Manaaki
Taha Moana

# Factors Affecting Populations of Toheroa

## *(PAPHIES VENTRICOSA)*: A LITERATURE REVIEW

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# FACTORS AFFECTING POPULATIONS OF TOHEROA (*PAPHIES VENTRICOSA*): A LITERATURE REVIEW

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## Mihi

Te ngākau pūaroha ki ngā ōhākī
‘E kore koe e ngaro- te kākano i ruia mai i Rangiātea
Puritia! Puritia! Puritia!

E ngā atua Māori, mō ōu whakaaro whānui mā a tātou, tēnā koutou.

E ngā mana, e ngā reo, e ngā iwi o te motu, tēnā koutou.
E ngā matāwaka, whītiki! Whītiki! Whītiki!
Te hunga ora ki te hunga ora, te hunga mate ki te hunga mate.

E kui mā, e koro mā, e whakawhānuitia te kaupapa nei, tēnā koutou

E nga kaitiaki hei whakamarohi i te Toheroa,
Kia koutou kua ū mai nei ki tēnei mahi nui, ki te atawhai, ki te manaaki i ngā taonga i tukua mai e ngā tūpuna o te takiwā nei, tēnā koutou.

E whaea mā, e matua mā, e ngā whānaunga katoa, e hoa mā, e kohikohi ana, e mahi tonu ana me te kaupapa nui mō Te Taiao.

Ko te tūmanako kia whakawhānuitia i ōu mātou tirohanga i roto i te whakatakotoranga kaupapa nei.

Nō reira, tēnā koutou, tēnā koutou, tēnā koutou katoa.

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# EXECUTIVE SUMMARY

Data on toheroa populations in New Zealand are available as far back as the early 1920s. Since that time, fluctuations in populations have been significant. Previous research indicates there is no single causative factor responsible for the fluctuations, and that changes in abundance and/or distribution have most likely resulted from the cumulative effects of a range of factors. The importance of different factors may vary across different coastal regions.

The review highlights that there is insufficient understanding of the biological requirements of the toheroa, which is required to successfully restore populations. In addition, the various factors that have been identified as possibly impacting toheroa populations have not been correlated with the various beach habitats in which they are found. Future work is required to identify suitable habitat conditions and physiological requirements for toheroa. Improving this understanding of the relationship between habitat characteristics and populations, both historically and present day, will significantly enhance the possibility and prospects of restoring toheroa numbers.

This report identifies a possible approach to surveying toheroa populations and the characteristics of their habitat, and another approach aimed at understanding distributions of a species of burrowing shrimp (*Biffarius filholi*) that local kaitiaki have reported as having expanded into areas previously occupied by toheroa. Based on discussions and observations during a field visit in November 2011, a study to investigate the expansion of colonies of *B. filholi* is recommended at this stage. A study of toheroa populations remains a possibility for subsequent investigation.

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# GLOSSARY

| Term | Definition |
|---|---|
| DoC | Department of Conservation |
| GIS | Geographical Information System |
| GPS | Global Positioning System |
| hapū | subtribe |
| iwi | tribe |
| MAF | Ministry of Agriculture and Forestry |
| MFish | Ministry of Fisheries |
| mātauranga Māori | A term for a body of knowledge that was first brought to Aotearoa by Polynesian ancestors of present day Māori. |
| pakiwaitara | Local narrative |
| tāngata whenua | people of the land |
| taonga | treasure |
| tūpuna | ancestor |

# 1. INTRODUCTION

## 1.1. Background to the Manaaki Taha Moana (MTM) project

This study is part of the research programme "Enhancing Coastal Ecosystems for Iwi: Manaaki Taha Moana" (MAUX0907), funded by the Ministry for Science and Innovation (previously known as the Foundation for Research Science and Technology, and the Ministry of Research, Science and Technology). Manaaki Taha Moana (MTM) is a six-year programme, running from October 2009 to September 2015, with research being conducted primarily in two areas: Tauranga moana and the Horowhenua coast.

Professor Murray Patterson of Massey University is the Science Leader of MTM, which involves a number of different organisations: Waka Taiao Ltd with support of Manaaki Taiao Trust in the Tauranga moana case study; Te Reo a Taiao Ngāti Raukawa Environmental Resource Unit (Taiao Raukawa) and Dr Huhana Smith in the Horowhenua coast case study; WakaDigital Ltd; Cawthron Institute; and Massey University.

The programme utilises both western science and mātauranga Māori knowledge to assist iwi and hapū to evaluate and define preferred options for enhancing/restoring coastal ecosystems. Action plans will be produced for improving coastal ecosystems in each rohe.

The research team works closely with iwi and hapū in the case study regions to develop tools and approaches to facilitate the uptake of this knowledge and its practical implementation. Mechanisms will also be put in place to facilitate uptake amongst other iwi throughout New Zealand. The key features of this research are that it is: cross-cultural, interdisciplinary, applied/problem solving, technologically innovative, and integrates the ecological, environmental, cultural and social factors associated with coastal restoration.

The MTM programme website (http://www.mtm.ac.nz) has more information about this research programme.

## 1.2. Surf clams in New Zealand

Discussions with local elders and kaitiaki along the Horowhenua coast have identified that reduced populations of surf clams are of major concern.

There are many surf clam species in New Zealand. The common types include trough shells (seven species), wedge shells (three species), wedge clams (four species which includes two species of tuatua, the toheroa and the pipi), venus shells (12 species), sunset shells (four species) and cockles (four species).

Figure 1. Toheroa (*Paphies ventricosa*).

The toheroa is an important shellfish in New Zealand and is highly valued by Māori. In the first half of the twentieth century it was harvested commercially in large numbers. Unfortunately, because of population decline, only limited cultural harvest is currently permitted throughout New Zealand. Numerous studies have been undertaken over the past century at all the major beaches with toheroa populations. Several theories have been proposed to explain the population fluctuations, but to date there are no definitive explanations.

The purpose of this literature review is to update a previous Cawthron survey of published literature which identified factors potentially influencing toheroa populations, and to outline options for new research on the habitat for surf clams along the Horowhenua coast.

This review focuses on the toheroa (*Paphies ventricosa)* because of all the surf clam species, it appears to have the most demanding habitat requirements and it has significant cultural importance

This report describes physical aspects of the toheroa and its environment that influence the abundance of this clam. Water and shellfish quality are outside the scope of this report, and will be considered in separate studies.

Information for this report is drawn from studies of toheroa populations on the Horowhenua coast (Wellington west coast), Ninety Mile Beach, Ripiro Beach (Dargaville) and Rangatira Beach (Muriwai) (see Figure 2). Studies at Te Waewae Bay (Blue Cliffs) and Oreti Beach in Southland are also noted. The report concludes with some recommendations for field research that would assist in understanding the factors contributing to changes in toheroa populations.

### Origins of Toheroa

The New Zealand toheroa (*Paphies ventricosa)* is well established in the history of New Zealand. Four versions of its origin have been found in Maori legends (Stace 1991). The first proposes that the seeds of the dune grass Pingao are blown from the dunes to the sand and take seed on the beach to become toheroa. The second is similar, but refers to the seed of the grass Spinifex doing the same. The third version refers to the seeds being brought from Hawaiki by the High Chief Mareoa who planted them on the west coast of North island.

