between the commercial beds and the cannery, and thus, toheroa were initially shucked on the beach and the shells left to rot *in situ*. It is speculated that rotting shellfish may have spread disease and contributed to the population decline on Ninety Mile Beach. Later, whole toheroa were transported to the cannery to be shucked (Rapson 1952, 1954, Redfearn 1974, Leigh 1991, Stace 1991, McKinnon & Olsen 1994, Redfearn 1997).

By 1966 the total commercial harvest of toheroa had dwindled to less than 10 tonnes of canned product per annum, and all commercial harvesting ceased in 1969 (Rapson 1952, Redfearn 1974, 1997).

#### **4.4.2.5 Recreational harvesting**

Recreational harvest restrictions for toheroa were implemented in 1932 as a result of the mass mortalities in northern toheroa populations that occurred in 1930 and 1931. Toheroa harvests were limited by 1) a daily limit of 50 toheroa for Europeans (Maori did not have a daily limit until 1941, when the daily limit was 80 toheroa, but were subject to the other regulations), 2) a minimum size limit of 3 inches (76 mm), 3) a 2-month closed season from October to November, and 4) the banning of the use of metal implements to dig for toheroa. Despite the harvest restrictions the rate of exploitation continued to increase, and in 1940 the northern beaches were closed for a year. In 1955 the recreational restrictions were amended to 1) a daily limit of 20 toheroa per person, and 2) a 10 month closed season from September to June (Redfearn 1974). The use of digging implements to harvest toheroa was also prohibited in 1962.

Annual surveys conducted by the Marine Department showed a large decrease in Northland toheroa populations in 1967. As a result, all Northland beaches were closed to harvesting for the year, and in 1972 the harvest restrictions were further amended to 10 toheroa per person per day or 30 toheroa per vehicle, with harvesting only permitted during two weeks in September (Greenway 1972). However, toheroa population numbers continued to decline and recreational toheroa harvesting has been prohibited from Ninety Mile Beach since 1971, from Muriwai Beach since 1976, from the Wellington beaches since 1978, and from Dargaville Beach since 1980. The two Southland beaches have been opened sporadically for one day per year since 1972. Since 1979 the minimum legal size has been 100 mm and the daily limit reduced to five toheroa per person. The last toheroa open seasons were held at Te Waewae Bay and Oreti Beach in 1980 and 1993, respectively.

#### **4.4.2.6 Customary harvesting**

Toheroa are a taonga (treasured species) for Maori and they are permitted to harvest toheroa for special occasions (e.g., hui and tangi). Kaitiaki manage the customary harvest of toheroa through the application of Ministry for Primary Industries permits. Kaitiaki also monitor the toheroa beds and may declare a rahui (temporary closure) on the beach if toheroa populations are thought to be particularly threatened.

#### **4.4.2.7 Illegal harvesting**

Illegal harvesting of toheroa may have a significant impact on population levels and large scale poaching has been observed in the past (Murton 2006, Akroyd et al. 2008). However, little information is available on the size of illegal harvests.

### **4.4.3 Chemical factors**

Chemical factors in this context are those factors which may affect the chemistry of the toheroa or their local environment.

#### 4.4.3.1 Phytochemicals

Given that land use adjacent to beaches has the potential to change the quantity and quality of groundwater, the influence of forestry plantations on the soil and water characteristics is of interest in investigating possible factors linked to mortality of toheroa. Phytochemicals, chemical compounds that occur naturally in plants, can be released into the soil and thus have the potential to influence soil and water chemistry and biology. Examples of phytochemicals include terpenes and phenolic compounds, which affect soil carbon and nitrogen transformations (Kanerva et al. 2008) and also inhibit the activity of soil enzymes (Kanerva et al. 2006). Terpenes (responsible for the pleasant odours given off by pine trees) were found to be more concentrated beneath stands of pine in comparison to birch in a study that investigated plant secondary metabolites beneath silver birch, Norway spruce and Scots pine (Kanerva et al. 2008). Concentrations of terpenes decreased relatively more with soil depth than did concentrations of total phenolics or condensed tannins (Kanerva et al. 2008). The potential toxicity of terpenes or other phytochemicals on toheroa, however, is unknown.

#### 4.4.3.2 Fertiliser, hormones and pesticides

The application of fertiliser or spraying of hormones and pesticides in the forests may also change the chemical composition of the water and sediments. Applying fertiliser is likely to enrich the wetland areas and streams (eutrophication), while hormones and pesticides may be toxic to certain flora and fauna, but the effects of any of these chemicals has not been studied. In the mid 1970s the coastal land behind Dargaville Beach was sprayed with the pesticide Dieldrin to control black beetle. It is anecdotally reported that toheroa have not grown near the sprayed area since that time (Akroyd 2002), although there is no data available on toheroa abundance in this area before spraying. Felling of mature pine trees may also increase the amount of sediment in coastal waters.

### 4.5 Local perspectives

As an important part of this review, a case study of local perspectives on factors thought to influence the abundance of toheroa was conducted in the Northland region (Smith 2009, see copy in Appendix 8). Historical qualitative and anecdotal information on toheroa and the beaches they inhabit was acquired from people closely associated with Northland beaches. The information was gathered using a 'key informant technique'. Informants expressed a range of views on factors that they felt influenced toheroa abundance and variability in recruitment. It is unlikely that their views are representative of other members of the community.

A thematic analysis, carried out to group the range of factors expressed, identified six themes:

1. Deleterious effects of vehicles
2. Negative features of the customary permit system
3. Attitudes on the loss of a stewardship ethic among Maori
4. Adverse effects from land use and land use practices
5. Attitudes about the effects of cyclical weather patterns
6. Negative effects from the preferential harvest of large toheroa.

It was suggested that natural processes were likely to account for the highest level of mortality and variability in recruitment, however, the cumulative effects of anthropogenic influences were thought likely to severely limit the ability of toheroa populations to recover from large scale natural mortality events or periods of poor recruitment. Measures that might help to restore toheroa populations were proposed, including increased enhancement, better informed permit issuers and the creation of harvest free and vehicle free reserves.

## 5. ASSESSMENT OF POTENTIAL MECHANISMS OF POPULATION DECLINE

From our literature review and the local knowledge gained through interviews with the Northland community, there were some possible mechanisms of population decline for which data were available which could be investigated further by desk study. These mechanisms included climate and weather, toxic algal blooms, vehicle impacts, and changes in land use adjacent to the beach.

### 5.1 Climate and weather

#### *Methods*

From the available literature, the months during which toheroa mass mortality events were observed were identified and the values of various climate indices were obtained for the month in which the mortality event was observed, one month before the event and three months prior to the event. Climate indices used were the Trenberth indices (Trenberth 1976) of meridional (M) and zonal (Z) flow, the Coupled ENSO Index (CEI, (Gergis & Fowler 2005)), and the Southern Annular Mode (SAM, (Marshall 2003)). Chi-squared tests were used to indicate whether the occurrence of mortality events coinciding with particular phases of the climate indices could have occurred simply by chance. For example, for a given climate index, we compared the number of observed mortalities occurring with positive and negative phases of the index with the number we would expect to observe by chance. For each, our null hypothesis was that there is no difference in the occurrence of toheroa mortality events observed between positive and negative phases of the climate index.

Within the Trenberth Index (Trenberth 1976), the meridional index (M value) permits the circulation over New Zealand in a North-South orientation to be interpreted, whilst the zonal index (Z value) permits the westerly circulation to be interpreted. The Z value used in the analysis was that appropriate for each location (i.e. Z1 for North Island, Z2 for South Island). Data were available for the Trenberth Index from 1881 until the present day. The CEI (Gergis & Fowler 2005) is a coupled ocean atmosphere index that simultaneously identifies anomalies in the ocean (Nino 3.4 region sea surface temperatures) and atmosphere (Southern Oscillation Index); the CEI gives an indication of whether the climate conditions are tending towards El Niño or La Niña and whether the SST or SOI are the most influential part of the combined classification, with negative values usually suggesting El Niño and positive values indicating La Niña. Data for the CEI were available from June 1871. For New Zealand latitudes, the SAM in its positive phase is associated with light winds and more settled weather, whilst in its negative phase westerlies increase over New Zealand (Renwick & Thompson 2006). Data for the SAM were available from 1957 onwards (Marshall 2003).

The Kidson weather types (Kidson 2000) that occurred during the month of interest were also obtained. There are twelve Kidson weather types recognised and daily weather patterns permit classification of that day into conforming to a particular Kidson type. Each month, the Kidson weather types that have occurred during the preceding month are reported as a percentage of the total days available. For the purposes of the present study, the dominant two Kidson weather types were obtained but on some occasions, where more than two Kidson types were equidominant during the month, up to four Kidson weather types were reported. Kidson weather type data was only available from 1958 onwards.

#### *Results*

Twelve toheroa mass mortality events were identified from the literature. The values of the various climate indices and Kidson weather types in relation to these mortality events is shown for the month in which the mortality was observed (Table 1), for one month before the mortality event was observed (Table 2) and for three months before the mortality event was observed (Table 3).

For the month in which the mortality was observed, eleven of the twelve mortality events occurred when the Trenberth index for zonal flow (Z) was negative, indicative of easterly zonal flow. Using a chi-squared test, this is significantly more than would be expected by chance ( $\chi^2 = 8.33$ , d.f.=1,  $p \leq 0.01$ ); we can reject our null hypothesis and infer that the observed mortality events were associated with negative Z. Eight of the twelve mortality events occurred when the Trenberth index of meridional flow (M) was negative, potentially suggesting an association with winds from the north, but this was not statistically significant ( $\chi^2 = 1.33$ , d.f.=1,  $p \geq 0.05$ ). Additionally, although more of the observed mortality events occurred when CEI and SAM were positive, the associations were not strong enough to be statistically significant. There was no obvious relationship with any of the Kidson weather types, although the HSE weather type (high to the south east of New Zealand) was the most dominant of the weather types during the month of a mass mortality. However, Kidson weather types were available only for part of the mass mortality series (Tables 1–3).

There did not appear to be any consistent patterns in the climate indices investigated one month or three months before a mass mortality event occurred.

Given the small sample size of observed toheroa mortality events, these results should be interpreted cautiously.

## 5.2 Toxic algal blooms

### *Methods*

To investigate whether there were possible links between mass mortalities and the occurrence of toxic algal blooms, data were obtained from the New Zealand Shellfish Marine Biotoxin Monitoring Programme. The programme was implemented in 1993, aiming to ensure food safety for shellfish consumers and enable export market access for NZ seafood consignments. The survey monitors for potentially toxic phytoplankton, although it should be recognised that the toxicity being monitored is in relation to the risk to human health rather than shellfish health. Phytoplankton from commercial and non-commercial shellfish harvest areas are sampled weekly, with certain levels of potentially toxic phytoplankton triggering shellfish monitoring and harvest closures (Hay et al. 2000). The data from the programme provide the opportunity to determine whether a toxic phytoplankton bloom had been recorded at the same time as a mass toheroa mortality event.

### *Results*

There were a total of four toheroa mass mortality events that have been recorded in the literature since 1993. However, the most recent report of the New Zealand Shellfish Marine Biotoxin Monitoring Programme only covered the period until March 2009, meaning that the small die-back reported at Oreti Beach in April 2009 by Futter & Moller (2009) was not able to be compared.

The results of the comparison are provided in Table 4. In two instances of toheroa mass mortality events being reported, there were also notable events within the biotoxin monitoring programme in either the same month or following month. At Oreti Beach, a sample of dredge oysters was found to have traces of paralytic shellfish poison (PSP) at levels below the regulatory level one month after a mass mortality event in January 1996. At Dargaville Beach, a mass mortality event was reported in January 2001 and a sample of toheroa taken at the same time from Glinks Gully on Dargaville Beach had PSP at levels that exceeded the regulatory level.

## 5.3 Vehicle activity

### *Methods*

Two approaches were used to investigate the level of historical and current vehicle activity on toheroa beaches. First, historical vehicle activity was quantified by searching the available literature for

references. Second, current vehicle activity was quantified by contacting district and regional councils in the areas where toheroa beaches are situated and requesting this information.

### *Results*

The results of the historical literature searches are provided in Table 5. It is clear that significant numbers of vehicles have used the two beaches for which data were available. Both off road vehicles and buses are represented within the data. In 2009, it was estimated that an average of 46 bus trips occurred each week at Ninety Mile Beach. There seemed to be a seasonal element to the bus trips, with more trips during the summer months.

Responses were received from two of the district and regional councils contacted. Of these responses, only Auckland Council (formerly Auckland Regional Council) monitors vehicle numbers regularly using an automated counter and were able to supply any figures. Data were provided for three roads leading to Muriwai Beach. To demonstrate the seasonal pattern in vehicle use on the beaches, the average number of vehicles using the beach on a weekend day and a weekday were calculated for each season (Summer: December to February; Autumn: March to May; Winter: June to August; Spring: September to November) and are shown in Figure 9.

## **5.4 Changes in land use**

### *Methods*

To investigate changes in land use in recent history for which estimates of toheroa abundance are available, a comparison of historical (1940s–1960s) and modern (1990s–2000s) land use within the catchments draining to Ninety Mile and Dargaville Beaches was undertaken using a geographical information system (GIS). For the purposes of this part of the study, Ninety Mile Beach was defined as encompassing the area from Scott Point in the north to the mouth of the Wairoa Stream in the south. Dargaville Beach was defined as running from Maunganui Bluff in the north to Mahuta Gap in the south. The definition of both of these areas was influenced by the area encompassed by historical topographic maps that were available for historical comparison. Historical survey data indicated that most of the toheroa beds on Dargaville Beach were south of Mahuta Gap, an area that unfortunately was unavailable on historic maps.

Historical maps for the areas surrounding Ninety Mile and Dargaville beaches were scanned electronically and georeferenced to a present day layer of the New Zealand coastline. For Ninety Mile Beach, maps drawn between 1958 and 1960 from the NZMS 2 series at a scale of 1:25000 were used; for Dargaville Beach, maps drawn between 1943 and 1944 from the NZMS 1 Provisional 1 Mile Series (Sheets N18, N22 and N23) at a scale of 1:63360 were used (Appendix 7).

Modern day land use was provided by the Land Classification Database 2 (LCDB2), a digital map of the land surface of New Zealand that incorporates satellite snapshots of land cover data from 1996–97 and 2001–02. As the database's most recent data is from 2002, both Northland and Auckland Regional Councils were contacted to determine whether any significant change in land use had occurred between 2002 and 2010.

Catchment polygons for catchments flowing to the beach in the areas described above were overlaid on the historical georeferenced maps and the LCDB2. The land use within each catchment polygon for each time period of interest was then coded. This enabled land use changes in a catchment over time to be identified and provided detail on the overall land use change for each beach.

To provide a broad overview of the possible changes that land use may have had in relation to surface water flowing to beaches, the number of watercourses counted in the same area on the historical topographic maps and modern maps (LINZ 1:50000 series) were compared.



Additionally to the GIS work, a brief review of historical and recent maps indicated that exotic forestry planting was a major factor in the changing landscape between historical to modern day. Where possible, the owners of major exotic forestry plantations were contacted to provide a historical overview of when planting, felling and other significant events occurred.

### *Results*

The land use change between historical and recent times in catchments draining to Ninety Mile and Dargaville Beaches is provided in Table 6 and Table 7 and is shown in Figure 10 and Figure 11.

Although land use has changed over time in catchments that drain to both beaches, the changes were of greatest magnitude at Ninety Mile Beach (Table 6). In particular, where historically 74% of the catchments draining to Ninety Mile were covered with dune, only 8% of these catchments have retained dune as land cover in modern times. A marked change in the amount of exotic forest in the catchments was also apparent, with less than 1% being forested historically but 72% being forested in modern times. The amount of pasture had also increased from about 1 to 13% between historical and modern times, whilst the amount of scrub had decreased from 22% to 5%. Other land use categories (infrastructure, wetland, freshwater, and native forest) occupied small proportions of the overall Ninety Mile catchments area examined in both historic and modern times, and the magnitude of changes between these times was relatively small.

At Dargaville Beach (excluding the southern extent for which historic maps were unavailable) there were less dramatic changes between historical and modern times in the land use categories of dune (decrease of 2 to 1%) and exotic forest (increase of zero to 9%) (Table 7). However, there was a large reduction (from 88% to 6%) in the area of scrub in catchments draining to the beach, and a substantial increase (from less than 1% to 75%) in pasture/short rotation cropland, between historic and modern times. Similar to the situation at Ninety Mile, other land use categories (infrastructure, wetland, freshwater, and native forest) occupied small proportions of the Dargaville catchments area examined in both historic and modern times, and changes in those categories between these times were relatively small.