The final *pakiwaitara* (local narrative) involves a pursued chief and his party who uttered a karakia beseeching their Atua to save them. A whirlwind appeared and told the chief his journey would be made clear. His men found small slits in the sand on the beach shortly afterwards and they dug, but found nothing. The whirlwind returned and gave them the message "Tohe roa, tohe roa!" ("Persist a long time"), which they did and found the shellfish which fed them all.

Valuable local and historical knowledge is held by tāngata whenua, particularly the tūpuna and kaitiaki. The research team had an initial discussion with kaitiaki in November 2011; further discussion and involvement is recommended as the field work proceeds.

The Ministry of Fisheries has also commissioned research by NIWA that addresses some of the issues reviewed in this report, namely to investigate source of mortality and variable populations of toheroa. The NIWA study was due to be available in November 2011 but has yet to be released (R Ford, pers. comm.).


Figure 2. Location of the major populations of toheroa (*Paphies ventricosa*) in New Zealand.

# 2. REVIEW OF TOHEROA IN NEW ZEALAND

## 2.1. Toheroa description and distribution

Toheroa (*Paphies ventricosa*) are a large (up to 160 mm long), endemic New Zealand clam belonging to the family Mesodesmatidae, which also includes pipi (*P. australis*), tuatua (*P. subtriangulata*) and the deep water tuatua (*P. donacina*) (Cassie 1955; Hooker 1995). Toheroa are distributed around the North and South Island coasts, and are most abundant on the exposed west coast surf beaches of northern New Zealand (Redfearn 1974). On these coasts toheroa distribution is limited to exposed ocean beaches with fine, sandy substrate, sufficient moisture retained in the sand at low tide to avoid desiccation, and sufficient abundance of phytoplankton (Cassie 1955).

Known populations are intertidal (typically found between the mean high tide and mean low water levels), and usually bury themselves up to 300 mm into the sand, with exhalent and inhalant siphons extending to the surface (Figure 1) when covered by the sea (Redfearn 1974). Observations of population size/frequency distributions indicate juveniles tend to occupy the upper beach within the surf-zone with larger toheroa typically found further down the intertidal beach zone (Stace 1991; Akroyd *et al*. 1999). There is some suggestion (Waugh & Greenway 1967) that toheroa are found in the sub-littoral zone, *i.e.* well below the low water mark, but this has not been conclusively proven.

As with the majority of New Zealand marine bivalves, toheroa undergo external fertilisation (broadcast-spawning) during spring and summer. The larval planktonic phase lasts around 20 days in the water column before the spat settle onto beaches. The growth is rapid in the first year, up to 65 mm in 12 months (Stace 1991). Individuals may mature in their first year or on reaching 47 mm (Redfearn 1974). Using a method of counting shell ridges as an indication of growth rates, Cassie (1955) and Redfearn (1974) suggested that North Island toheroa take approximately 2.5 years to get to 75 mm and 4.5 years to get to 100 mm, while Southland toheroa take five years to get to 75 mm and nine years to get to 100 mm.

Spawning may occur throughout the year however there are two spawning peaks: the main spawning in August/October and a lesser spawning in February/March (Mandeno 1999). Redfearn (1974) reported spawning in December and January, and observed spat in November and December, suggesting an October spawn. Duration of the larval stage varies; Rapson (1952) estimated larvae to be in the water column for 10-12 days (Rapson 1952), while DoC (2006) suggests 20 days. The latter is considered to be more likely.

After the larval stage they metamorphose and settle in the intertidal zone. Apparently little is known regarding the early spat phase between metamorphosis and when they reach 2 mm in length. Toheroa of 2 mm in length can be carried up the beach at the wave front and quickly dig down to a depth or 1-2 cm (Redfearn 1974). The wave action and disturbance of the beach substrate influence the juveniles' ability to dig in and remain on the beach (Redfearn 1974). Redfearn (1974) goes on to state that the juveniles are probably continually washed off and back onto the beach until they establish quite high up the beach. They then appear to move down the intertidal area as they get larger.

Large fluctuations appear to be a natural feature of the toheroa population dynamics (Morrison and Parkinson 2001, Redfearn 1974), with large-scale mass mortalities and near total disappearances observed on numerous occasions (Cassie 1955; Stace 1991). Redfearn (1974 reported that even strong recruitment [1]years do not necessarily contribute to adult stocks and that established juveniles may have a mortality rate as high as 50% per year, although this figure may have been influenced by harvesting practices. The mechanisms for this erratic recruitment and high post-recruitment mortality are unknown.

Figure 3. Photo of toheroa siphons on Bluecliffs Beach, August 2002.

A number of individual toheroa were transplanted in the mid 1950s at the eastern end of Te Waewae Bay, near Monkey Island (Southland), where toheroa can still be found. Recent population surveys undertaken on Ninety Mile Beach (Northland), Ripiro Beach (Dargaville, Northland) and Rangatira Beach (Muriwai, Auckland) (Akroyd *et al*. 1999; Morrison and Parkinson 2001; Akroyd *et al.* 2002) found that toheroa are common in only a few small areas and their distribution is patchy. The survey also found that, although large numbers of toheroa were present indicating large recruitment events are possible, most toheroa were small with few of legal size for harvesting (>100 mm).

[1] Recruitment refers to juveniles surviving and maturing to a point where they are considered part of a population, *e.g.* when they can be detected in their adult form.

## 2.2. A brief history of toheroa harvesting

Toheroa supported a large commercial and recreational fishery in the early twentieth century and there is quite a lot of historical information available as stock biomass surveys were relatively common (Stace 1991). Commercial harvesting of northern beaches began in the late 1800s, and a number of canneries were operating by the early 1900s. Toheroa were canned in Northland, Wellington and Southland for brief periods at various times (Redfearn 1974).

Commercial harvesting peaked in 1940 at an estimated 77 tonnes of toheroa product from Ninety Mile and Dargaville beaches (Stace 1991).Population declines saw commercial harvesting cease in the late 1960s, while recreational harvesting was banned on Ninety Mile (in 1971), Muriwai (in 1976) and Dargaville (in 1980) beaches. The Southland beaches still support a customary fishery (McKinnon and Olsen 1994) and have been the only beaches in New Zealand able to support very limited and sporadic recreational open seasons (*e.g.* single day seasons with a five toheroa per person bag limit in 1990 and in 1993). Unfortunately contamination of the water from rivers may result in a ban on eating shellfish, so even if the shellfish could be collected, they cannot always be safely consumed.

Monitoring has indicated that adult populations have not recovered substantially since the major declines of the late 1960s, even though only limited customary harvesting has been permitted. This would suggest that the population has declined, possibly due to over-fishing, to the point where recovery may be very difficult or a very long process. The size of the illegal toheroa harvest is unknown, although in 1991 it was identified as significant (Stace 1991).

## 2.3. Area-specific population studies

It is important to note that the toheroa population numbers below are estimates with a likely degree of inaccuracy due to the following reasons:

- Inconsistency in the use of sampling methods by researchers.
- Variance in the length and area of beach sample sizes.
- Difference in the times of the year that the sampling was done, which could influence the number of juveniles collected, or cause a recruitment event to be missed.

### *2.3.1. Horowhenua (Wellington) Coast*

For the purpose of this report, the Horowhenua (Wellington) coastal area extends from the Rangitikei River in the north to the Waikanae River in the south. In some studies this region has been split into five sub-areas: Foxton, Waitarere, Hokio, Otaki and Waikanae.

Redfearn (1974) states that the Wellington coast does not have large toheroa populations compared with those north of Auckland, and that recruitment on these beaches is very irregular. As shown in Appendix 1, the toheroa population on Waitarere Beach in 1935 was estimated at 2.5 million but in 1955 it was down to just under 100,000. It slumped further to 45,760 in 1961 and then recovered in 1965 to an estimated 475,500. Over the same period the population estimates at Hokio Beach fluctuated between 311,520 and 16,720.

### 2.3.2. Northland Beaches

The Northland beaches include Ninety Mile Beach, Rangatira Beach (Muriwai) and Ripiro Beach (Dargaville). A number of researchers using a variety of methods have reported on the toheroa numbers in this area. Morrison & Parkinson (2006) state that toheroa on Rangatira Beach are found in discrete populations along 55 m-110 m stretches. These discrete stretches have kilometres of beach between them where there are no toheroa populations. Ripiro Beach, in contrast, although not densely populated by toheroa, had beds that extended for kilometres.

Of importance to these Northland beaches is the fact that toheroa were harvested in large numbers for a cannery on Ripiro Beach that operated from the 1880s (Stace 1991) until 1969 (Redfearn 1974) when stocks were deemed uneconomic. Up to 1.5 million toheroa per year were harvested for the cannery in the early 1930s (Cassie 1955, Stace 1991). Stace (1991) reported an estimated population of 30 million on Ripiro beach in 1930. Cassie (1955), using data from a number of authors, estimated the population to have fluctuated between less than 1 million and 15 million during the period 1937 to 1952. Mass mortalities were recorded on Ninety Mile Beach in 1930 (Anon 1931 and Rapson 1954) attributed to smothering by wind-blown sand and in 1932 due to high temperatures (Rapson 1954). Another mortality event in 1938 was reported over all the Northland beaches by Rapson (1954). This was reportedly due to low tides and calm weather causing heat stress and low oxygen levels. Greenway (1971) reported a major mortality event in 1970-71 but did not provide a reason for it. This highlights the variability of local populations of toheroa.

Toheroa catches were first controlled in 1932 with a closed season of two months and a minimum size of 75 mm (Redfearn 1974). In 1955 the length of the open season was reduced, and in 1967 all beaches were closed. The low abundance of toheroa since 1967 has resulted in occasional open days, but these ceased in 1980 (Akroyd 1999).

Population estimates for toheroa on Northland beaches are available in Appendix 2. There are two important trends indicated by this data:

1. There are huge variations in the populations (*e.g.* compare 1986 with 1990-93).
2. An abundance of juveniles does not correlate with a high number of adults.

The very high number of toheroa estimated by Akroyd in 1999 may be a reflection of the sampling methods used and an assumption that the population was evenly dispersed over the whole area, when this may not have been the case.

By 2006 the number of toheroa on Ninety Mile Beach was estimated at 8.8 million. This may seem like a large population, but to put this into perspective, there were an estimated 486 million tuatua on the same beach at the same time. It also suggests that the beach habitat is favourable for surf clams, but there are some factors that are limiting toheroa populations.

### 2.3.3. Southland Beaches

Surveys of the Southland toheroa stocks have been conducted on a regular basis since 1971 (McKinnon and Olsen 1994) under the management of the Ministry of Agriculture and Fisheries (MAF) and later the Ministry of Fisheries. The surveys collect data to estimate the size of adult shellfish and provide size/frequency data in order to manage open seasons.

In 1990, two new objectives were added to the monitoring programme:

1. To estimate juvenile toheroa numbers to determine recruitment.
2. To monitor harvesting pressure during a season by car counts (McKinnon and Olsen 1994).

The physical conditions at Bluecliffs Beach in Te Waewae Bay are quite different to those in other areas where toheroa are found and make direct comparisons difficult. But the same declining population trend appears to occur at this beach and recovery is partial.

### 2.3.4. Summary of area-specific population studies

- Toheroa were historically an important commercial fishery, and remain a highly valued customary species.
- Toheroa have been very abundant at times, but population numbers are highly variable, with irregular recruitment and apparently high juvenile mortality.

- Populations around New Zealand have declined since the late 1960s and have not recovered sufficiently to enable harvesting, except for very limited customary purposes.
- There is a lack of understanding of the reasons for physical movement of populations along the beach.

# 3. POTENTIAL FACTORS INFLUENCING TOHEROA POPULATIONS

This section draws extensively on an earlier report prepared for Meridian Energy (Keeley *et al.* 2002).

A wide range of factors have been proposed to explain possible fluctuations in and decline of toheroa populations over the years. Historical harvesting may still be having a significant influence on present day toheroa populations. The research suggests that toheroa populations have not recovered from this activity. This poor recovery may be influenced by a number of factors. These include aspects such as climate variability, changes in beach morphology, land use changes, changes in predator abundance, and human disturbance and extraction (*e.g.* Stace 1991). There is also the possibility that, when toheroa populations decline, beach ecology changes to the point that inter-species competition makes the re-establishment of toheroa more difficult.

## 3.1. Factors relating to climate and weather

### *3.1.1. Desiccation*

Desiccation affects toheroa, particularly in the upper regions of the intertidal zone. Toheroa habitat is limited to where the sand remains saturated at low tide, which prevents desiccation of the shellfish and facilitates oxygen transfer (Redfearn 1974, Cassie 1955). Climatological or synoptic weather events may result in the upper extent of the toheroa beds becoming uninhabitable through a reduction in sea level. This may be caused by localised changes in air pressure during storm events, coinciding with spring tides and prolonged periods of strong offshore winds. The offshore winds may blow dry sand onto the beach during neap tides, possibly smothering the toheroa (Rapson 1954). The smothering may encourage the toheroa to come closer to the surface, increasing the potential for desiccation, heat stress and predation. Unlike storm events (see below) the relationship between toheroa mortality and the frequency and extent of offshore winds does not appear to have been studied.

### *3.1.2. Storm events*

Following prolonged periods of strong onshore winds, wave action, rain and cold weather, toheroa have been observed washed up on beaches along with large numbers of other sub-littoral species (*e.g. Mactra discors*, *Resania lanceolata*) (Eggleston & Hickman 1972). Local weather events (severe storms) have been linked to mass mortalities in the North Island west coast populations, *e.g.* Ninety Mile Beach in 1938 and 1971 (Stace 1991).

### 3.1.3. Downwelling and upwelling events

Weissberger & Grassle (2003) found that surf clams in the United States (US) have greater settlement when a downwelling event follows an upwelling event.

Upwelling events on Ninety Mile Beach are known to bring in seaweed laden with mussel spat, which is utilised by the aquaculture industry. The frequency of upwelling events are variable both within and between years and may also influence beach structure and toheroa settlement and survival. This could explain variability in toheroa recruitment events, but does not account for chronic and persistent recruitment failures.