To determine what the possible effect of land use change is on the hydrology of the area, it is important to know not only the overall change in land use within the catchments draining to the beaches but also the way in which modern land use has changed relative to its previous land use. A land use matrix can show which areas have remained in the same type of land use over time and, where there have been changes, which land uses have replaced the original land use.

The land use matrices for the beaches are shown Table 8 and Table 9. The matrices indicate that the major land use conversion at Ninety Mile Beach has been from dune to exotic forest, whereas at Dargaville Beach the same conversion has not occurred, with conversion of scrub to pasture/short rotation cropland being the most dominant change in land use.

The number of watercourses counted on historical and topographic maps on each beach is presented in Table 10. It is clear that the number of watercourses has decreased for Ninety Mile Beach and Dargaville Beach from historical to present day.

A summary of the forestry operations that have been carried out on part of the Aupouri Peninsula is given in Table 11.

## **6. CONCLUSIONS**

### **6.1 Time series of abundance**

From the available time series data for the six main toheroa populations, it is evident that there has been a general decline in the abundance of toheroa recorded over time, with the exception of Oreti Beach where numbers have increased since the 1990s. There is a great deal of variation in the abundance estimates, and not all populations have followed the same fluctuations over time. This indicates that there may be different local influences acting on the populations rather than a major overriding influence at a national level. The overall downturn observed has not been as marked in some populations as others, with Dargaville Beach (and Oreti Beach) appearing to have greater densities of juveniles than the other beaches suggesting that recruitment is better in some areas than others.

### **6.2 Harvesting**

It is clear that the historic harvesting of toheroa was intensive and focused on larger individuals in dense beds. Commercial harvesting has been prohibited since 1969 after landings dwindled to less than 10 tonnes per annum; recreational harvesting ceased in the 1970s on North Island beaches and ceased in the 1980s–90s on Southland beaches. None of the populations harvested have recovered to historic levels, despite the cessation of these harvests. In recent times, provision has been made for the taking of toheroa for special occasions under the Customary Regulations. The customary permit system came under criticism during the key informant interviews in the Northland case study on local perspectives, with questions being raised regarding the inappropriate issuing of permits and compliance with permit conditions.

Stock depletion and collapse can result from recruitment overfishing; this occurs when the adult population was fished so heavily that the number and size of the adult population (spawning stock) was reduced to the point that it did not have the reproductive capacity to replenish itself. However, while it is not possible to determine whether the continued low abundance of toheroa at some beaches is the result of recruitment overfishing, it is unlikely that this is the main factor. High recruitment has been observed on several occasions (e.g., at Ninety Mile Beach) at times when the local abundance of spawning stock was very low.

### **6.3 Local perspectives**

Interviews carried out with local iwi and others closely associated with toheroa in Northland identified six themes that grouped the factors that were thought to influence toheroa abundance. These themes were the deleterious effects of vehicles on beaches, negative features of the customary permit system, the loss of a stewardship ethic among Maori, adverse effects from land use, effects of cyclical weather patterns, and negative effects from the preferential harvest of large toheroa. Natural processes were considered to have a major influence on toheroa mortality and recruitment, but the cumulative effects of anthropogenic influences were thought likely to severely limit the ability of toheroa populations to recover from large scale natural mortality events or periods of poor recruitment.

### **6.4 Assessment of potential mechanisms of population decline**

#### **6.4.1 Climate and weather**

There was an association between toheroa mass mortality events reported in the literature and negative values of the Trenberth index  $Z$  at the time of the event, indicative of easterly zonal flow. This corroborates anecdotal observations that these events often coincide with easterly winds. The tendency towards an easterly flow in the month of a mass mortality event could suggest that wind influences the water rising up the beach and may cause toheroa to be left uncovered for longer periods than usual during the tidal cycle, possibly leading to desiccation stress. In the South Island, it is

possible that exposure to low air temperatures during periods that toheroa are uncovered may cause thermal stress. There was not a strong relationship with any of the Kidson weather types although it did appear that the HSE weather type (high to the south east of New Zealand) was the more common weather type during the month of a mass mortality.

#### **6.4.2 Toxic algal blooms**

Across New Zealand, PSP was the only toxin to be found in toheroa between July 1999 and March 2009. There has been an increase in PSP activity from 2003 to 2010, with the west coast of the North Island now experiencing events (McCoubrey 2010). Two of the toxin events in which phytoplankton numbers were high enough to trigger a shellfish assay occurred at the same time as a mass mortality event was recorded in the literature. However, it is unlikely that toxic phytoplankton events can solely account for the decline in toheroa numbers as there have been mass mortalities recorded where there were insufficient algae numbers to trigger a shellfish assay.

#### **6.4.3 Vehicle impacts**

The literature review provided strong evidence that toheroa are vulnerable to the effects of vehicles traversing the beach. However, there are few data available on the number of vehicles driving on toheroa beaches at present to be able to compare to historical values. Furthermore the areas that vehicles use when traversing the beach are also not regularly monitored. Vehicle users may not be aware of the potential impacts of driving vehicles on beaches where toheroa are present (Reynolds 2009). A programme that aims to educate beach users about the possible effects could be used in tandem with zoning to reduce impacts and increase awareness.

#### **6.4.4 Changes in land use**

The land adjacent to Ninety Mile Beach was shown to have changed markedly in use from historic to present times. Historic dune areas may have originally been forested before the first Polynesian settlers arrived. It may be that the removal of native forest during settlement changed the hydrology of the area in a way that was advantageous to toheroa. There is currently no information regarding toheroa numbers before and during settlement. It is possible, although unlikely, that toheroa were absent before settlement. Carbon dating suggests that shells found at Muriwai Beach are over 1000 years old (Stace 1991) and it seems reasonable to assume that if toheroa were in existence at Muriwai, they were also present at Ninety Mile at this time.

Northland Regional Council reported in 1991 that since pine afforestation commenced on the south Kaipara Heads, over half the dune lakes had completely dried up over a 20 year period, and on the Aupouri Peninsula nearly all of the temporary pan wetlands had disappeared (Northland Regional Council 1991). Comparisons of historic and modern land use may provide an indication of how the hydrology in an area may have altered over time. For Ninety Mile Beach, the biggest land use conversion has been from dune to exotic forest. Whilst there are no direct estimates of the water balance effects of a conversion of dune to pine forest, the conversion of pasture to pine forest is estimated to increase evaporation by at least 20%, delay flow by 17% and decrease stream flow by at least 20% after 8–10 years, with some estimates suggesting that stream flow could decrease by 30–50% following this change in land use (Fahey & Rowe 1992). Where water drains to groundwater, afforestation under full pine cover could reduce groundwater recharge by as much as 70% (Duncan 1993).

Looking only at land that has been converted to forestry since the 1950s, a total of 148 km<sup>2</sup> of land adjacent the beach at Ninety Mile that was historically pasture (1 km<sup>2</sup>) and dune (147 km<sup>2</sup>) has been converted. For the mid to northern region of the Dargaville Beach catchment, for which maps were available for our analysis, there has been a large decrease in scrub land and a significant increase in pasture/short rotation cropland. The differences over time in land use conversion between Ninety Mile Beach and Dargaville Beach may suggest that water balance (and hence freshwater seepage) in these

areas could have altered but at different scales, with possible changes being greater at Ninety Mile than Dargaville. A comparison between historical topographic maps (1950s) and current topographic maps (LINZ 1:50000 series) suggested that the number of watercourses annotated on the maps in 1950 was 15 historically compared with 9 in the present day for Dargaville Beach and 83 historically compared with 30 in the present day for Ninety Mile Beach. For Ninety Mile, this provides further indication that the hydrology of the area has been affected over time, with fewer watercourses being evident in recent times than were present historically.

Changes in land use have not occurred throughout all of the catchments draining Ninety Mile and Dargaville beaches but there are some general comments that can be made. Only the northernmost part of Ninety Mile Beach has retained its dunes habitat whereas the majority of the land behind the beach to the south has been afforested. Less dramatic changes have occurred in the mid to northern region of Dargaville Beach, although some afforestation has occurred on land behind the in the southern end of the beach. It seems likely that these changes in land use could have altered the local hydrological regime but it is unknown how important such changes may have been for toheroa. The most recent survey data indicate that toheroa abundance was very low at Ninety Mile Beach in 2010, and relatively high (albeit patchy) in central and northern parts of Dargaville Beach in 2011. It is difficult to say whether these distributions have any relationship to land use as there are many other factors that confound the issue.

At Oreti Beach, the marram grass covered dunes have been retained over time with little change in land use. At Bluecliffs Beach, the land behind the beach is covered with native forest and cliffs and this land use has remained the same over time. However, a decline in toheroa populations has occurred at both of these beaches since the 1960s (although the Oreti population has shown a subsequent increase since the 1990s), despite land use in the beach catchment having remained the same. This further indicates that populations may be responding to locally changing conditions, such as beach erosion at Bluecliffs Beach (Beentjes et al. 2006), and that a range of factors may be influencing toheroa abundance and distribution at a national level.

## **7. FUTURE WORK**

This review has highlighted a number of factors likely to influence toheroa abundance. To investigate the causal mechanisms operating, a combination of monitoring, experimental, and modelling studies may be necessary. Some ideas for future work are listed below.

Regular monitoring of key toheroa populations is required to provide a basis for assessing population status in relation to the potential explanatory factors identified in this review. Monitoring would need to be carried out using appropriate survey designs and sampling methods, but with suitable training and guidance the work could be conducted effectively by local people. Engaging the local community in the work would also raise awareness of the various issues affecting toheroa.

Field studies to characterise the habitat conditions associated with toheroa densities at different life stages could greatly improve our knowledge of which habitat factors exert the greatest influence on toheroa growth and survival. It should be straightforward to measure the physical position on the beach and the nature of the sediment (grain size, chemistry, organic content including microalgal pigment levels), especially the temperature and freshwater levels in the sand, which appear to have some bearing on toheroa mortality events. Such fieldwork could inform experimental work in the field and/or laboratory to investigate the processes responsible for patterns observed. Other field and modelling work could investigate the relationship between land use (e.g., dune, plantation forest), the hydrology of the area and the beach, and toheroa dynamics.

Improved education regarding vehicle use on beaches may help to reduce toheroa mortalities. A campaign that encourages people to limit their use of vehicles on the high intertidal zone of the beach may reduce impacts on juvenile toheroa. Undertaking zoning work on toheroa beaches by restricting

vehicle access to permit comparisons of populations living under the same environmental conditions, but without vehicle stress, may give further insight into the impacts of vehicles on toheroa. The creation of 'vehicle-free' zones could enable studies on the longer term effects of vehicles on toheroa to be carried out.

The toheroa time series data collated in the present study could be used in a further investigation to assess common trends in toheroa abundance at the six main populations surveyed, and the effects of climate and weather conditions on these populations. Multivariate time-series analysis, such as dynamic factor analysis (Zuur et al. 2003), may be appropriate for estimating underlying common patterns in this set of time-series, evaluating interactions between response variables and determining the effects of explanatory variables.

Any work on toheroa is likely to require concerted efforts between multiple end user groups, including iwi, the public, industry, local and national government bodies, and research providers. Holding a workshop on toheroa may help to communicate the findings of this project to these groups, promote discussion of the issues, and prioritise plans for the future management of toheroa and their associated beach environments.

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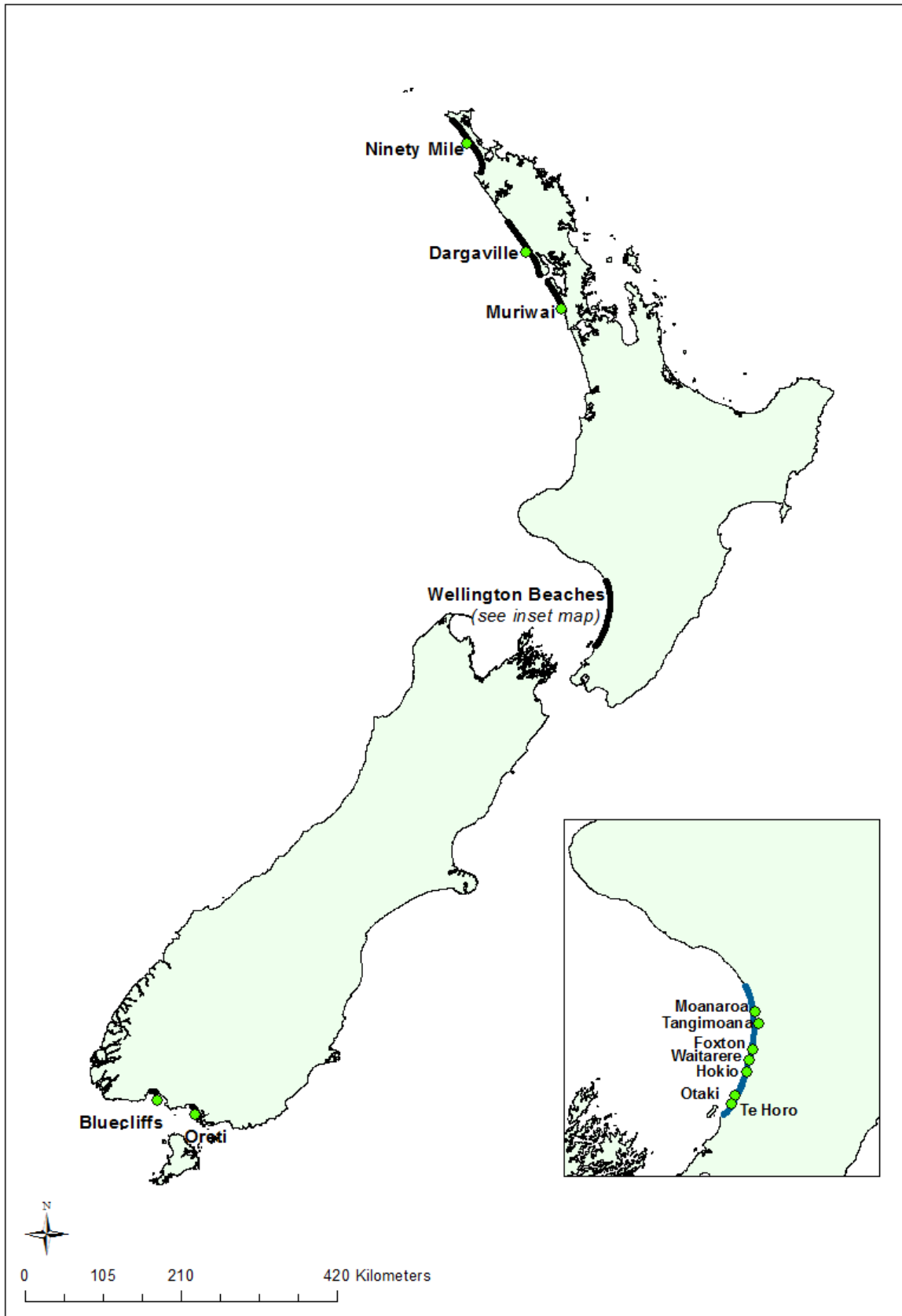
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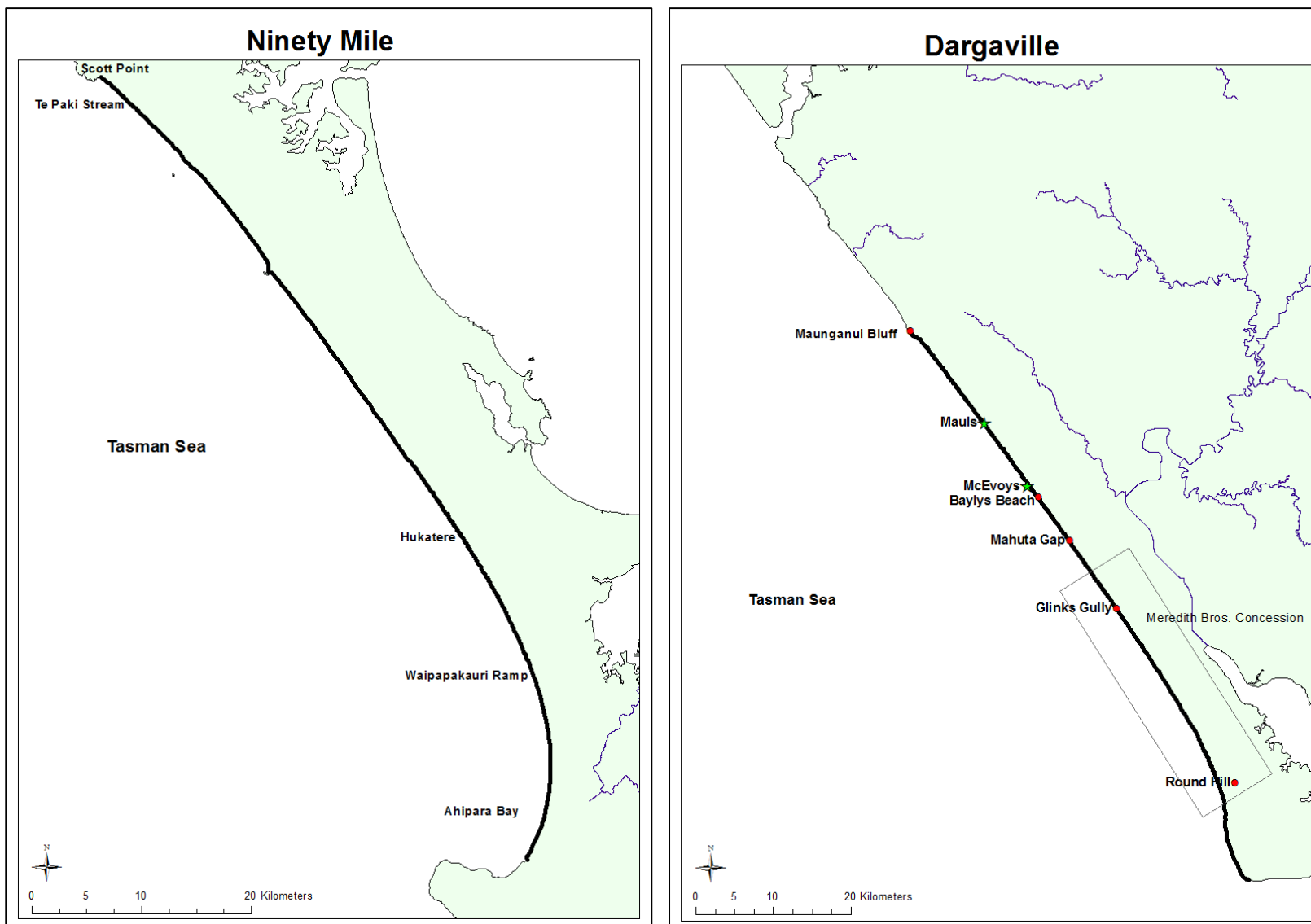