It is unknown if there are upwelling or downwelling events on the Wellington west coast, but marine charts show a complex interaction between tide, wind, waves and currents influenced by Cook Strait (Holland, 1983). These currents may play an important part in beach structure and in turn recruitment and survival of toheroa in this area.

### 3.1.4. Temperature and salinity shock

It has been postulated by Eggleston & Hickman (1972) that exposure to cold and low-salinity water, limits the ability of toheroa to counteract the scouring effects of the heavy seas by digging themselves back into beach sediment. This factor has not been substantiated but may be important. If the toheroa are close to the surface, a cold event could increase mortality, particularly amongst juveniles. Toheroa can obviously tolerate a range of temperatures given there are populations throughout New Zealand (from Northland to Southland coasts). However, there are no records of studies on the temperature tolerance of toheroa and therefore the impact of temperature is difficult to determine. Yu & Song (2009) found that acute water temperature change affects haemocytic and haemolymphatic functions, reducing immunosurveillance in stressed surf clams (*Mactra veneriformis*). This would make them more susceptible to disease and less able to overcome other stressors.

## 3.2. Availability of food

Toheroa are thought to feed on dense concentrations of phytoplankton (especially diatoms), delivered by onshore winds (Cassie 1955). The periodic supply of such food presumably relies on the right conditions for phytoplankton to bloom in combination with onshore winds and increased wave activity, which re-suspend particles and drive the phytoplankton ashore.

Land run-off can raise near-shore nutrient concentrations and therefore can enhance phytoplankton growth. However, land run-off can also carry high levels of fine sediments, which may reduce photosynthesis in near-shore phytoplankton and also increase the percentage of silt consumed by toheroa and other filter feeding shellfish, thereby reducing feeding efficiency. Different species of phytoplankton can be affected differently by these factors, possibly favouring species that are not the preferred diet of toheroa. This is speculative, however, as no studies have investigated this.

The supply of nutrients to Te Waewae Bay has probably declined as a result of the Waiau River control associated with the Manapouri Hydroelectric Power Scheme. This could potentially affect toheroa populations in Te Waewae Bay, although Robertson (1993) estimated that the reduction of nutrients would be slight.

The Manawatu River can have a significant impact on nutrients, salinity and sediment delivered to beaches on Wellington's west coast when it is at high flow (McArthur, 2010). Smaller streams and rivers may have localised impacts on food supply and other factors.

Other species may be competing for the same food resource, *e.g.*, the diatom *Chaetocerus armatus* has been shown to be the main dietary component of both toheroa and ghost shrimp (*Biffarius filholi*) (O'Shea 1986).

## 3.3. Toxic algal blooms

Toxic algae blooms have been suggested as a possible reason for some of the mass strandings of toheroa that have occurred (Cranfield 1996). The irregularity and infrequency of toxic algae blooms makes it unlikely to be a major contributing factor to the decreasing trend observed in the Bluecliffs population. Observations suggest that toxic algae blooms are becoming more frequent, although this may simply reflect the increased monitoring effort. Given the present lack of understanding about such relationships, it cannot be ruled out as a potential contributing factor leading to reduced toheroa populations.

## 3.4. Groundwater and related processes

A reduced groundwater flow may reduce the supply of nutrients to benthic diatoms which live on the sediments within the surf zone and are an important food source of toheroa. Reduced groundwater flow may also reduce the amount of water being discharged to the coast via beach sediments, possibly reducing the size of habitable areas and increasing the potential for desiccation. A lowering of the water table near the coast also has the potential to affect erosion of beach sediments and alter temperature and salinity regimes that might be important cues for spawning, or directly affect the ability of toheroa to survive. The impact of pine forests on the groundwater (*e.g.* acidity) is unknown and may influence the beach habitat.

Toheroa beds have been linked (*i.e.* situated near) to seepage from brackish lagoons that are often situated behind adjacent sand dunes. This linkage has not been scientifically tested but is based on anecdotal reports. Freshwater seepage from the lagoons provides water rich in nutrients that promote the growth of phytoplankton, mainly diatoms (Morton & Miller 1973). Inshore phytoplankton, benthic diatoms and dinoflagellates are all important food sources for toheroa (Rapson 1954). Draining coastal lagoons (normally for agricultural purposes) or even altering the residence time and therefore temperature regimes could impact on the productivity of the adjacent beach.

Laudien & Schiedek (2002) reported 'sulphide eruptions' (sulphur-based compounds released from decomposing organic matter) occurring along highly productive inshore regions of Namibia which influence juvenile surf clam survival. There is no evidence to suggest that these events occur along our coasts; however, no studies have been found which investigated this factor in New Zealand.

## 3.5. Changes in beach morphology and sediments

Toheroa are almost exclusively found in the intertidal zone of long, wide, exposed fine-sand ocean beaches (Rapson 1952, Cassie 1955, Redfearn 1974), all of which are constantly in different states of erosion or accretion. It is suggested that toheroa combat the dynamic nature of sediments in which they live by being rapid burrowers and digging deep. Kondo & Stace (1995) reported that toheroa dug down to 15 cm (when measured from the top of the shell to the beach surface), Akroyd (2002) recorded depths of 30 cm. They are also capable of relocating on the beach profile by withdrawing their siphons and foot and being dragged by the tides/waves (Rapson 1952).

Despite these abilities, large-scale movement of sand has been considered as one of the largest causes of mortality, either directly, by burying them too deep, or by leaching the animals out of the sediment, exposing them to predation (Redfearn 1974), desiccation and temperature shock, *etc.* This latter situation would presumably be exacerbated when erosion removes fine sediments leaving only coarser material that complicates or restricts re-burrowing. Patches of coarse sediment on the surface inshore from the beds may also pose problems during attempts to use the waves to relocate, as would layers of coarser material situated below the surface. It therefore follows that in order to withstand beach erosion, toheroa require a reasonably thick veneer (~ 20 cm+) of fine sandy sediment that extends up the beach immediately in-shore, and around the area of the main bed.

Beach stability and the availability of suitable sediments seem to be important influences of toheroa survival. Dadon (2005) suggests that changes to the beach sediment structure will have influences on species assemblage and distribution. Since toheroa cannot sift inorganic and organic particles at the mouth, a significant increase in silt may have a negative impact on the feeding ability of the toheroa potentially resulting in mortality or movement of the animal to cleaner waters.

Changes in local land use and river input have the potential to alter the supply of suitable sediments to the beach. Kirk & Shulmeister (1994), working near the Waiau River in Southland, concluded that toheroa were found on an accretional (dissipative) beach and not on an erosional beach.

Wave and water currents can alter beach morphology, influenced by sediment type and volume. Figures 3 and 4 below show how beach morphology can change, which undoubtedly has an influence on the surf clam populations.

Figure 4. Otaki River Mouth 1983 (Source: Manawatu Catchment Board and Regional Water Board Coastal Survey progress report No 4, 1983.).


Figure 5. Otaki River Mouth 2011 (Source: Google Earth).

## 3.6. Beach community dynamics

McLachlan and Dorvlo (2005) state that, "*The composition and abundance of invertebrate assemblages are controlled primarily by the physical environment, intertidal swash and sand conditions, being harshest on reflective beaches and more benign on dissipative beaches. Consequently, more species can colonise dissipative beaches, but fewer species, mainly robust crustaceans, can establish populations on reflective beaches*". Anecdotal evidence suggests that toheroa prefer reflective beaches.

Cranfield (1996) acknowledged that changes in the erosional regime and the composition of the beach sediments, and therefore habitat, are likely to affect toheroa populations. This may result in feeding, burrowing and exposure issues for the toheroa. Localised mortality of shellfish may play a part in community dynamics (Dadon 2005). If one species *e.g.* toheroa, has a mass mortality, the cause of that mortality may also impact on other species within the beach community and also allow less dominant species to replace or exclude toheroa. This could account for the low recovery of toheroa populations in some areas after a mass mortality event.

## 3.7. Vehicle disturbance

Vehicle traffic on beaches can cause significant damage to shellfish and may hinder the recovery of populations (Schlacher & Thompson 2008). As well as crushing juveniles with the weight of the vehicle, traffic along the beach semi-liquefies the sand, and the toheroa tend to rise towards the surface, forming 'hummocks' in the sand

(Redfearn 1974). The impact of this is not clear, but the toheroa may be more at risk of predation, desiccation or further traffic damage (Stace 1991).

Hooker and Redfearn (1998) studied the possible impacts of vehicle traffic on toheroa populations on Ninety Mile Beach. Their survey coincided with three days of a fishing competition held on the beach and the repeated high levels of traffic over the beds resulted in up to 14% mortality of juveniles ranging in size from 6 to 23 mm, but little immediate mortality of adult shellfish was observed. Sheppard & Pitt (2009), working on a *Donax* species, found that body mass of individuals near traffic routes was reduced and also that burrowing times of the clam was significantly slower in areas where vehicle traffic had been. This would make them susceptible to predation.

## 3.8. Space limitation

During years of high abundance, adult toheroa have been observed to dominate the preferred habitat, forcing juveniles to live in the upper sediment strata and tidal elevations (Stace 1991, Rapson 1952). This is an indication that toheroa populations have, at times, been 'space limited'. This is unlikely to have any bearing on survival in populations that are not at maximum densities.

It is not common to find large toheroa populations alongside large tuatua populations (Rapson 1954) which may indicate that tuatua have a wider habitat tolerance and may out-compete toheroa under certain circumstances. Literature has indicated that *P. subtriangulata* may 'smother' toheroa populations (Rapson 1954; Greenway 1969), while *P. donacina* appears to occupy the same sediment depth as toheroa (Richardson *et al.* 1982).

O'Shea suggests that the lower limit of adult toheroa distribution appears to be a measure of the intensity of competition for spatial and nutritional resources between toheroa and ghost shrimp (*B. filholi*).

## 3.9. Natural predation

Predators of the toheroa include black-backed gulls (*Larus dominicanus*) (Redfearn 1974), red-billed gulls (*Larus novaehollandiae*) (Rapson 1952), oystercatchers (*Haematopus* spp) (Street 1971), paddle crabs (*Ovalipes catharus*) (Wear & Haddon 1987), and burrowing crustaceans (*B.filholi*) (O'Shea 1986).

Brunton (1978) determined that black-backed and red-billed gulls were important predators of toheroa. Brunton observed that small toheroa were eaten whole, while larger toheroa were taken into the air and dropped to crack the shell. Up to 20 toheroa were eaten per day per bird. At 12 toheroa per day, the estimated 350 seagulls found on Ripiro Beach would consume over 1.5 million toheroa per year.

An examination of the foregut contents of paddle crabs revealed that toheroa are an important dietary component of this species in some locations (Wear & Haddon 1987). However, O'Shea (1986) argues that because paddle crabs live subtidally they could not have a significant effect on the population dynamics of toheroa unless the larger crabs migrate in with the advancing tide. Indeed, adult toheroa populations are protected to some extent by long periods of exposure during mid to low tides, and by depth of burial and high density acting as refuges from crab predation (Haddon *et al.* 1987).

Although there is no direct evidence that ghost shrimp predate upon toheroa, a number of anecdotal reports suggest this is the case. Williamson (1967-1970) reported that ghost shrimp density and distribution increased dramatically in the same period that a coincident decline in toheroa density and distribution was observed along Wellington west coast beaches (O'Shea 1986). O'Shea (1986) noticed that on Orepuki Beach the highest levels of toheroa larval recruitment occurred where ghost shrimp were absent or present at a very low density.

O'Shea (1986) suggests that the lower limit of juvenile toheroa distribution is determined by predation of the newly recruiting toheroa larvae by adult ghost shrimp in a manner described by Woodin (1976). Woodin's paper asserts that adult-larval interactions are extremely important in the community structure development of dense infaunal assemblages. A Californian study examining the interactions between ecologically equivalent species, a ghost shrimp (*Callianassa californiensis*) and a large, actively burrowing, suspension feeding bivalve (*Sanguinolaria nuttali*), supports the hypothesis that ghost shrimp could control juvenile toheroa distribution. A negative correlation in density was found between the two species and extensive juvenile recruitment of *S. nuttalli* occurred when *C. californiensis* was experimentally removed.

## 3.10. Harvesting and excavation techniques

Historically, there have been periods when harvesting pressure at some of the beaches has been considerable. Harvesting regulations were first introduced in 1994 and have been frequently revised. Currently, there is no permitted commercial or recreational harvest of toheroa, and only limited customary collecting. Customary take estimates from Bluecliffs Beach suggest that between 2,000 and 9,000 toheroa are taken annually (1998-2002), although this may underestimate actual levels given that reporting is voluntary. Problems are likely to arise when visitors from outside of the region come to harvest toheroa without an appreciation of the state of the bed, or the procedural requirements. Conversations with locals collecting toheroa on Bluecliffs Beach confirm this, with some reporting seeing large numbers of toheroa taken which were unlikely to have been formally documented. There is also likely to be a considerable and unquantifiable amount of poaching taking place. Together, customary harvest and poaching could easily amount to an on-going harvest in the order of 20,000 toheroa per year, having a potentially important impact on the suppressed population (estimated at 40,000-155,000 in 2001; Appendix 3).

Small toheroa have been damaged by tools used for recreational harvest. As a result, regulations now state that only hands may be used (McKinnon and Olsen 1994).

## 3.11. Recruitment variability

Settlement and recruitment by toheroa is notoriously variable. Large fluctuations in many of the populations around New Zealand have often been attributed to natural variations in settlement. The specific factors determining recruitment success or failure are not clear and are probably influenced by a wide range of variables *e.g.* specific water properties (temperature or salinity) required for spawning cues and successful gamete development; nutrients to fuel primary production and larval food; availability of suitable settlement substrate; predation; and the correct water currents to deliver larvae to suitable beaches *etc.* The sources of larvae which ultimately settle on the beach are unknown. It may be that the spawn from the local population reseeds their beach of origin. It is equally possible that the larvae may be sourced from other populations.