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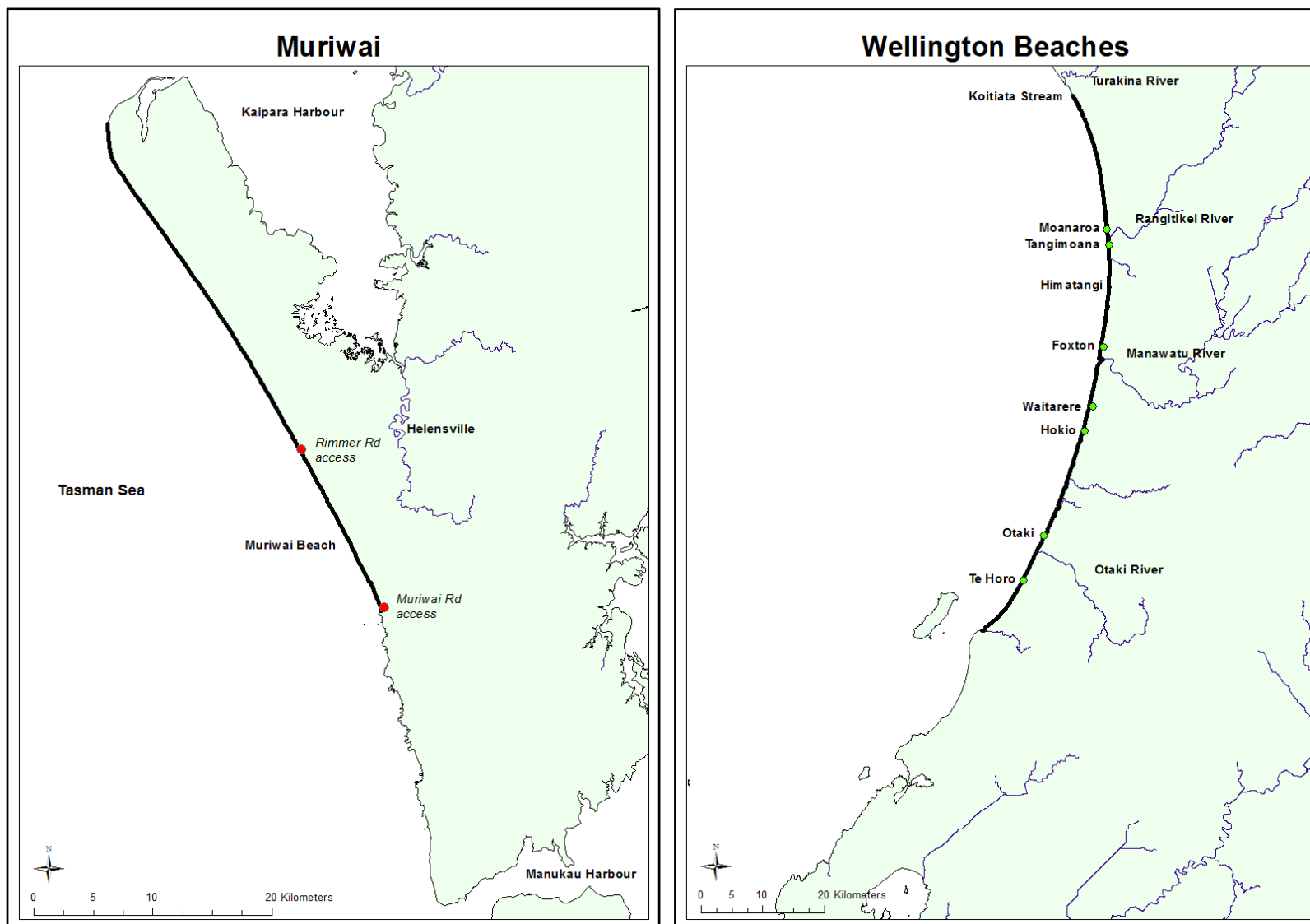
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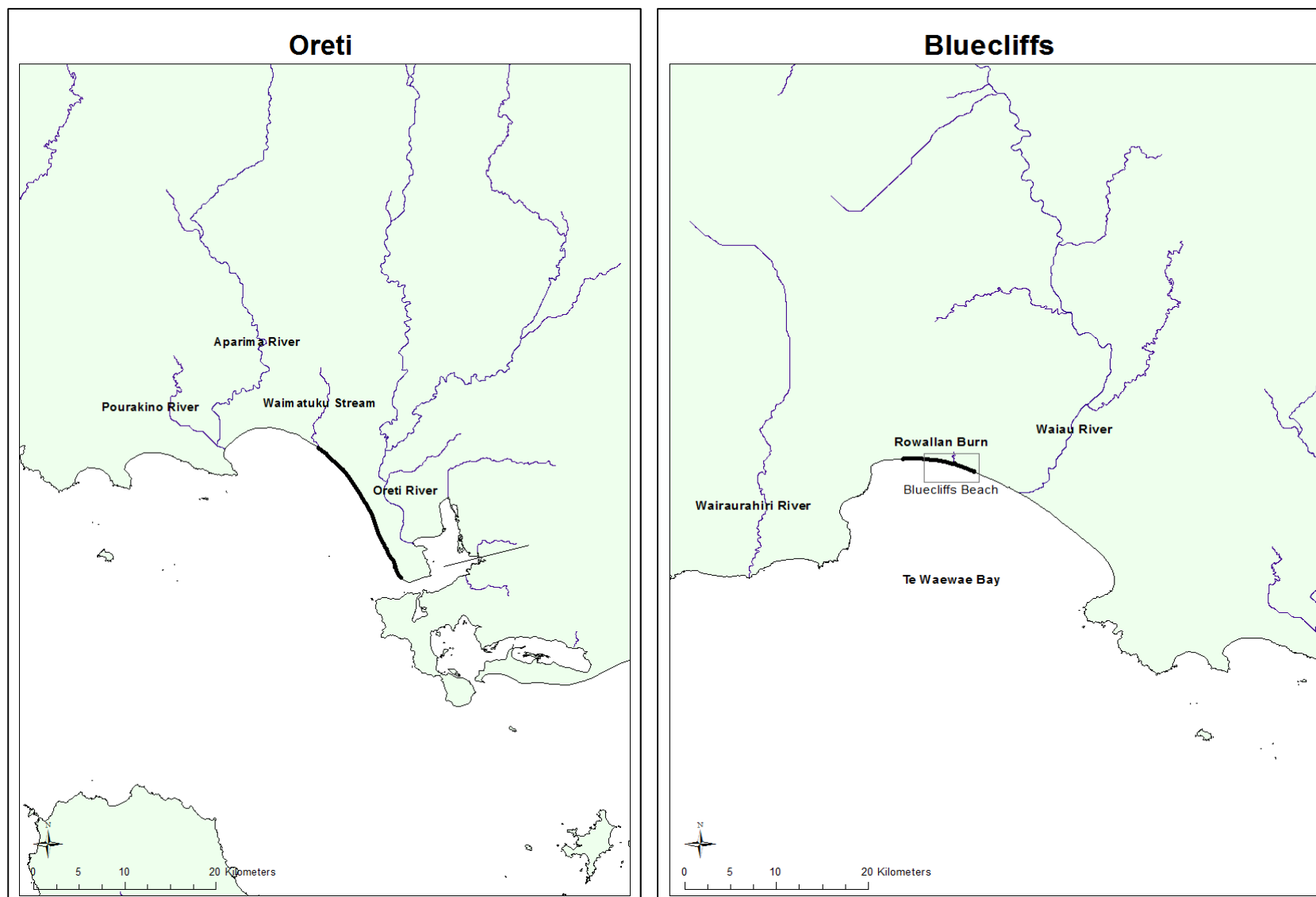
**Figure 1: Toheroa distribution around New Zealand, as determined from surveys. Dark shading denotes survey limits.**



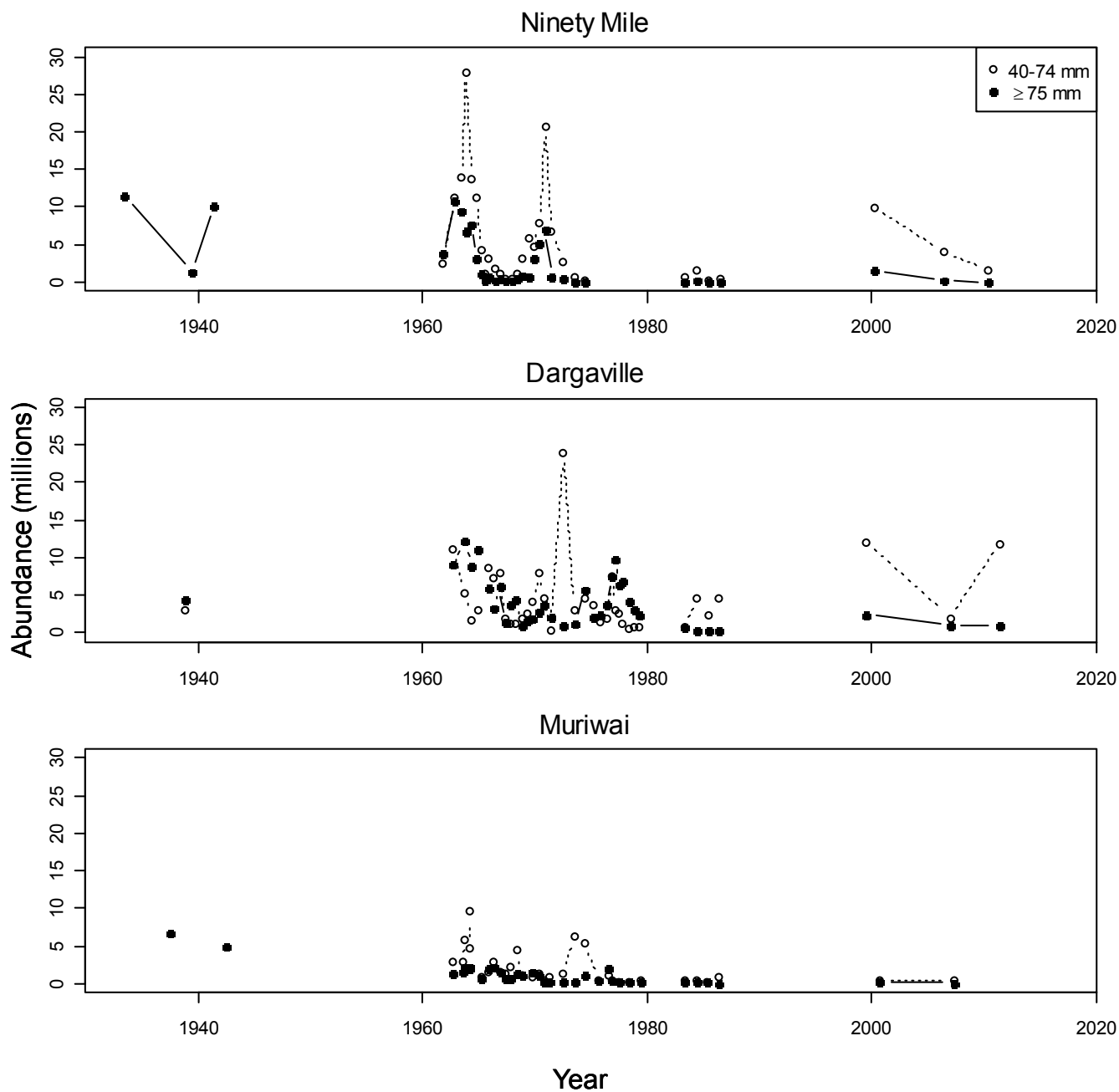
**Figure 2: North Island beaches where major populations of toheroa have been surveyed: Ninety Mile Beach and Dargaville Beach.**



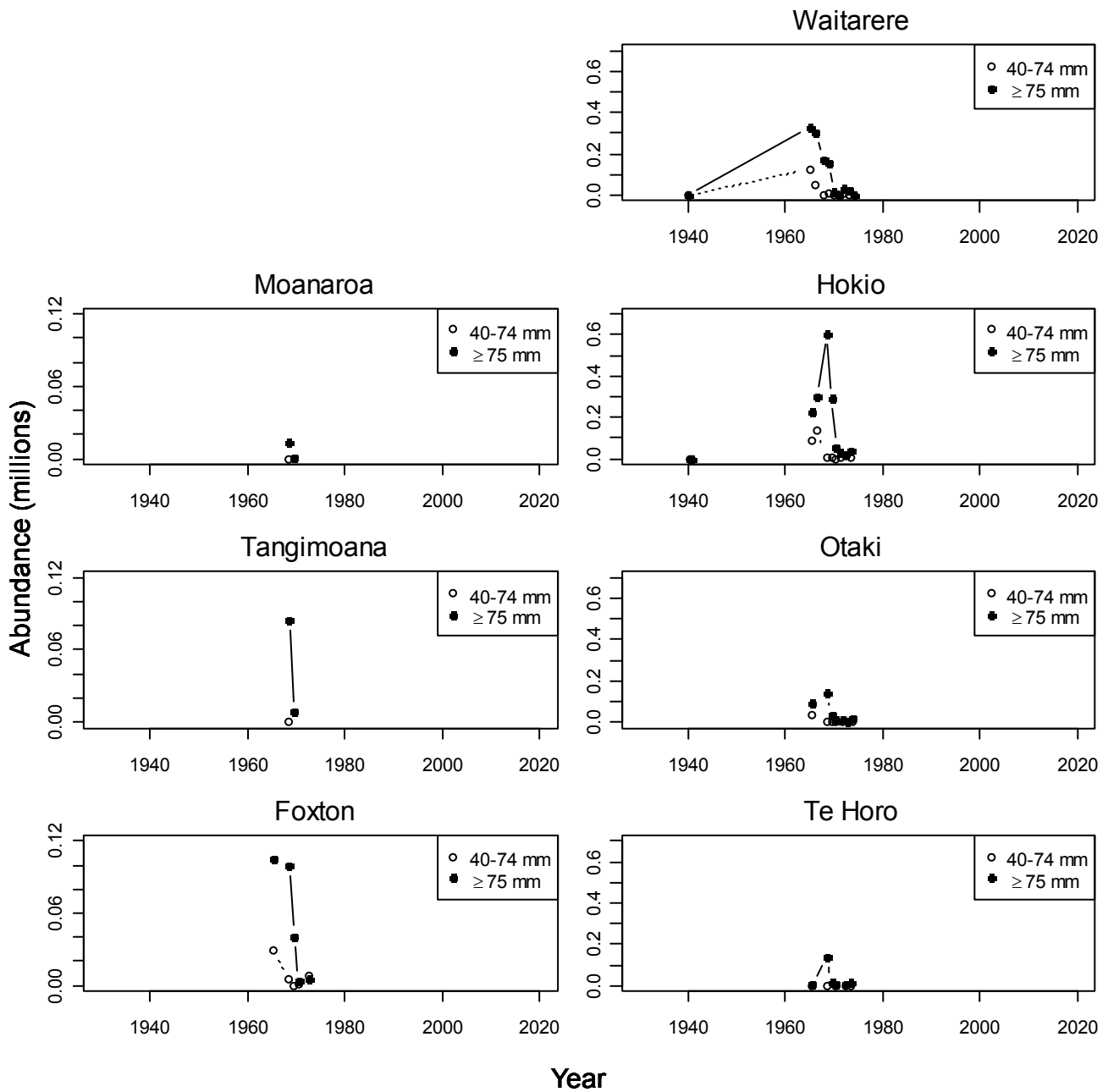
**Figure 3: North Island beaches where major populations of toheroa have been surveyed: Muriwai Beach and the ‘Wellington’ region beaches.**



**Figure 4: South Island beaches where major populations of toheroa have been surveyed: Oreti Beach and Bluecliffs Beach.**

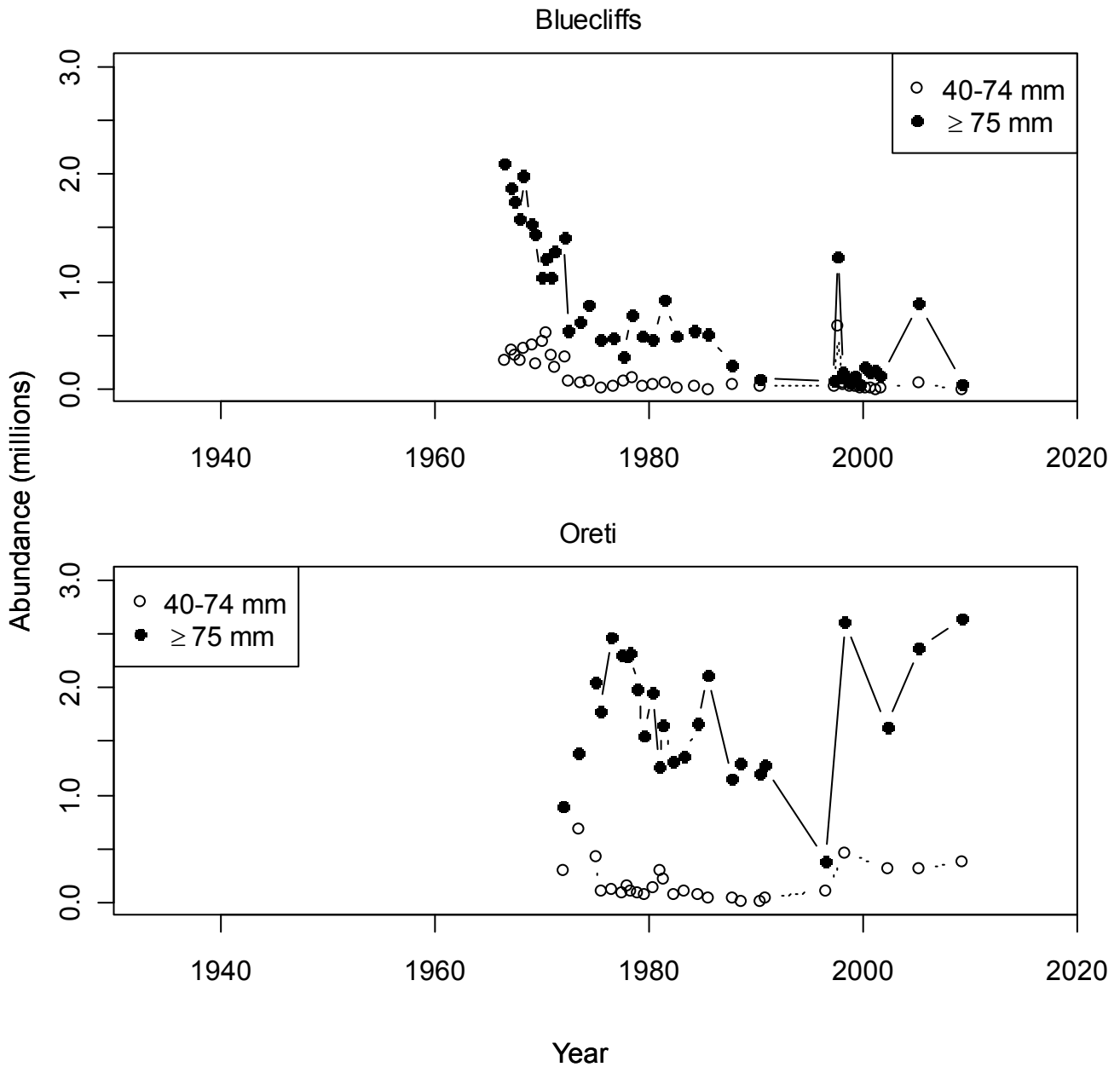


**Figure 5: Estimated abundance of toheroa from surveys at Ninety Mile, Dargaville, and Muriwai beaches in Northland from 1930 to present. Two shell length categories are plotted: 40–74 mm (open circles, dotted lines) and 75 mm or larger. Data from Cassie (1955), Redfearn (1974), Greenway & Allen (1962), Greenway (1972, 1974), Akroyd et al. (2002, 2008), Morrison & Parkinson (2001, 2008), and Williams et al. (2013).**

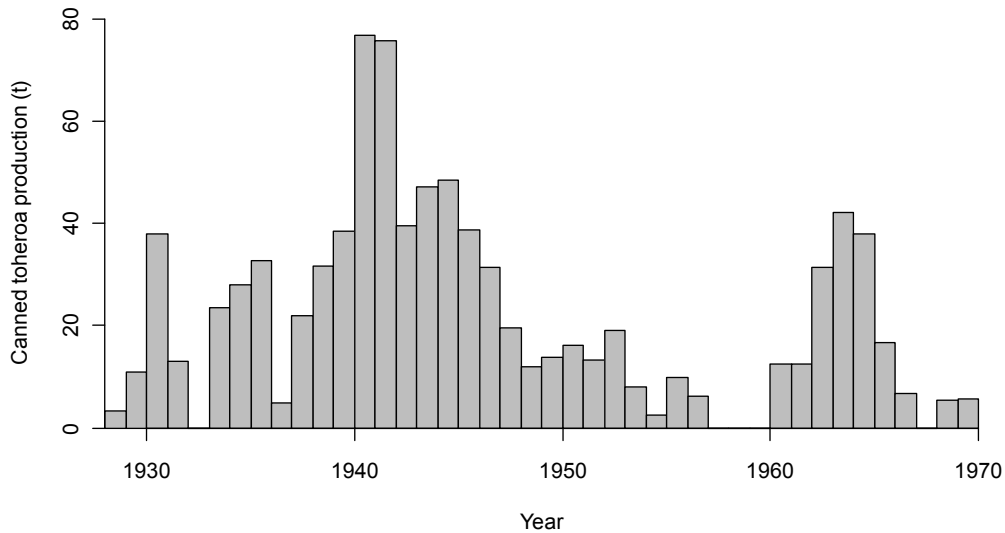


**Figure 6: Estimated abundance of toheroa from surveys at seven beaches along the Manawatu/Kapiti coast west of Wellington from 1930 to present. Two shell length categories are plotted: 40–74 mm (open circles, dotted lines) and 75 mm or larger. Data from Tunbridge (1967, 1969) and Williamson (1969b, a, 1970, 1971, 1972, 1973).**

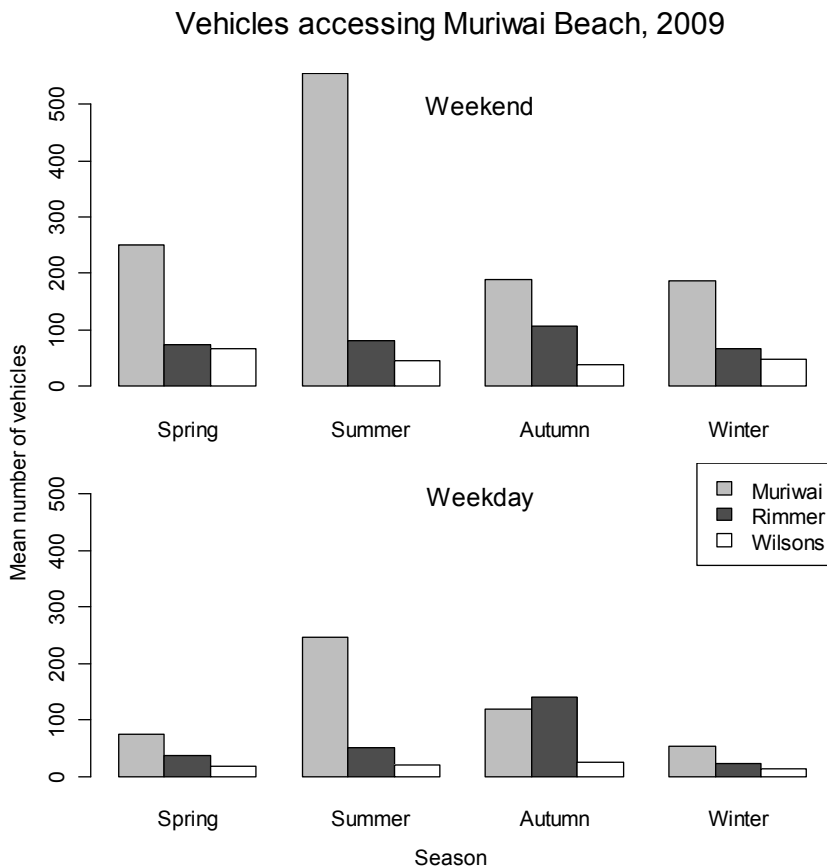




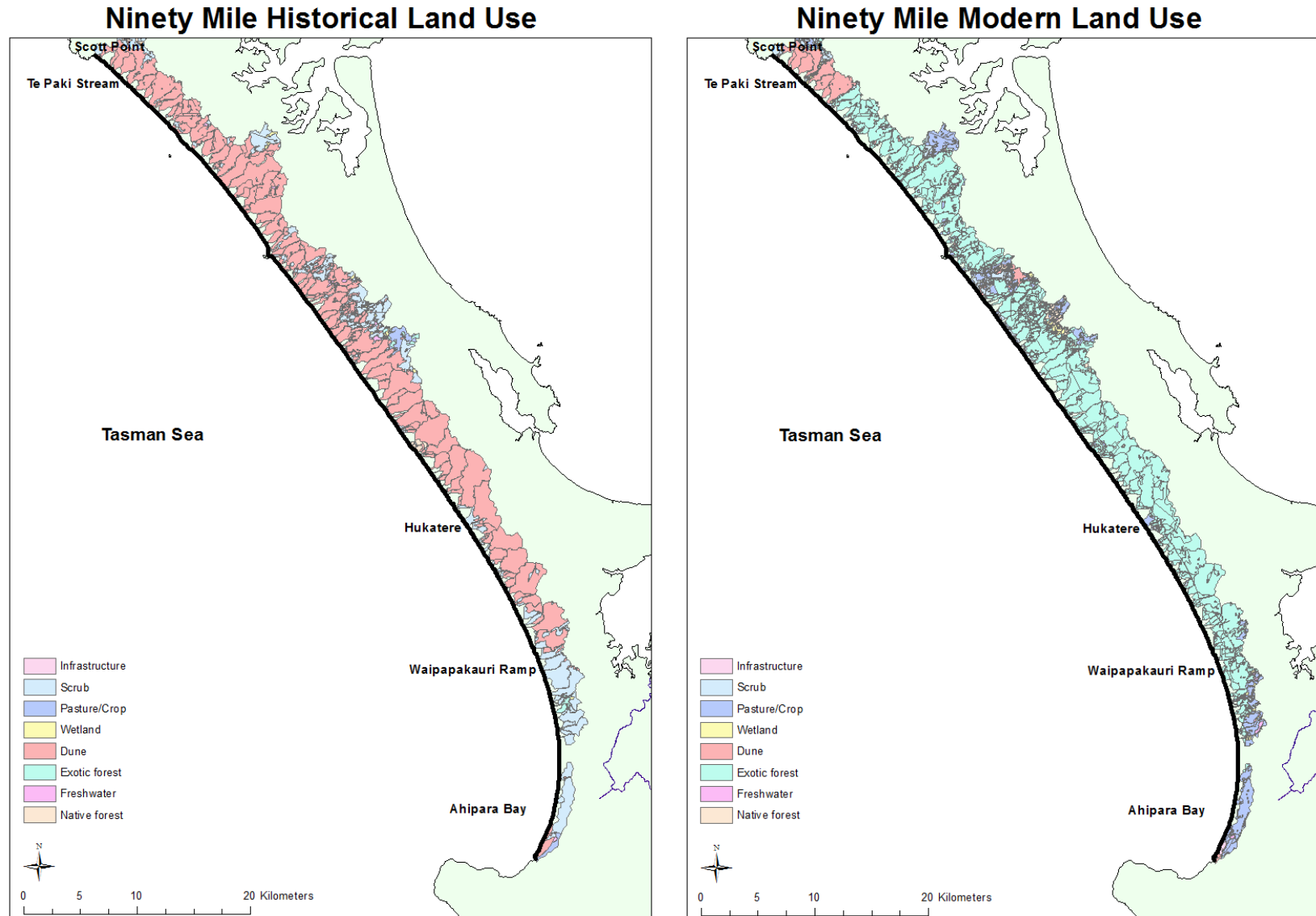
**Figure 7: Estimated abundance of toheroa from surveys at Te Waewae and Oreti beaches in Southland from 1930 to present. Two shell length categories are plotted: 40–74 mm (open circles, dotted lines) and 75 mm or larger. Te Waewae data from Millar & Olsen (1995), Carbines (1997a), Carbines & Breen (1999a), Beentjes et al. (2003), Beentjes & Gilbert (2006a), and Beentjes (2010b). Oreti data from Street (1971, 1972), McKinnon & Olsen (1994), Carbines (1997b, 1998, 1999, 2000), Carbines & Breen (1999a), Beentjes & Carbines (2001), Beentjes & Gilbert (2006a), and Beentjes (2010a).**