## 3.12. Subtidal populations

Some studies have proposed that toheroa can also inhabit the subtidal zone (Cassie 1955; Waugh and Greenway 1967). This is due to large empty shells being found with holes from predatory boring gastropods (Waugh & Greenway 1967), the mass strandings of adult toheroa along with other shellfish species (Eggleston & Hickman 1972) and under-representation of some cohorts in the intertidal population. This raised questions about the possibility of recruitment from subtidal populations to the beds on the beaches. However, preliminary dive surveys conducted by Street (1971) at Te Waewae Bay found no evidence of subtidal populations. No other evidence has been found to confirm the existence of subtidal toheroa in New Zealand.

# 4. CAUSES OF TOHEROA DECLINE – DISCUSSION

As can be seen from the summary above, there are a large number of possible causes for toheroa population fluctuations. It is likely that a number of these factors are acting simultaneously and interacting and responding to each other.

There has been some good work relating to reseeding on Ninety Mile Beach over the last 30 years where seed has been transferred from established populations to unpopulated areas of the beach by kaitiaki. However it is possible that this is not a closed population, and since larvae swim for up to 20 days (DOC 2006) before settling, the origin of that seed is not known. If the seed origin is from Ninety Mile Beach, then over-harvesting will decimate the population unless a broodstock population elsewhere can replenish it. The supply of juveniles will however be safe if most larvae recruiting to Ninety Mile Beach originate elsewhere and that broodstock population is preserved.

As described in the previous section, a number of studies have looked at various issues associated with toheroa populations in New Zealand. However as far as can be ascertained there have been no studies which simultaneously look at beach morphology, hydrodynamics, environmental aspects and toheroa population variation on the same beach for any length of time. Nor are the sources and movement of toheroa larvae known. Hence it is not yet possible to attribute the fluctuations of toheroa populations to particular factors or events.

In summary, little is known about the environmental and habitat requirements of toheroa. Therefore the challenge is not only to understand all aspects of beach habitats (environmental, hydrodynamic, morphological, flora and fauna, *etc.*) but also to monitor those facets simultaneously with the population fluctuations of the toheroa in order to draw connections between cause and effect. This would ideally be complemented by genetic studies of toheroa populations and modelling of larval dispersal to determine whether toheroa larvae on Horowhenua beaches are from that region or have been transported longer distances.

A study of this magnitude over an extended time period would be a significant undertaking and require a substantial financial and logistical commitment. Such a study is not envisaged at this time. Instead, two possible approaches to investigate toheroa populations and habitat are identified and discussed in the next section.

# 5. RESEARCH RECOMMENDATIONS

Two possible approaches to investigate factors influencing the decline of surf clam populations are outlined in this section. The first approach, surveying surf clam populations and habitats (Section 5.1), was designed based on the literature review and prior to a site visit. The site visit, and discussion with local kaitiaki, prompted further consideration and led to the second approach, focusing on a species that appears to compete with toheroa. This approach is presented in Section 5.2.

## 5.1. Survey of surf clams and habitat

A recommended approach to investigate surf zone habitats for surf clams is to focus on populations of specific surf clams, particularly toheroa, and attempt to identify key habitat features that could explain their decline on Horowhenua beaches. To do this, a two-phase design would be appropriate. In Phase 1, initial rapid surveys would be carried out to establish what can be achieved and determine the optimal sites for long-term and more detailed studies (Phase 2).

The following objectives are suggested for Phase 1:

### Objective 1

- Conduct a broad-scale survey of the research beach(es) (including historical populations based on local knowledge) to map the location of surf clams in the area and establish long-term monitoring locations for finer-scale surveys. Ideally, all intertidal surf clam species would be monitored using methods consistent with Ministry of Fisheries toheroa surveys (*e.g.* Beentjes & Gilbert 2006). The survey would aim to establish if any trends are general to surf clams or specific to toheroa.
- Based on distribution information collected from the broad-scale survey above, conduct a toheroa population survey that includes abundance, densities and size frequency – this provides initial information on total estimated numbers, patchiness of distribution, recruitment, *etc.* If this is completed by December and then repeated several months later, some indication of recruitment could be obtained. In addition the variation in populations could be confirmed or recorded. Figure 5 depicts the spatial sampling frame; frequency of sampling would be determined taking into account available resources.
- Analyse data and prepare a report on the estimated numbers, patchiness of distribution, size distribution *etc.* of the toheroa and/or other surf clams.

**Objective 2**

- Conduct a baseline survey of habitat characteristics and quality and develop finer scale surf clam population information at monitoring sites identified in Objective 1. The survey would be on a beach scale, rather than at a regional scale. Habitat variables could include parameters such as sediment grain size, organic content and chlorophyll-*a* content within the sediment and particulate organic matter within the water column as a measure of food *etc.* The number of sample sites on research beach(es) will be determined by the sampling costs and staff logistics. The sampling should be repeated to establish spatial and temporal variability.
- Collect ancillary data on the environmental conditions/characteristics. This includes regional scale factors *e.g.* water currents, temperature profile of the water column and over time, food availability *etc.* (as against a beach scale).

**Objective 3**

- Compile and analyse the data captured in Objectives 1 and 2 above to identify causal factors for the population variations (decreases and increases) of surf clams. Refine sampling methods as required. This data will form the basis for further work on causative factors of population variations in Phase 2.
- Develop a long-term survey and monitoring protocol to enable more detailed analysis of impacts on the populations at the research beach(es) (Phase 2) which will attempt to link amelioration efforts and natural events to population fluctuations. As noted earlier in this report, this could be complemented by genetic studies of toheroa populations and modelling of larval dispersal to determine whether toheroa larvae on Horowhenua beaches are from that region or have been transported over longer distances.

Whether this long term survey proceeds will be determined by Taiao Raukawa and the Mana9aki Taha Moana research management group, based on findings from Phase 1 and other research priorities.