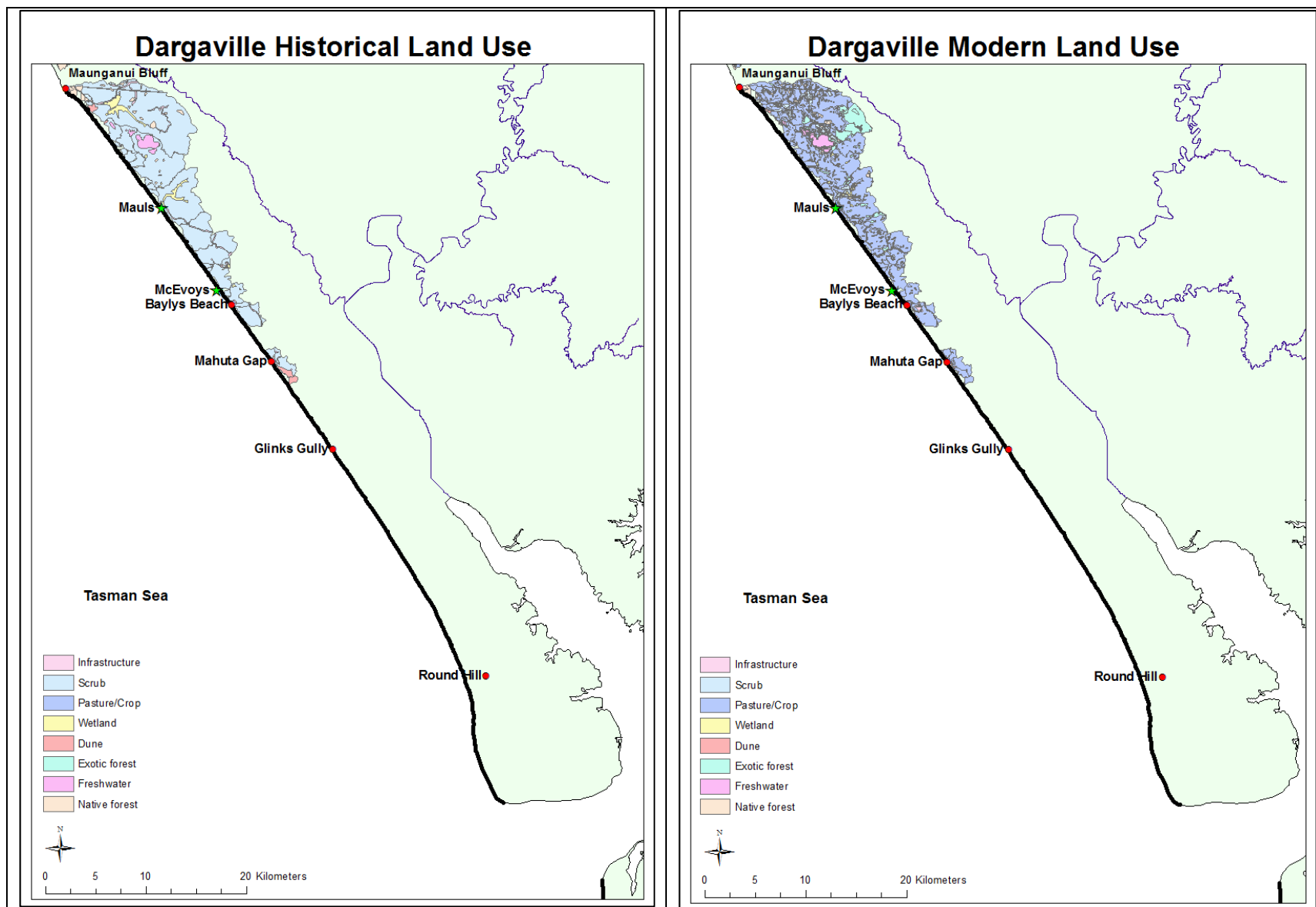
**Figure 8: Total commercial production of toheroa (tonnes of canned toheroa product) from canneries at Northland beaches (Dargaville, Ninety Mile, and Muriwai) from 1928 to 1969. Data from Marine Department Annual records for 1928–40 and 1943–48 tabulated by Cassie (1955) and for 1941–42 and 1949–69 graphed by Redfearn (1974).**



**Figure 9: Average number of vehicles accessing Muriwai Beach via three sites (‘Rimmer Road’, ‘Wilsons Road’, and ‘Muriwai’) by weekend and weekday in 2009. Data recorded by automated counters, provided by Auckland Council.**



**Figure 10: Historical and modern land use for Ninety Mile Beach. Historical land use was based on an analysis of maps of Ninety Mile drawn between 1958 and 1960 from the NZMS 2 series. Modern land use was provided by the Land Classification Database 2 (LCDB2), a digital map of the land surface of New Zealand that incorporates satellite snapshots of land cover data from 1996–97 and 2001–02.**



**Figure 11: Historical and modern land and use for Dargaville Beach. Historical land use was based on an analysis of maps of Dargaville Beach drawn between 1943 and 1944 from the NZMS 1 Provisional 1 Mile Series (Sheets N18, N22 and N23). Modern land use was provided by the Land Classification Database 2 (LCDB2), a digital map of the land surface of New Zealand that incorporates satellite snapshots of land cover data from 1996–97 and 2001–02.**

**Table 1: Climate index values (+, positive; -, negative) and Kidson weather types for the month in which a toheroa mass mortality event was observed. Trenberth indices (Trenberth 1976): M, meridional index; Z, zonal index. CEI, Coupled ENSO Index (Gergis & Fowler 2005). SAM, Southern Annular Mode (Marshall 2003). Abbreviations in other columns refer to the 12 Kidson weather types (Kidson 2000); shaded cells with a '1' denote the dominant weather type (or equidominant, possibly including up to four types). For events 1–3, in which the mortality was observed to span two months, the index values shown are those of the first month. Data were not available (NA) for SAM before 1957 or for Kidson weather types before 1958 or for CEI in 2009.**

Event	Year	Month	Location	Reference	Climate indices				Kidson weather types															
					M	Z	CEI	SAM	TSW	T	SW	NE	R	HW	HE	W	HNW	TNW	HSE	H				
1	1930	4–5	Ninety Mile	(Hefford 1931, Rapson 1954)	-	-	-	NA																
2	1932	2–3	Ninety Mile	(Rapson 1954)	+	-	-	NA																
3	1938	2–3	Dargaville, Muriwai, Waitarere	(Hefford 1938)	-	-	+	NA																
4	1938	11	Dargaville, Muriwai, Waitarere	(Rapson 1954)	-	-	+	NA																
5	1967	9	Bluecliffs	(Street 1972)	+	-	+	+	1														1	
6	1968	4	Bluecliffs	(Street 1971)	-	-	+	-						1					1					
7	1971	2	Ninety Mile, Dargaville, Muriwai	(Redfean 1974)	-	-	+	+				1			1							1		
8	1973	2	Dargaville Muriwai	(Greenway 1974)	-	-	-	+			1											1		
9	1993	4	Oreti	(Futter & Moller 2009)	+	-	-	+									1							
10	1996	1	Oreti	(Carbines 1997a)	-	-	+	+					1									1		
11	2001	1	Dargaville	(Akroyd et al. 2002)	+	-	+	+			1											1		
12	2009	4	Oreti	(Futter & Moller 2009)	-	+	NA	-								1							1	

**Table 2: Climate index values (+, positive; -, negative) and Kidson weather types for one month before a toheroa mass mortality event was observed. Trenberth indices (Trenberth 1976): M, meridional index; Z, zonal index. CEI, Coupled ENSO Index (Gergis & Fowler 2005). SAM, Southern Annular Mode (Marshall 2003). Abbreviations in other columns refer to the 12 Kidson weather types (Kidson 2000); shaded cells with a '1' denote the dominant weather type (or equidominant, possibly including up to four types). For events 1–3, in which the mortality was observed to span two months, the index values shown are those of the first month. Data were not available (NA) for SAM before 1957 or for Kidson weather types before 1958 or for CEI in 2009.**

Event	Year	Month	Location	Reference	Climate indices				Kidson weather types																
					M	Z	CEI	SAM	TSW	T	SW	NE	R	HW	HE	W	HNW	TNW	HSE	H					
1	1930	4–5	Ninety Mile	(Hefford 1931, Rapson 1954)	+	+	-	NA																	
2	1932	2–3	Ninety Mile	(Rapson 1954)	+	+	-	NA																	
3	1938	2–3	Dargaville, Muriwai, Waitarere	(Hefford 1938)	-	-	+	NA																	
4	1938	11	Dargaville, Muriwai, Waitarere	(Rapson 1954)	+	+	+	NA																	
5	1967	9	Bluecliffs	(Street 1972)	-	+	+	+		1						1						1			
6	1968	4	Bluecliffs	(Street 1971)	-	-	+	-					1										1		
7	1971	2	Ninety Mile, Dargaville, Muriwai	(Redfean 1974)	-	-	+	-					1										1		
8	1973	2	Dargaville Muriwai	(Greenway 1974)	-	-	-	-							1									1	
9	1993	4	Oreti	(Futter & Moller 2009)	+	-	-	+															1	1	
10	1996	1	Oreti	(Carbines 1997a)	-	+	+	+							1							1			
11	2001	1	Dargaville	(Akroyd et al. 2002)	-	+	+	-		1													1		
12	2009	4	Oreti	(Futter & Moller 2009)	+	-	NA	+															1		

**Table 3: Climate index values (+, positive; -, negative) and Kidson weather types for three months before a toheroa mass mortality event was observed. Trenberth indices (Trenberth 1976): M, meridional index; Z, zonal index. CEI, Coupled ENSO Index (Gergis & Fowler 2005). SAM, Southern Annular Mode (Marshall 2003). Abbreviations in other columns refer to the 12 Kidson weather types (Kidson 2000); shaded cells with a '1' denote the dominant weather type (or equidominant, possibly including up to four types). For events 1–3, in which the mortality was observed to span two months, the index values shown are those of the first month. Data were not available (NA) for SAM before 1957 or for Kidson weather types before 1958 or for CEI in 2009.**

Event	Year	Month	Location	Reference	Climate indices				Kidson weather types															
					M	Z	CEI	SAM	TSW	T	SW	NE	R	HW	HE	W	HNW	TNW	HSE	H				
1	1930	4–5	Ninety Mile	(Hefford 1931, Rapson 1954)	+	+	-	NA																
2	1932	2–3	Ninety Mile	(Rapson 1954)	-	+	+	NA																
3	1938	2–3	Dargaville, Muriwai, Waitarere	(Hefford 1938)	+	+	-	NA																
4	1938	11	Dargaville, Muriwai, Waitarere	(Rapson 1954)	-	-	+	NA																
5	1967	9	Bluecliffs	(Street 1972)	+	+	+	+										1					1	
6	1968	4	Bluecliffs	(Street 1971)	+	+	+	-	1	1			1	1										
7	1971	2	Ninety Mile, Dargaville, Muriwai	(Redfean 1974)	-	-	+	+						1	1							1		
8	1973	2	Dargaville Muriwai	(Greenway 1974)	-	-	-	+							1								1	
9	1993	4	Oreti	(Futter & Moller 2009)	+	+	-	-								1						1		
10	1996	1	Oreti	(Carbines 1997a)	+	-	+	-		1								1						

**Table 4: Comparison between toxin events recognised by the New Zealand Shellfish Marine Biotoxin Monitoring Programme and toheroa mass mortality events recorded in the literature. Data from (Hay et al. 2000, McCoubrey 2010). NSP, neurotoxic shellfish poison; PSP, paralytic shellfish poison; DSP, diarrhoetic shellfish poison; YSP, yessotoxin shellfish poison; ASP, amnesic shellfish poison.**

Mass mortality event details			Toxic events recognised by biotoxin monitoring programme				
Date	Location	Reference	NSP	PSP	DSP	YSP	ASP
April 1993	Oreti	(Futter & Moller 2009)					
January 1996	Oreti	MFish pers.comm. in (Carbines 1997a)		Feb 1996: Foveaux Strait. Sample collected from dredge oysters. Below regulatory level.			
January 2001	Dargaville	(Akroyd et al. 2002)		Jan 2001: Glinks Gully. Sample collected from toheroa. Exceeded regulatory level.			

**Table 5: Information on vehicle use on toheroa beaches.**

Date	Beach	Number of vehicles reported	Time period over which reported	Reference
1968	Muriwai	37 000	Two week open season	Stace 1991
1991	Muriwai	800–900 off road vehicles	One weekend	Stace 1991
1991	Ninety Mile Beach	35 tourist buses	Day (peak summer)	Stace 1991
1998	Ninety Mile Beach	400	Day	Hooker & Redfearn 1998
2009	Ninety Mile Beach	2 400 bus trips	Year	Enquires in present study

**Table 6: Historical (1960s) and modern (2002) land use as a percentage of all studied catchments draining to Ninety Mile Beach.**

	Infrastructure	Scrub	Pasture/Short rotation cropland	Wetland	Dune	Exotic forest	Freshwater	Native Forest
Historical	0.00	21.84	1.43	0.52	73.89	0.75	0.95	0.62
Modern	0.24	4.67	12.58	1.29	7.50	71.91	0.61	1.19

**Table 7: Historical (1940s) and modern (2002) land use as a percentage of all studied catchments draining to Dargaville Beach.**

	Infrastructure	Scrub	Pasture/Short rotation cropland	Wetland	Dune	Exotic forest	Freshwater	Native Forest
Historical	2.25	88.11	0.25	3.19	1.68	0	2.33	2.16
Modern	0.44	6.47	75.13	1.22	0.75	9.37	2.34	4.28

**Table 8: Land use change matrix for Ninety Mile Beach, 1960s to 2002. Values in square kilometres.**

	2002								
1960s	Infrastructure	Scrub	Pasture/ Short rotation cropland	Wetland	Dune	Exotic forest	Freshwater	Native Forest	1960s Total
Infrastructure	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
Scrub	0.04	4.74	17.26	1.83	0.55	25.51	0.95	1.97	<b>52.85</b>
Pasture/Short rotation cropland	0.02	0.07	1.71	0.00	0.11	1.43	0.01	0.10	<b>3.45</b>
Wetland	0.00	0.10	0.39	0.12	0.00	0.45	0.05	0.16	<b>1.26</b>
Dune	0.50	5.04	8.58	0.95	16.4	146.53	0.30	0.52	<b>178.82</b>
Exotic forest	0.00	0.04	0.33	0.10	0.00	1.24	0.00	0.09	<b>1.81</b>
Freshwater	0.00	0.15	0.36	0.09	0.19	1.20	0.20	0.10	<b>2.29</b>
Native Forest	0.00	0.61	0.1	0.02	0.00	0.74	0.02	0.02	<b>1.51</b>
<b>2002 Total</b>	<b>0.57</b>	<b>10.76</b>	<b>28.74</b>	<b>3.11</b>	<b>17.25</b>	<b>177.09</b>	<b>1.53</b>	<b>2.96</b>	
<b>Change from 1960s to 2002</b>	<b>+0.57</b>	<b>-42.09</b>	<b>+25.28</b>	<b>+1.84</b>	<b>-161.57</b>	<b>+175.28</b>	<b>-0.76</b>	<b>+1.45</b>	

**Table 9: Land use change matrix for Dargaville Beach, 1940s to 2002. Values in square kilometres.**

	2002								
1940s	Infrastructure	Scrub	Pasture/ Short rotation cropland	Wetland	Dune	Exotic forest	Freshwater	Native Forest	1940s Total
Infrastructure	0.03	0.14	2.45	0.02	0.01	0.07	0.00	0.12	<b>2.85</b>
Scrub	0.52	6.47	87.39	1.26	0.44	10.76	0.83	3.73	<b>111.41</b>
Pasture/Short rotation cropland	0.00	0.01	0.30	0.00	0.00	0.28	0.00	0.00	<b>0.60</b>
Wetland	0.00	0.84	2.62	0.23	0.00	0.04	0.00	0.30	<b>4.04</b>
Dune	0.00	0.09	1.75	0.00	0.23	0.00	0.03	0.00	<b>2.10</b>
Exotic forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
Freshwater	0.00	0.07	0.26	0.00	0.01	0.04	2.38	0.19	<b>2.95</b>
Native Forest	0.00	0.17	1.26	0.01	0.00	0.21	0.02	0.83	<b>2.51</b>
<b>2002 Total</b>	<b>0.56</b>	<b>7.80</b>	<b>96.04</b>	<b>1.53</b>	<b>0.68</b>	<b>11.41</b>	<b>3.27</b>	<b>5.17</b>	
<b>Change from 1940s to 2002</b>	<b>-2.29</b>	<b>-103.61</b>	<b>+95.45</b>	<b>-2.50</b>	<b>-1.42</b>	<b>+11.41</b>	<b>+0.32</b>	<b>+2.65</b>	



**Table 10: Number of watercourses counted on historical and modern day topographic maps which run to Ninety Mile and Dargaville Beaches.**

	Number of watercourses	
	Ninety Mile Beach	Dargaville
Historic	83	15
Modern	30	9

**Table 11: Summary of forestry operations on the Aupouri Peninsula (data provided by Murray Braithwaite, Juken New Zealand Ltd). –, no data or no comments.**

Year	Area	Activity	Density (stands per hectare)	Comments
1963–1987	North of Waipapakauri Ramp to Te Aria reserve	Planting	1600	Protection stands (which will not be felled) planted 300 m into forest from Western edge of forest at 2400 stands per ha at first, 1200 stands per ha latterly.
1970s	South of Waipapakauri Ramp	Planting	1600	Protection stands (which will not be felled) planted 300 m into forest from Western edge of forest at 1200 stands per ha.
1978–1980	Adjacent to Waipapakauri Ramp	Felling then replanting	1200	–
2000	Strip behind protection zone from Waipapakauri to Hukatere	Clear fell of 200 ha.yr	–	–
2001–2010	Various areas	Felling 500-600 ha.yr Replanting as cut.	1200	–

## APPENDICES

### Appendix 1. 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 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<sup>2</sup>) 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 (Williams et al. 2013); 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 2. 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<sup>2</sup> 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<sup>2</sup> 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, 1974). In 1974, an additional survey was made at Dargaville Beach in the 16 km stretch between Glinks Gully and Chases Gap, in which the transect coverage was three times the usual coverage (Greenway 1969, 1974).
- 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<sup>2</sup> 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<sup>2</sup> 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 (Williams et al. 2013). 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.

### Appendix 3. Survey methodology for Muriwai Beach (1948–2007)

- 1937 Toheroa beds at Muriwai Beach were surveyed by digging three to five 0.37 m<sup>2</sup> quadrats along transects that ran perpendicular to the beach. The quadrats were spaced at 2.7 m intervals above and below mid-tide level. The quadrats were dug out with a garden fork and all toheroa (2.5 cm or larger) present in the quadrats were counted. Transects were sampled approximately every 160 m along the beach (Rapson 1954).
- 1948 Toheroa beds were surveyed by digging 0.37 m<sup>2</sup> quadrats along transects that ran perpendicular to the beach. The quadrats were spaced at 4.8 m intervals above and below mid-tide level, until the upper and lower edges of the bed were reached. Transects were sampled approximately every 27 m along the beach for the first 26 km of the beach, and thereafter transects were sampled approximately every 53 m along the beach. The quadrats were dug out with a garden fork (Cassie 1955).
- 1949–52 Individual quadrats were replaced by a continuous 18 cm wide trench that ran perpendicular to the beach from the upper limit of the toheroa bed to the lower limit of the bed. The trenches were dug out with a garden fork and all toheroa present were counted. The trenches were dug at 50 m intervals along the beach (Cassie 1955).
- 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; each trench was 18 cm wide and was centred at the mid-tide level. Trenches were randomly located to give an approximate coverage of 0.9 m per 800 m of beach. All toheroa found in the trenches were counted (Greenway 1969).
- 1965–73 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<sup>2</sup> quadrats that were dug at regular intervals along a 27 m transect that ran perpendicular to the beach and was centred at the mid-tide level. 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, 1974).
- 2007 Muriwai Beach was divided into five equal sections. Within each section 7–11 transects that ran perpendicular to the beach were placed at 1 km intervals, with a random starting point within the section. Quadrats (0.5 m<sup>2</sup>) were dug at 5 m intervals along each transect, starting at a random location 1–5 m from the high water mark. The quadrats were excavated to a depth of 30 cm, the contents sieved, and all toheroa present were counted and measured. In total, 48 transects were surveyed (Akroyd et al. 2008).

#### Appendix 4. Survey methodology for the 'Wellington' region populations (1965–1973)

- 1965 The survey was conducted using 30 cm wide trenches that ran perpendicular to the beach between Foxton and Te Horo (Figure 3). The trenches were centred at mid-tide level and continued out past the ends of the beds towards the high water mark and the low water mark, or to 13 m, whichever was the longest. Trenches were spaced at 400–1600 m intervals depending on the beach structure, time available, and expected toheroa density. Generally beach areas with low toheroa densities were sampled every 400 m, whereas beach areas with high toheroa densities were sampled every 1600 m. The trenches were dug out with a potato fork and the toheroa present were divided into two groups for counting: over 76 mm and under 76 mm (Tunbridge 1967).
- 1966 Sampling methodology was consistent with the 1965 survey except that the survey covered only the area between North Waitarere and Hokio (Figure 3). Trenches were spaced at 119–805 m intervals along the beach (Tunbridge 1969).
- 1968 Sampling methodology was consistent with the 1965 survey except that the survey covered the area between Moanaroa and Te Horo (Figure 3) (Williamson 1969b).
- 1969–73 Sampling methodology was consistent with the 1965 survey except that the survey only covered the area between Moanaroa and Te Horo, and the trenches were spaced at 400 m intervals (Williamson 1969a, 1970, 1971, 1972, 1973).

## Appendix 5. Survey methodology for Oreti Beach (1971–2005)

- 1971–90 Annual toheroa surveys were conducted at Oreti Beach (Figure 4) using transects that ran perpendicular to the beach from the high to low water marks (a distance of about 115 m). The survey began close to the mouth of the Oreti River and extended north, with transects spaced at approximately 330 m intervals. An average of 54 transects (range 20–78) were sampled covering about 17 km. Quadrats (0.5 m<sup>2</sup>) were placed at 5 m intervals along each transect and dug out with a garden fork to a depth of 30 cm. The contents of the quadrat was scattered over the beach and all visible toheroa present were counted and measured to the nearest 5 mm. Surveys were conducted before the proposed open season date. If an open season was held then a post-season survey was also conducted (McKinnon & Olsen 1994, Beentjes & Gilbert 2006b).
- 1990 In April 1990 an additional survey for juvenile toheroa was conducted. Transects ran perpendicular to the beach and were spaced at 660 m intervals. Quadrats (0.5 m<sup>2</sup>) were placed at 5 m intervals along each transect from mid-tide level to the high water mark and the top 3 cm of substrate from each quadrat was carefully removed with a spade. All toheroa present were counted and measured to the nearest 2 mm (McKinnon & Olsen 1994).
- 1996 The methodology used was consistent with the 1971 survey, except that the transect spacing along the beach changed from 330 m to 350 m (Carbines 1997a).
- 1998 A two-phase stratified random design was conducted. The beach was divided into eight strata of various lengths based on the 1996 survey results. In phase 1, 3–9 transects were allocated to each stratum depending on the estimated area of the stratum and its likely toheroa density. In phase 2, an additional 0–7 transects were sampled in each stratum, the number of additional transects was calculated by maximising the reduction of variance estimates. A total of 59 transects was sampled. Transects were randomly located within each stratum and ran from high water to low water, with a minimum distance of 20 m between transects. Quadrats (0.5 m<sup>2</sup>) were placed at 5 m intervals along each transect and dug out with a garden fork to a depth of 30 cm. The contents of the quadrats were scattered over the beach and all toheroa found were measured to the nearest millimetre and then returned to the substrate. In addition, two transects per stratum were used to sample juvenile toheroa (less than 40 mm shell length). The contents of each quadrat was placed in a fine mesh bag and placed in the surf to remove the sand. All toheroa present were measured to the nearest millimetre (Carbines & Breen 1999a).
- 2002–05 The methodology used in these surveys was consistent with the 1998 survey, except that 60 transects were sampled in total, with 3–18 transects per stratum in phase 1 and an additional 0–11 transects per stratum in phase 2. The juvenile toheroa population was sampled by sieving the quadrats from two or three transects per stratum with a fine mesh metal sieve. In 2005 the substrate type in each quadrat was also categorised (Beentjes et al. 2003, Beentjes & Gilbert 2006a).

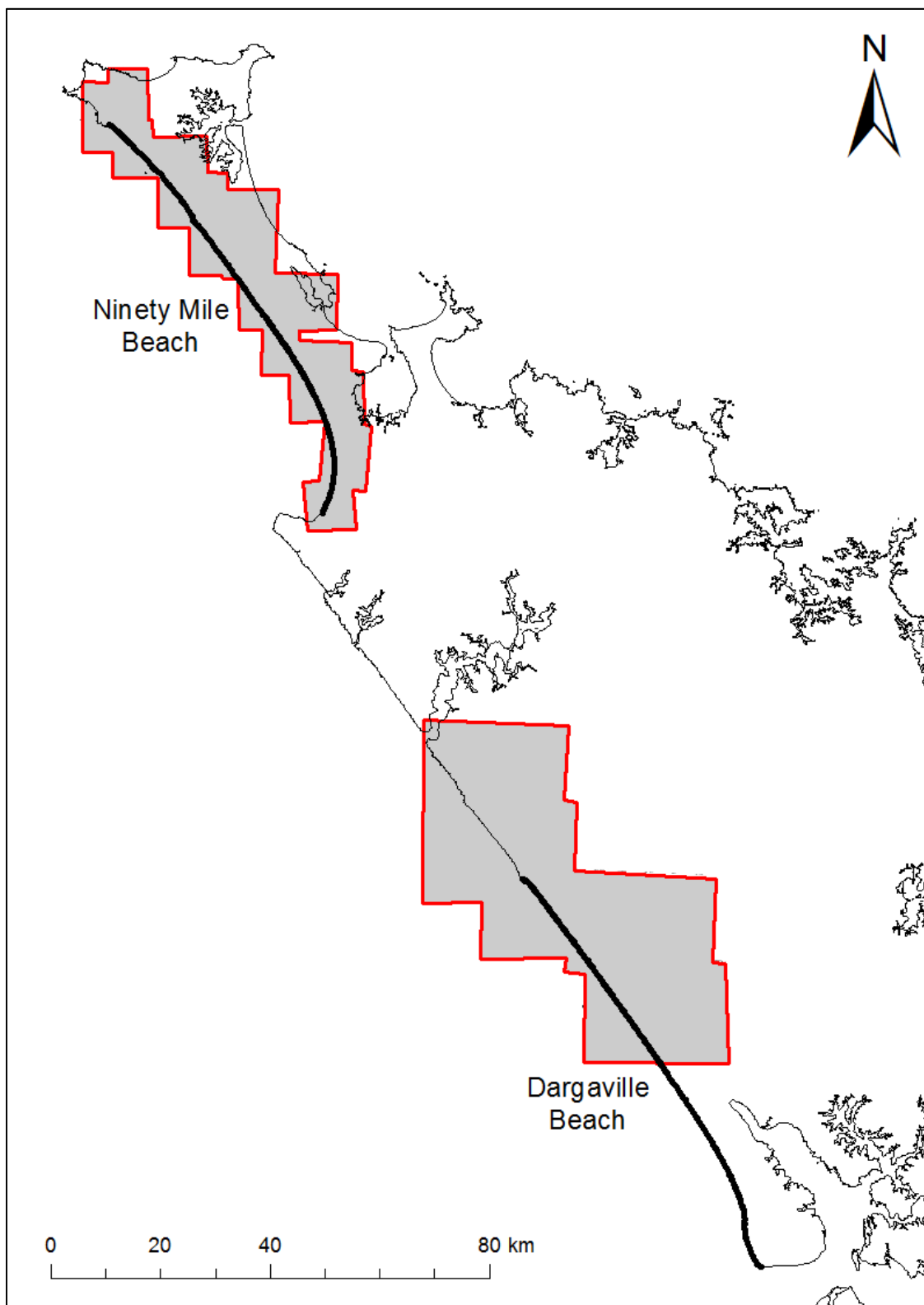
The number of juveniles (less than 40 mm shell length) in the population would have been underestimated in surveys before 1990 as these surveys did not sieve the quadrats. There is also anecdotal evidence to suggest that not all transects were surveyed up to the high water mark, but were assumed to contain no toheroa and were simply allocated zero abundances (Beentjes & Gilbert 2006a). Juveniles are known to settle high on the beach, and thus, are likely to have been missed. Surveys before 1998 only estimated toheroa abundance within the high to low water beach slope surveyed (a distance of about 115 m), and were not extrapolated to take into account toheroa below mean low water or above mean high water, and therefore may have underestimated abundance. Latter surveys covered a much greater extent of the beach slope with an average transect length of 205 m (Beentjes et al. 2003). Furthermore, surveys after 1998 used a stratified random design, which can provide a more precise estimate of the toheroa population, as it focuses most sampling effort where toheroa beds are most dense (Beentjes & Gilbert 2006a).

## Appendix 6. Survey methodology for Bluecliffs Beach (1971–2005)

- 1971–1988 Annual toheroa surveys at Bluecliffs Beach (Figure 4) were conducted using transects that ran perpendicular to the beach from mean high water to mean low water. Quadrats ( $0.5 \text{ m}^2$ ) were placed at 5 m intervals along each transect and dug out with a garden fork to a depth of 30 cm. The contents of the quadrat were scattered over the beach and all visible toheroa present were counted and measured to the nearest 5 mm. Transects were spaced at approximately 321 m intervals. Prior to the 1985 survey, the area surveyed extended from 1.6 km east of Grove Burn to Hump Burn (11 km, 35 transects). In 1985 erosion of the beach structure and loss of sand prevented access to the beach west of Waikoau River, and the western end of the survey was truncated near the river (6.1 km). In 1987 the surveyed area was further truncated at the east end to start at Grove Burn (4.5–5.4 km). Surveys were conducted before the proposed open season date. If an open season was held then a post-season survey was also conducted (McKinnon & Olsen 1994, Beentjes & Gilbert 2006b).
- 1990 The methodology used was consistent with previous Bluecliffs Beach surveys except that the transect interval was changed to 330 m. An additional survey for juvenile toheroa was conducted simultaneously with the annual population survey. For every alternate transect, the top 3 cm of each  $0.5 \text{ m}^2$  quadrat from mid-tide level to the HWM, was carefully removed with a spade. All toheroa present were counted and measured to the nearest 2 mm (McKinnon & Olsen 1994).
- 1998 A two-phase stratified random design was conducted. The beach was divided into eight strata of various lengths based on previous survey results. 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 0–7 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. Transects were randomly located within each stratum. Quadrats ( $0.5 \text{ m}^2$ ) were placed at 5 m intervals along each transect and dug out with a garden fork to a depth of 30 cm. The contents of the quadrat were scattered over the beach and all visible toheroa were counted and measured to the nearest mm. In addition, two transects per stratum were used to sample juvenile toheroa (less than 40 mm shell length). The contents of each quadrat were placed in a fine mesh bag and placed in the surf to remove the sand. All toheroa present were measured to the nearest mm (Carbines & Breen 1999b).
- 1997–2001 The toheroa population was surveyed biannually, in summer and winter, along permanently marked transect lines. Transects were located in the middle of the area covered in previous surveys, and were spaced at 250 m intervals along the beach and ran perpendicular to the beach from mean high water to low water. Quadrats ( $0.5 \text{ m}^2$ ) were placed at 5 m intervals along each transect and dug out with a garden fork to a depth of 30 cm. During the summer surveys the contents of the quadrat were scattered over the beach and all toheroa present were counted and measured to the nearest millimetre. This method was consistent with previous surveys but is likely to underestimate the number of juvenile toheroa. During the winter surveys the contents of the quadrats from every second transect were sieved using a fine mesh bag to retain all juveniles larger than 7 mm shell length. In addition, the substrate type of each quadrat was categorised (Carbines 1997b, 1998, 1999, 2000, Beentjes & Carbines 2001).
- 2005 A two-phase stratified random design was used to survey 5 km of Bluecliffs Beach west of Grove Burn, using the same eight strata used in the 1998 survey. In phase 1, 3–9 transects were allocated to each stratum depending on the estimated area of the stratum and its likely toheroa density. In phase 2, an additional 0–7 transects were sampled in each stratum, the number of additional transects was calculated by maximising the reduction of variance estimates. A total of 35 transects were sampled in phase 1 and 12 transects in phase 2. Transects were randomly located within each stratum and extended from high water to low water, with a minimum distance of 20 m between transects. Quadrats ( $0.5 \text{ m}^2$ ) were placed at 5 m intervals along each transect and dug out with a spade to a depth of 30 cm. All toheroa found were measured to the nearest mm and returned to the substrate. In addition, two transects per stratum were used to sample juvenile toheroa (less than 40 mm shell length). The contents of each quadrat were placed in a trolley lined with a fine mesh metal sieve, and wheeled down to the sea where the sand was washed away. All toheroa present were measured to the nearest millimetre (Beentjes & Gilbert 2006b).



Appendix 7. Historical topographic map coverage (grey polygons with red outlines) used in analysis of changes in land use for Ninety Mile and Dargaville beaches. Solid black lines define the extent of the beaches.



## **Appendix 8. A case study on local perspectives of factors influencing toheroa in Northland**

A client report on the above case study by EAM Ltd. was prepared for NIWA as part of project TOH2007-03. A copy of the report is appended below. The citation for the report is:

Smith, S. (2009). Factors influencing the abundance of toheroa (*Paphies ventricosa*) on Northland beaches: Perspectives from the beach. EAM Ltd. Client Report EAM101 prepared for NIWA as part of Ministry for Primary Industries project TOH2007-03. 21 p. (Unpublished report held by NIWA, Auckland.)



**EAM**

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ENVIRONMENTAL  
CONSULTANTS

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**Factors influencing the abundance of Toheroa  
(*Paphies ventricosa*) on  
Northland beaches:**

*Perspectives from the beach.*

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Report to NIWA for  
MPI project TOH200703

EAM101

February 2013

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## Executive Summary

Historical qualitative and anecdotal information on Toheroa and the beaches they inhabit was gathered from people closely associated with Northland beaches. The key informant technique was used to gather the information. Informants expressed a range of views on factors that they felt influenced Toheroa abundance and variability in recruitment. It is unlikely that their views are representative of other members of the community.