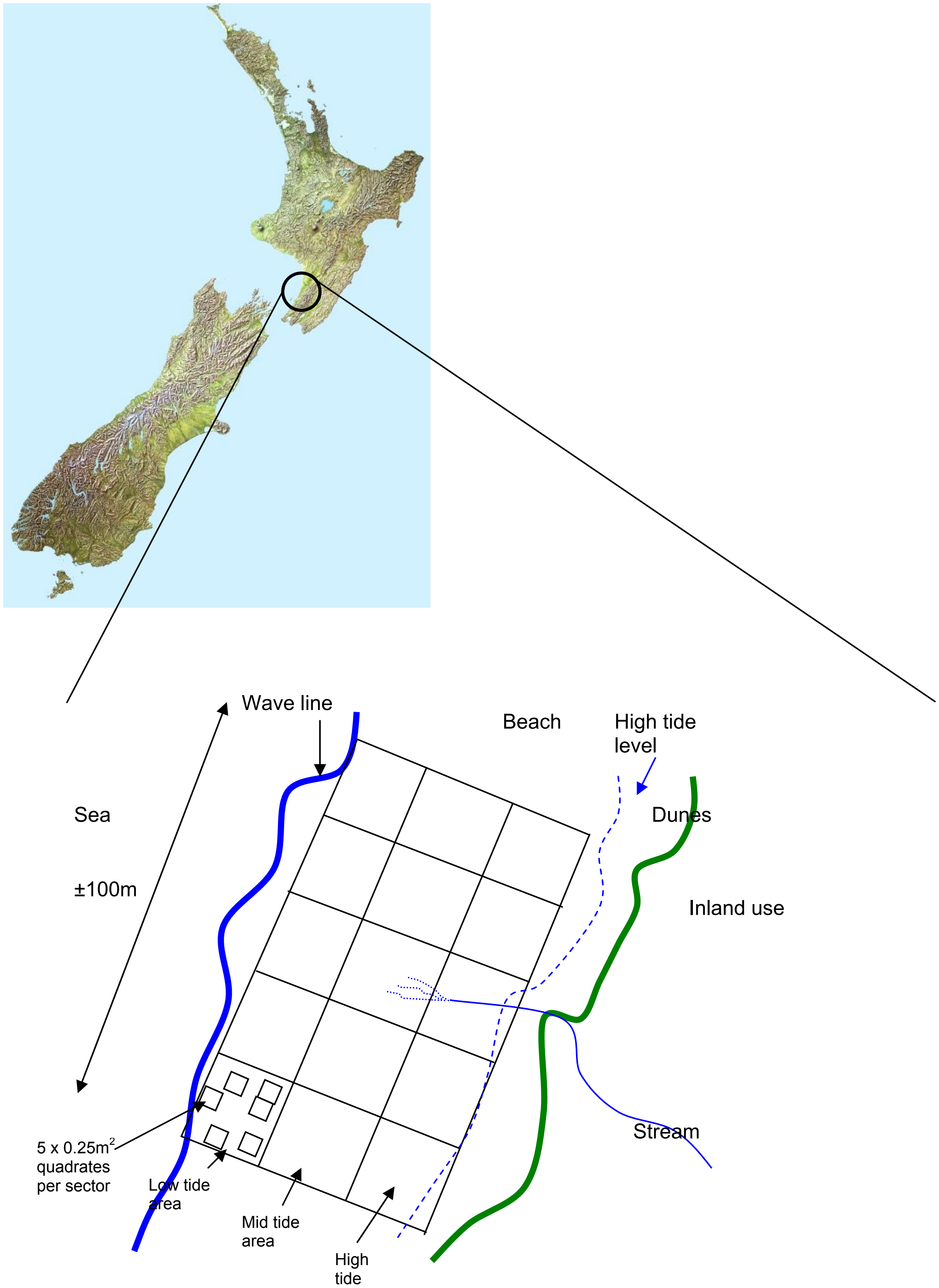


Figure 6. A diagrammatic representation of a sampling regime for surf clam populations.

## 5.2. Study of ghost shrimp colonies

### 5.2.1. Rationale for focus on ghost shrimp

During a field visit in November 2011, Cawthron staff discussed with local kaitiaki the decline of toheroa and other species. Included was a visit to the mouth of the Ōhau River to look for toheroa and consider the feasibility of the research approach presented in the previous section.

In the course of the visit, it became apparent that the study design was unlikely to be practical due to low population densities of toheroa and the time-consuming methods required for sampling. The large number of factors potentially implicated in shellfish decline also meant it would be difficult to attribute the decline to a particular set of factors. For instance, sediment plumes from large floods on the Manawatu River could impact on shellfish, as could significant changes to local conditions of freshwater/surf zone interaction.

On the beach, kaitiaki pointed out a phenomenon they referred to as 'worm holes'. These are large areas dominated by a burrowing animal known as ghost shrimp (*Biffarius filholi*) that appears to have colonised areas where toheroa were once abundant. While this expansion could be either a cause or an effect of shellfish decline (or neither), it would be informative to compare the areas inhabited by ghost shrimp with those where toheroa are still found, and to document the extent of ghost shrimp beds along the coastline.

### 5.2.2. Research aim and design

This study would investigate how habitat previously occupied by culturally significant shellfish species has changed with the expansion of ghost shrimp colonies, and consider how this species interacts with shellfish populations. As discussed in Section 3.9, *Biffarius filholi* have been identified as competitors of, and possibly predators of, toheroa (O'Shea 1986). Ghost shrimp may also modify the habitat by changing sediment quality through burrowing and irrigation activities. In order to research effects of ghost shrimp colonies on shellfish populations, we suggest field research that would have the following components.

**Objective 1**

- Document location, size, and density of ghost shrimp colonies along the Horowhenua coastline. Map the location of each colony with a GPS device and measure density by conducting nine quadrat counts in each colony. Repeat over time based on an assessment (to be done) of the life cycle of *Biffarius filholi*.

- Interview local kaitiaki to document:

    - changes in ghost shrimp colonies over time
    - relationship to previous shellfish beds
    - any other relevant local knowledge.
- Summarise interviews for inclusion in a project report.

### Objective 2

- Conduct a habitat survey of ghost shrimp colonies and other areas for comparison, including areas where toheroa are known to be present in numbers and areas where neither ghost shrimp nor toheroa are present.
- Use GIS information on changes to the coastline and in land-use to describe changes in coastal morphology and sediment deposition from land-based activities (budget permitting).
- Use ordination analysis and other techniques to characterise surf zone habitat and identify links between key variables.
- Produce report incorporating both western science and mātauranga Māori evidence on changes to surf zone habitat over time and possible effects on surf clam populations.

Based on discussions and observations during a field visit in November 2011, a study to investigate the expansion of ghost shrimp colonies (*Biffarius filholi*) is recommended at this stage. A study of toheroa populations remains a possibility for subsequent investigation.

# 6. REFERENCES AND SUGGESTED READING


Akroyd, J.M. 2002. Investigation into the enhancement of Toheroa (*Paphies ventricosa*) Populations on a North Island West Coast Beach, New Zealand. Submitted in partial fulfilment for the degree of Master of Applied Science, Auckland University. 72p plus appendices.

Akroyd, J.M.; Walshe, K.A.R.; Millar, R.B. 1999. Distribution of toheroa (*Paphies ventricosum*) beds, and the abundance and size structure of toheroa at Ripiro Beach, Dargaville. Final report to the Ministry of Fisheries, project TOH9801. Akroyd Walshe Ltd. 21p.

Akroyd, J.M.; Walshe, K.A.R.; Manly, B.F.J. 2002. Distribution and abundance of toheroa (*Paphies ventricosa*) on Muriwai Beach, Auckland, 2000. Report to the Ministry of Fisheries, project TOH 2000/01. Akroyd Walshe Ltd. 25p.

Akroyd, J.M.; Walshe, K.A.R.; Millar, R.B. 2002. Abundance, distribution and size structure of Toheora (*Paphies ventricosa*) at Ripiro Beach, Dargaville, Northland, New Zealand. *New Zealand Journal of Marine and Freshwater esearch*, Vol 36, No3.

Bannister, R.C.A., 1991. Stock enhancement (workshop report), ICES Mar.Sci.Symp., 192:191-192.

Brunton, P.M., 1978. Toheroa predation by Black-backed Gulls on Dargaville Breach, North Auckland. *Notornis* 25: 128-140.

Cassie, R.M., 1955. Population studies of the toheroa (*Paphies ventricosa*) Grey (Eulamellibranchiata). *Australian Journal of Marine and Freshwater Research*, 6, 348-391.

Castagna, M. 2001. Aquaculture of the Hard Clam, Mercenaria mercenaria. In: Biology of the Hard Clam, Chapter 15, J.N. Kraeuter and M. Castagna (Eds.).