A thematic analysis was carried out to group the range of factors that they felt influenced Toheroa abundance and variability in recruitment. This analysis identified six themes:

- Deleterious effects of vehicles
- Negative features of the customary permit system
- The loss of a stewardship ethic among Māori
- Adverse effects from land use and land use practices
- The adverse effects of cyclical weather patterns
- Negative effects from the preferential harvest of large Toheroa

It was suggested that natural processes have had the largest influence on mortality and variability in recruitment, however, the cumulative effects of anthropogenic influences likely severely limit the ability of Toheroa populations to recover following large scale natural mortality events or periods of poor recruitment. Informants also outlined measures aimed to restore Toheroa populations; including increased enhancement, better informed permit issuers and the creation of harvesting free and vehicle free reserves.

# 1. Introduction

## 1.1 Background

Expansive open coast sandy beaches are a highly turbulent and dynamic environment for infaunal inhabitants. Multiple physical, biological and anthropogenic influences result in populations with a mosaic of distribution in both space and time. In these harsh environments the New Zealand surf clam, Toheroa (*Paphies ventricosa*) can be found, and on particular beaches, such as Northlands west coast beaches, they can dominate the infaunal biomass.

The large flesh size and tendency for individuals to aggregate into 'beds' that occur around the mid tide level make Toheroa an attractive species to collect for food. Historically Toheroa have been a highly valuable resource among commercial, recreational and customary harvesters. The first Toheroa processing and canning factories appeared on the major Toheroa producing beaches in the late 1800's and at their peak in 1940, 77 tonnes were taken from the two major beaches in Northland (Stace 1991). For local Māori, Toheroa were not just food but taonga (treasures), linked to people through whakapapa (genealogy) and given the same respect as the family, or tribal entity, and engendering a fierce ethic of stewardship, or kaitiakitanga. For Pakeha New Zealanders, Toheroa retains a unique status as a national delicacy, along with pavlova and whitebait fritters, with the picking of Toheroa enjoyed as a national pastime.

Unfortunately the characteristics that make Toheroa an easy target for collection renders them prone to over harvesting. Coupled with seemingly inherent extreme inter-annual recruitment variability, large scale harvesting led to an increasingly scarce resource. Over a sustained period of time Toheroa populations declined, such that by 1970 commercial harvesting had virtually ceased. Towards the late 1970's the first of the year round closures of Toheroa stocks to recreational harvest were introduced on Northern beaches. Eventually these closures were in place nationwide, and continue to this day. At present customary fishers are the sole group permitted to harvest Toheroa, and to harvest the fisher must be in possession of a customary permit issued by a nominated representative of a marae, hapu or iwi organisation.

Despite the bans on recreational and commercial harvesting and the customary permit system Toheroa populations continue to exhibit high variability. Traditionally, Northland's west coast beaches supported some of the country's largest populations

of Toheroa, and as recent as 1999, on Ripiro<sup>1</sup> Beach, the highest abundance estimate ever recorded for this beach was made, with 113 million (SE<sup>2</sup> 33 million) individuals of all sizes and 3.3 million (SE 480 thousand) individuals equal to or greater than the previous legal size ( $\geq 75\text{mm}$ ) (Akroyd 2002). However, in the follow up survey of Ripiro Beach in 2006/07 the population was estimated to be between 24 million and 58 million of all sizes (c.v.<sup>3</sup> 26.8% and 59% respectively) with only around 174 thousand (c.v. 20%) individuals equal to or greater than the previous legal size (Akroyd 2008). The average 64% decrease in total numbers and 95% decrease in numbers of Toheroa above the previous legal size illustrate the continuing extreme fluctuations in abundance.

Although the population surveys indicate that Toheroa populations are highly variable, there is little information provided in these surveys on reasons why. Anecdotal information can provide context to the 'snapshots' of Toheroa abundance given by population surveys, and can offer insights into the mechanics of a system. In the case of Ripiro Beach, anecdotal information supplied during interviews described how prior to 1999 a group of Kaitiaki undertook an extensive program of enhancement through translocation of mature individuals into areas along the length of the beach that were scarce of Toheroa. However between 1999 and 2007, the translocation programme by Kaitiaki was largely curtailed. Although the cessation of enhancement may not have been singularly responsible for the decline borne out in the 2006/07 survey the information provides an interesting context to the survey results. Thus an important part of the research to better understand the sources of variability among Toheroa populations is the review of historical qualitative and anecdotal information.

## 1.2 Rationale

There is increasing recognition of the value of historical qualitative, and anecdotal information to provide further information, insights and context to quantitative studies (Ervin 2005). Consideration of this information alongside quantitative data can greatly assist in the development of 'Best of the Best' management plans and strategies and allows local communities the opportunity to participate in resource management. Therefore anecdotal information, and related traditional environmental

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<sup>1</sup>Ripiro Beach has previously been referred to as North Kaipara Beach, Dargaville Beach and Ocean Beach.

<sup>2</sup> s.e. = Standard Error a measure of the reliability of an estimate or the dispersion of a dataset. The smaller the s.e. the more reliable the estimate.

<sup>3</sup> c.v. = Coefficient of Variation is another measure of the reliability of an estimate, but differs to the s.e. in that the c.v. is a dimensionless value.



knowledge is used in the present study to investigate sources of mortality among Toheroa and the factors affecting the recruitment of Toheroa.

### **1.3 This study**

The key informant technique was used to gather historical qualitative and anecdotal information about Northland Toheroa and to gain perspectives on potential factors that influence Toheroa population dynamics. The study aims to describe these influencing factors and how they relate to one another, and to report on the visions of people who are closely associated with the beaches on how best to address problems facing the sustainable harvest of Toheroa.

## **2. Methodology**

### **2.1 Study Area**

The expansive Northland west coast beaches; Ninety Mile Beach and Ripiro Beach are regarded as two of the country's principal Toheroa producing beaches. These beaches together with a less well known beach that support Toheroa, Mitimiti, were the focus of this study (Figure 1). The morphology of these beaches are classified as intermediate dissipative beach types, and are characterised by a high energy wave climate of plunging and spilling breakers, mobile fine grained well sorted sediments (<0.25mm) with a relatively flat swash dominated beach slope (*pers obs*). Common elements in the alongshore topography include rhythmic series' of cusps and welded bars, while rip currents and circulation cells are often well developed in the nearshore. Among the study beaches Ripiro Beach has traditionally supported the largest population of Toheroa followed by 90 Mile Beach and lastly Mitimiti. Also included in the study was a beach on the Northland east coast, Tokerau Beach, as several historical anecdotal accounts suggested that this beach had in the past supported a population of Toheroa.

### **2.2 Key Informant Technique**

The key informant technique is an ethnographic research method which allows high quality data to be collected in a limited period of time. Key informants are characterised by the following attributes (as described by Marc-Adelard Tremblay in (Burgess 1989)):

*Role in community.* Their formal role should expose them to the kind of information being sought by the researcher.

*Knowledge.* In addition to having access to the information desired, the informant should have absorbed the information meaningfully.

*Willingness.* The informant should be willing to communicate their knowledge to the interviewer and to cooperate as fully as possible.

*Communicability.* They should be able to communicate their knowledge in a manner that is intelligible to the interviewer.

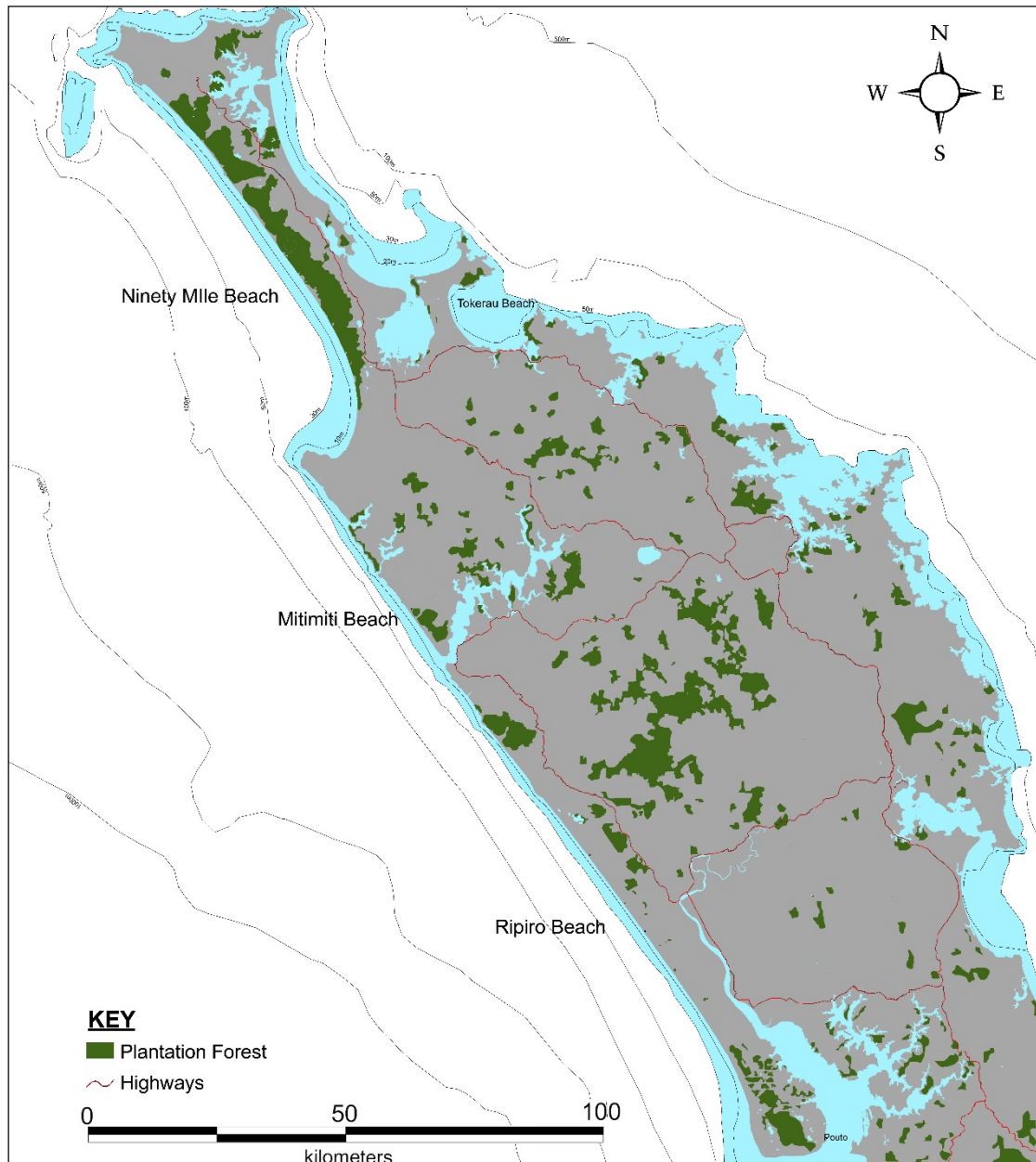
*Impartiality.* Key informants should be objective and unbiased. Any relevant biases should be known to the interviewer.

There are however a number of potential weaknesses of the technique including errors in identifying key informants, i.e. an *informer* is chosen rather than an *informant*. An *informer* is described as being more likely biased or to have their own agenda. Another potential weakness is that informants are unlikely to represent the majority view of individuals in their community, while differences in status between informant and researcher can result in uncomfortable interaction. Additionally, in this study, without proper attention to the cultural aspects of information provided by Maori, there was the potential for information to be withheld.

Potential key informants were identified by the author after talking to iwi and hapu organisations, kaitiaki and community groups. Informants were then chosen on the basis of their ability to fulfil the selection criteria as described above. Individuals from a range of iwi organisations, marae, conservation groups and educational institutes were selected. Subjects were telephoned to invite their participation in the study and to arrange a convenient time and place for a meeting and interview. The duration of the interviews was between 30 and 50 minutes and they were conducted by the author, face-to-face. A questionnaire was developed based on a review of scientific and grey literature and was used to guide the interview and provide consistency among interviews. The participants were free to deviate from it and the interviewer intervened only to clarify issues or introduce a new theme. The interviews were audio-taped and transcribed by the author. In total there were 18 informants interviewed, over a period of 5 days, comprising 10 males and 8 females, 16 Maori and 2 Pakeha and ranging in age from 32 to 88 years old, with an average age of 62 years.

Data from the transcripts were analysed thematically, i.e. patterns and themes were identified from the informants' stories and grouped under thematic headings. Within each theme a number of factors were identified that potentially influence Toheroa

mortality and recruitment. The relationship between factors within themes, and how the different themes interconnect, forms the basis of the discussion section of this document.



**Figure 1:** Location of Northland beaches that the interview data from this study relates to (Plantation Forestry data: MAF 2008).

### 3. Results

The results focus upon describing the broad range of views obtained and not upon average or representative opinions. The key informants fitted most of the attributes of an 'ideal' key informant, consequently they all had a formal role, either as an

individual or as part of a group, which exposed them to information about Toheroa and the beaches on which they reside, and they were all willing to co-operate and communicate.

The thematic analysis identified six key themes that reflect the myriad of factors that the informants felt affected Toheroa, including (in no particular order):

1. Deleterious effects of vehicles
2. Negative features of the customary permit system
3. The loss of a stewardship ethic among Māori
4. Adverse effects from land use and land use practices
5. The adverse effects of cyclical weather patterns
6. Negative effects from the preferential harvest of large Toheroa

As part of the interviews key informants were also asked about how they would best address the issues facing Toheroa sustainability; these visions are also presented.

### **3.1 Deleterious effects of vehicles**

In general people were very concerned about the deleterious effects of vehicles on Toheroa. There were a number of vehicle impacts identified, from acute to sub-lethal effects. One such acute impact was said to be the crushing of juvenile Toheroa and spat when vehicles drove in the soft upper intertidal sand, where these size classes aggregate following settlement. This practice was said to have become a more common occurrence with the increase in the size of the 4WD and SUV fleet and the ability for these vehicles to travel along the beach at virtually any time of the day, irrespective of the tidal height.

Another common element brought up by nearly all people (15 of 18 key informants) was the use of these vehicles to traverse the dune systems backing the beaches and the direct impact this activity has on the dune plants, particularly Pīngao (*Desmoschoenus spiralis*). For Māori there is a whakapapa (genealogical) relationship between Toheroa and Pīngao, i.e. they are intrinsically connected, with the health and well being of Pīngao interconnected with the health and well being of Toheroa. Hence from a Māori perspective the degradation of dune plants has a direct consequence on the viability of sustaining a healthy Toheroa population.

In terms of direct effects from vehicles driving along the mid tide region and over adult beds, it was suggested that the vibrations of the vehicles were a source of sub-lethal stress. It was said that Toheroa also suffered from heat stress during hot days as a consequence of being floated upwards toward the surface of the beach following vehicles passing over the top of a bed. It is thought that the mechanism by which this occurs is a combination of the behavioural response of Toheroa to the passing vibrations of the vehicle and the thixotropic effect (Redfearn 1974). It was also suggested by one informant that the tourist buses that travel up and down Ninety Mile Beach were a particularly important stressor because of the high speeds they travel at and their large size which was suggested to increase vibrations within beds. One informant showed a considerable appreciation of the mechanics of the process:

“That [driving over beds] does bring the Toheroa to the surface and that’s when you get that pancaking. They squirt their water out and they haven’t got the ability to get down because they rely on pumping the water down to blow his foot up so they can pull the shell over. So they got to sit there until the next lot of water comes in from the tide, and that makes them vulnerable to the heat. They let the water out when you drive over them and can’t get back down because he can’t pump his foot back up, because he’s got no water left in him.”

Aside from the direct impact that vehicles can have on Toheroa, several informants noted how improved vehicle accesses to the beach, and increased numbers of 4WD’s had indirectly impacted Toheroa. The suggestion was that the improvements in access and increased abundance of vehicles with off road capabilities allowed more people onto the beach than in the past, increasing the potential for direct impacts but also making it easier for people to find and dig for Toheroa, legally or otherwise:

“It wasn’t until the late 50’s that tourists started using the beach, because before that they would always get stuck. They didn’t know where the holes were. Now the creek is like concrete, it’s hard as, the buses did that.”

There was a sense of disempowerment from some informants that nothing could be done to stop vehicles from using the beach and generally informants lamented the increase in traffic on the beach, and the effect this has had not only on Toheroa but on the use and respect for the beach environment as a whole:

“There are more vehicles on the beach now than ever in the past, more hoons doing wheelies. Old people were more practical in their use of the beach, which has not continued with the current generation.”

### **3.2 Negative features of the customary permit system**

Some of the strongest opinions on influencing factors were expressed in regard to the efficacy of the current permit system to manage the customary harvest of Toheroa. Almost all informants, and particularly those informants that came from backgrounds of resource management within iwi and hapu organisations, held a strong view that in its present form the permit system does not promote sustainable customary harvest. They felt that in many cases people who were issuing permits had no right to issue them in the first place, had little knowledge of the current status of the resource or little regard for the sustainability of the resource:

“I’ve seen permits on the coast, gather, take as much as you can, bins full. I’ve seen another one 5000. I’ve seen one and the permit was issued from Turangi...that’s where the people have got mixed up. They are calling permit issuers Kaitiaki and they’re not”

It was also felt that part of the problem was that resolutions from iwi organisations that aimed to protect the Toheroa resource, for example by placing a rāhui (restriction) on harvesting, did not necessarily preclude constituent marae from continuing to issue permits for customary harvest, and applying for new permit books from the Ministry of Fisheries (MFish) now the Ministry for Primary Industries (MPI). The suggestion was that the autonomous nature of marae and continuing development of Kaimoana Customary Fishing Regulations by iwi organisations in some areas provides an opportunity for individual marae to determine themselves how best to deal with customary harvest, with Regulation 27a of the Fisheries (Amateur Fishing) Regulations 1986 used to legally authorise harvest:

“When the permit issuer runs out of permits he just gets another book. He’s the designated one from that marae. It’s got nothing to do with the iwi, it’s the marae committee...So if one marae decides no, they’re not going to go with them [the iwi]...they can still do their own thing”

Another aspect of the permit system that was mentioned by some informants as being deficient was the general lack of information written on the permits by the issuer, such as where to collect from and an allowable size range. The feeling was that many permit issuers did not have sufficient information on the current

status of the beds in terms of abundance or size structure to be able to direct people where to pick their Toheroa from and what size to take. People were therefore concentrating their harvesting efforts on certain well known beds, and targeting the largest individuals to get more meat for their efforts. It was suggested that not only did this behaviour result in a major decline in numbers of individuals that contribute the most to reproduction but large numbers of smaller shellfish also being subjected to predation from Black Backed Gulls (*Larus dominicanus*) or being crushed by vehicles after being left on the beach surface following excavation and not taken as part of the harvest:

“The biggest effect on the Toheroa at this stage, right now, is the people going out to dig their permit, digging and leaving the little stuff on the top for the gulls to eat. They not only taking today's big Toheroa but they taking tomorrow's as well by letting the birds eat them”

Poor enforcement coverage of the beaches within the last 10 years by MFish was cited by many informants as a reason why they felt the permit system was open to abuse. There was also little feedback from MFish on the compliance of permit conditions, levels of customary harvest and the incidence of poaching. To fulfil in part the statutory obligations of the Fisheries Act 1996, the Ministry has a duty to ensure sustainability of the Toheroa resource, and as such the amount of fisheries resources permitted to be taken by customary harvesters must be reported back to the Ministry annually. One informant who was involved in resource management for an iwi organisation said that information in relation to Toheroa harvested under Regulation 27a was not being reported back to the Ministry and therefore no reliable estimates on the amount of Toheroa harvested over the past few years were available to guide management decisions.

On one beach it was acknowledged that people regularly came to collect Toheroa as a customary harvest without having a permit which the informant felt was acceptable considering Toheroa are a traditional food. However there was also an acknowledgement of poaching:

“People come to take them alright, but only enough for a feed. You never get anybody taking them by the bucket, or if they did it would be to sell them by the side of the road”

Although not connected to the issues surrounding the customary permit system, it is worth mentioning here that some informants, especially those actively involved in

kaitiakitanga of the beach, felt there were significant barriers to the acquisition of special permits to carry out traditional enhancement. There is some evidence to suggest that traditional enhancement is successful in bolstering populations in areas previously scarce of Toheroa (Akroyd 2002a). The enhancement involves translocation of mature individuals and requires a Ministry special permit to disturb and convey the shellfish. Aside from the informants saying the process to acquire a permit was financially expensive and bureaucratic, it left them feeling beholden to the Ministry for a job that they did voluntarily, and had always done for the benefit of all.

### **3.3 The loss of a stewardship ethic among Māori**

A disregard or ignorance of the concept that whakapapa plays in kaitiakitanga by sectors of the Māori community was cited as a contributing factor to the continued fluctuation in Toheroa numbers. According to Māori the whakapapa relationship that people share with Toheroa is ultimately based on the kinship relationship between Rangī and Papa (sky father and earth mother) and their seventy odd children, two of which are Tangaroa, god of the sea and all within, and Tūmatauenga, god of war and god of man. The whakapapa relationship creates a responsibility and empathy to a kin entity rather than a resource base. Some informants felt that over time there has been an erosion of the regard for this relationship and effectively the complementary elements of tapu (sacredness) and noa (free from tapu) among sectors of the Māori community so that people these days for example do not respect rāhui, and the ethic of kaitiakitanga and the responsibilities that go hand in hand with using the resources of the beach.

This erosion of kaitiakitanga was felt by one informant to have manifested itself in an altered concept of manakitanga (the act of giving mana (utmost respect) to another through the expression of hospitality and generosity):

“If it’s [Toheroa] seen as an aspect of the mana, reputation, of the people, which it was in our grandparents time, people would come here and they would be given a kai of Toheroa...as they wouldn’t be able to get it. Two things would happen, one; we’d know how to get it and two; we’d know how to provide it to our visitors. That’s the key to it [sustainability], it’s seen as part of who we are. So if that’s the case our mana used to be to put it on the table for the visitors, so actually we have to change our perspective of our mana being not just able to provide it willy nilly but also to ensure that it is able to be provided, which is actually less about taking it and more about conserving, preserving it”



Some of the Māori Informants said the main purpose of a visit to the beach was to collect something, generally seafood, and that it was a waste of time to go to the beach and come back with nothing, resulting in a person losing face. It was suggested that this need to come back with something meant that the Toheroa resource would, in some sectors, continue to be harvested with or without a permit.

### **3.4 Adverse effects from land use and land use practices**

There was some concern (5 of 18 key informants) expressed about adverse effects on Toheroa as a result of agricultural pollution and certain types of land use in areas adjacent to beaches. It was suggested that agricultural pollution could have direct, immediate and lasting effects on Toheroa while certain types of land use had more of an indirect and longer term effect.

One event was described by an informant where agricultural chemicals were stockpiled on the beach to await loading into a top dressing plane for spreading over farm paddocks adjacent to the beach:

“Next big event we had of losing Toheroa would have been in the early 70’s late 60’s when they used the Dieldrin Super for killing the black beetles. They were top dressing the paddocks at the top of the cliffs and they just came along with a truck and tipped it onto the beach and loaded it into the plane. That killed the Toheroa, everything from little ones to big ones, the whole food chain, for about 10km of beach and they’ve never come back. Since then none of our enhancement has ever worked in that area”

Some informants felt that because Toheroa tend to aggregate around the freshwater streams and seeps that run out onto the Northland beaches Toheroa are particularly susceptible to any contaminants entering these streams as runoff:

“The 1994 decline came with the introduction of the spraying of Escort. I actually went to the Environmental Court over the spraying of Escort into the drains by the Council and we actually won, we stopped it. But it didn’t stop individual farmers from doing it”

It is thought Toheroa prefer the damp, wet areas of the beach and particularly around freshwater streams and seeps because they remain cool during the hot days of summer, when the beds can be uncovered for long periods. In these areas once the tide recedes Toheroa quickly withdraw their siphons and effectively close themselves off from this environment until the tide returns. The suggestion from one informant

was that agricultural pollution entering waterways, including the Northern Wairoa River and the discharges along the beach, has a negative effect on Toheroa because of the effects on the plankton species upon which they feed:

“1992 we had a huge mortality; it was the algae bloom affected it. We had huge spatfalls after it but we also had a big exodus of shellfish to deep water, Toheroa that is.”

Within Northland large areas of land adjacent to beaches that support Toheroa have extensive plantation forests (Figure 1). Some of these forests are now into the second or third rotation. Many informants suggested that the planting of large tracts of pine forest in these areas has decreased the prevalence or flow of the freshwater streams and seeps that run out onto the beaches, indirectly affecting Toheroa because of the perceived reduction in habitat. They also noted that when tracts of the forests were harvested the flows of the streams increased and the beach had more seeps but the water quality was highly degraded:

“There’s a drain behind my daughter’s house and the water in there is draining off the hills and it’s rotten, black, stinking. It was ok when the trees were there but now they’ve been taken out. It must have some effect, the runoff”

Also noted was the effect of the forestry on the movement of sand, with the trees providing an effective barrier to the inland transport of sand. One informant said that dune systems had increased in size in areas planted out with pines, and that the North Kaipara Head coastline had effectively grown out into the sea by more than 4km in his lifetime. The suggestion from one informant was that Toheroa beds were being displaced by sand dunes.

### **3.5 The adverse effects of cyclical weather patterns**

There was an acknowledgement among some informants (4 of 18 informants) of the existence of cyclical weather patterns, and that they periodically result in mass mortality events. The annually occurring weather patterns were quite well documented and were said to be fairly predictable in their timing and effects on Toheroa:

“If you get an easterly wind, which are particularly common during February, and occasionally in December, where you might get up to a week of easterlies, it’s so calm. As the tide goes out and the water goes off the Toheroa the sun is on the sand heating it up for 2 to 3 hours, cooking the Toheroa, and because it’s so calm when

the tide comes in it doesn't come up very far I've seen it here with a big bed of Toheroa that after 2-3 days of hot, easterly weather all the shells were shot, all dead"

Some informants also suggested these hot easterly weather patterns promoted an increase in the incidence of harmful algae blooms which were felt to be detrimental to Toheroa:

"The algae bloom did affect our Toheroa in a big way as well. It brought them to the surface making them vulnerable to predation from the Black Backed Gulls and Oyster Catchers. That was our last big mortality, in 1998. The Oyster Catchers would only eat half the Toheroa leaving half in the sand, all the rest were stinking and rotten and I've been taught that one dead shellfish in the bed the rest will have to shift or they'll all die"

Interestingly, two informants described how following two separate mass mortality events on different beaches a large spatfall event occurred soon after, prompting the observation that "they were trying to protect the species". However, one of the informants noted:

"This is the worst I've ever seen it, we've gone through cycles before but it always comes back hard, but now its just slowly getting lesser and lesser all the time"

Informants were understandably less aware of any longer term weather patterns; however one informant described how the La Nina weather pattern was identified and the effect on the beach:

"I've seen the cycles, about 10-12 year cycles. And you pick it up on things that are quite gruesome. When somebody drowns here for years and years all the bodies would go north and all of a sudden we'd start to get some going south. That's the La Nina; it creates great big high banks offshore with the channels beside them. The offshore currents and eddies change direction, the whole tidal profile of the beach changes"

Although the effects from longer term weather patterns, such as the El Nino/La Nina oscillation, were not elucidated by informants it was felt that these processes did have a significant influence on Toheroa population dynamics.

### **3.6 Negative effects from the preferential harvest of large Toheroa**

The setting of a minimum legal size for Toheroa in the late 1940's was seen by some informants as an incentive to target larger individuals:

“In those days there was no season for a start and the seasons only started in about 1945-46 and then it was 50 per person. But then they brought the regulation in that they be over 3 inches [7.62cm], so everybody, once the amount you could take came down, they took the biggest they could get to get the most meat they could get”

It was felt that this practice of targeting the largest shellfish reduced the overall magnitude and quality of the reproductive effort, resulting in fewer spat and subsequently fewer new recruits into the fishery:

“When we last finished digging Toheroa [commercially] the most Toheroa where still in the commercial area where we dug because the small Toheroa that come out went back into the bed where we dug, the middle size Toheroa we took in cans and the big Toheroa we took to the bottom end of our beds where we resowed them. We never took a Toheroa over 4 inches...the scientists told us that they did lay a better egg”

A simple solution to the problem of targeting the largest Toheroa was suggested by the key informants. Specifying a maximum size as well as a minimum size on customary permits was felt to be important, with a size range between 73-98mm suggested by one informant as an appropriate range for harvest. It was also felt that communication between scientists, permit issuers and Kaitiaki to facilitate education of harvesters was a priority.

“In all fisheries...if there's a minimum size to take there should also be a maximum size...because they're taking the breeding stock out. You shouldn't be just allowed to take that minimum [size] and I think that needs to come into legislation. Education is the key, you can put it into law but you've still got to educate people to do it”

### **3.7 Visions for the future**

Only one informant stated a clear vision for the future, suggesting that the focus of any restoration process be on enhancement activities and better equipped Kaitiaki. As well as enhancement through translocation it was suggested that enhancement

would also occur by reseeding hatchery reared juveniles. It was suggested that Kaitiaki would be educated in both the scientific knowledge and mātāuranga Māori (traditional knowledge) of Toheroa. The Kaitiaki role would be full time, and tasked with coordinating the enhancement program, including identifying areas of beach suitable for translocating and reseeding, assessing the status of existing beds, and liaison with government agencies to develop better environmental outcomes for the beach ecosystem. In terms of better managing the customary harvest the Ministry would have to check whether marae have authority from iwi to issue permits within an area before giving out permit books and permit issuers would have to consult with Kaitiaki as to where the shellfish should be collected from and the size range to collect.

Other measures suggested by informants to improve the current position of Toheroa included; setting aside reserve areas free of traffic and harvesting, better targeted rāhui, and improving the communication between Marae and iwi on resource management issues.

## **4. Discussion**

The highly turbulent, physically dominated environment of Northland's open coast sandy beaches represents a high stress habitat for Toheroa. Identification of processes that shape the distribution and abundance of these shellfish is difficult due to the intermingling of physical, biological and anthropogenic influences. The results of this study indicate a number of potential factors that individually may be relatively minor in their effects but combined may have large and long lasting effects. Six themes were identified from interviews with key informants that were representative of the range of views expressed on factors that influence the abundance of Toheroa including;

1. Deleterious effects of vehicles
2. Negative features of the customary permit system
3. The loss of a stewardship ethic among Māori
4. Adverse effects from land use and land use practices
5. The adverse effects of cyclical weather patterns
6. Negative effects from the preferential harvest of large Toheroa

The effects from vehicles were in general felt to be worsening, as more people ventured out onto the beaches with 4WD capable vehicles that provided access to all areas of the beach including dune systems at virtually any tidal height. Although vehicles were felt to have an impact on Toheroa by crushing them or floating them toward the surface of the beach for exposure to either predation from birds, or heat or to simply signify their whereabouts to would be collectors, vehicles on beaches can also be responsible for bringing people to the beach with little respect for the environment and/or the responsibilities that go along with using the resources of the beach.

The perception of a decline in respect for the beach environment is reflected in the feeling that the concepts of tapu and noa, and consequently kaitiakitanga and manakitanga have also declined over time. It is highly unlikely that these perceptions result in the mortality or predation of large numbers of Toheroa. However when combined with a permit system based on the concept of kaitiakitanga that is felt to be lacking, where permits are issued for large numbers of shellfish, and the largest, most fecund individuals are targeted it is highly likely that the present variability among Toheroa populations will continue. Moreover perceived barriers to enhancement activities by Kaitiaki, lack of compliance on the beaches to protect either newly established, or existing beds and paucity of data on the level of customary harvest does little to foster kaitiakitanga among those attempting to actively promote the growth of Toheroa populations.

Possibly the largest potential for mortality among Toheroa populations and subsequent variability in recruitment comes from the influences that stem from habitat loss, or degradation of habitat, pollution of nearshore coastal waters, predation, and adverse weather or oceanographic conditions at critical periods of the life cycle, such as during spawning and spatfall. Aside from the effects from land use and land use practices; predation, weather and oceanographic influences are natural processes that are an inherent part of the beach environment. With attention given to addressing the anthropogenic effects and inadequacies of current systems, and adoption of some of the measures outlined by informants it is hoped that populations will be sufficiently buffered to allow for strong recruitment recovery following large natural scale mortality events.

## 5. Conclusions

Key informants expressed a range of views on factors that they felt influence Toheroa. It is unlikely that their views are representative of other members of the community.

A thematic analysis carried out to group the range of factors expressed identified six themes:

1. Deleterious effects of vehicles
2. Negative features of the customary permit system
3. The loss of a stewardship ethic among Māori
4. Adverse effects from land use and land use practices
5. The adverse effects of cyclical weather patterns
6. Negative effects from the preferential harvest of large Toheroa

Natural processes are likely to account for the highest level of mortality and variability in recruitment. Just one informant had a comprehensive vision for the future restoration of Toheroa populations; including increased enhancement, better informed permit issuers, creation of harvesting free and vehicle free reserves.

## 6. References

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