Cranfield H.J., 1996. Population changes in toheroa and subtidal clams in Te Warwae Bay and possible impacts of reduced water flow of Waiau River, Unpublished report.

Dadon, J.R., 2005. Changes in the intertidal community structure after a mass mortality event in sandy beaches of Argentina. Contributions to Zoology, 74, 1-13.

Defeo O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M. and Scapini, F., 2009. Threats to sandy beach ecosystems: A Review. *Estuarine, Coastal and Shelf Science*, 81, 1–12.

Department of Conservation 2006. Accessed December 2011 http://www.doc.govt.nz/upload/documents/about-doc/concessions-and-permits/conservation-revealed/northland-west-coast-lowres.pdf

Eggleston, D.; Hickman, R.W. 1972. Mass stranding of molluscs at Te Waewae Bay, Southland, New Zealand. *New Zealand Journal of Marine and Freshwater Research 6*: 379-382.

Greenway, J. P. C. 1969. Population surveys of toheroa (Mollusca: Eulamellibranchiata) on Northland beaches, 1962-67. *New Zealand Journal of Marine and Freshwater Research* 3: 318-338.

Greenway, J.P.C., 1972. Further data from population surveys of toheroa (Mollusca: Eulamellibranchiata) on Northland Beaches, 1962-1971. *Fish. Tech. Rep. N.Z. Mar. Dep 85*. 33pp.

Haddon, M.; Wear, R. G.; Packer, H. A. 1987. Depth and density of burial by the bivalve *Pahies ventricosa* as refuges from predation by the crab *Ovalipes catharus. Marine Biology* 94: 25-30.

Hefford, A.E., 1945. Report of the Chief Inspector of Fisheries. *Rep.Mar.Dep. N.Z.*

Hooker, S.; Redfearn, P. 1998. Preliminary survey of toheroa (*Paphies ventricosa*) populations on Ninety Mile Beach and possible impacts of vehicle traffic. Prepared for Northland Regional Council. *NIWA client report No. AK98042*. 36p.

Holland, L.D. 1983. Coastal Investigation: literature review and Biography. Manawatu Catchment Board and Regional Water Board Report 52.

Hooker, S.H., 1995. Life History and demography of the pipi. PhD Thesis, University of Auckland, New Zealand.

Jacobson, L. and Weinberg, J. 2006. Status of Fishery Resources off the Northeastern US NEFSC - Resource Evaluation and Assessment Division**.**

http://www.nefsc.noaa.gov/sos/spsyn/iv/surfclam/

Keeley, N., Gibbs, M., Thompson, S. and Robertson, B. 2002. A review of factors affecting the viability of the Te Waewae Bay Toheroa Population. Cawthron Report 757 (confidential).

Kirk, R.M.; Shulmeister, J. 1994. Geomorphic processes and coastal change in the lagoon system, lower Waiau River, Southland. Report to the Waiau River Working Party, convened by Southland Regional Council. 77p.

Kondo, Y.; Stace, G. 1995. Burrowing ability and life position of toheroa (*Paphies ventricosa*: Mesodesmatidae), an unusually large, deep-burrowing ocean beach bivalve endemic to New Zealand. *Jap. Jour. Malac.* 45(1): 67-76.

Laudien, J., Schiedek, D., Brey, T., Pörtner, H.-O. & Arntz, W.E. (2002). Survivorship of juvenile surf clams Donax serra (Bivalvia, Donacidae) exposed to severe hypoxia and hydrogen sulphide. *J. Exp. Mar. Biol. Ecol*. 271: 9-23.

McArthur, K.J. 2010: Evidence presented at Horizons Regional Council hearing on behalf of Horizons Regional Council relating to the Proposed One Plan

McKinnon, S.L.C. and Olsen D.L.,1984. Review of Southland Toheroa Fishery. *New Zealand Fisheries Management: Regional Series* 3. 25p.

McKinnon, S.L.C; Rayns, N.R.; 1992. Review of the Southland toheroa fishery. Report No.2. *MAF Fisheries South Marine Fisheries Report Series.* MAF Fisheries South, Dunedin. 11p plus figures and tables.

McLachlan, A., Dorvlo,A., 2005.Global patterns in sandy beach macrofauna communities. Journal of Coastal Research 21, 674–687.

McLachlan, A.; Dugan, J.E.; Defeo, O.; Ansell, A.D.; Hubbard, D.M.; Jaramillo, E.; Penchaszadeh, P.E. 1996. Beach clam fisheries. *Oceanography and Marine Biology: an Annual Review 34*: 163-232.

Millar, R.B. 1994. The number of takeable toheroa at Oreti Beach. 4p plus figures.

Millar, R.B.; Olsen, D. 1995. Abundance of large toheroa (*Paphies ventricosa* Gray) at Oreti Beach, 1971-90, estimated from two-dimensional systematic samples. *New Zealand Journal of Marine and Freshwater Research 29*: 93-99.

Morrison, M.; Parkinson, D. 2001. Distribution and abundance of toheroa (*Paphies ventricosa*) on Ninety Mile Beach, March 2000. *New Zealand Fisheries Assessment Report 2001/20*. 27p.

Morton, J. and Miller, M. 1973. The New Zealand seashore. Collins, London. pp 653.

O'Shea, S. 1986. Environmental Impact Report on the Orepuki Beach, Southland for Platinum Group Metals N.L. 3 March 1986. 70 p.

Rapson, A.M. 1952. The toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata) development and growth. *Australian Journal of Marine and Freshwater Research.* 3: 170-98.Rapson, A.M. 1954. Feeding and control of toheroa (*Amphidesma ventricosum* Gray) (Eulamellibranchiata) populations around New Zealand. *Australian Journal of Marine and Freshwater Research.* 5: 486-512.

Redfearn, P. 1974. Biology and distribution of the toheroa, Paphies (Mesodesma) ventricosa (Gray). Fisheries Research Bulletin, New Zealand Ministry of Agriculture & Fisheries 11.

Richardson, J. R.; Aldridge, A. E.; Smith, P. J. 1982. Analysis of tuatua populations – *Paphies subtriangulata* and *P. donacina. New Zealand Journal of Zoology* 9: 231-238.

Robertson, B.M. 1993. Waiau Catchment Water Quality Review. Southland Regional Council, June 1993.

Schlacher, T.A. and Thompson, L.M.C., 2008. Physical impacts caused by off road vehicles (ORVs) to sandy beaches: special quantification of car tracks on an Australian barrier Island. *Journal of Coastal Research*. 24, 234-242.

Sheppard,N. and Pitt, K., 2009. Sub-lethal effects of off-road vehicles (ORVs) on surf clams on sandy beaches. *Journal of Experimental Marine Biology and Ecology*, Vol 380, Issue 1-2, 113-118.

Spencer, B.E., 2002. Molluscan shellfish farming. Blackwell Science, Oxford, 274p.

Stace, G. 1991. The elusive toheroa. *New Zealand Geographic 9*:18-34.

Street, R.J., 1971. Studies on Toheroa at Te Waewae Bay, Southland. Fish Tech Report, NZ Marine Department, 70. 22p

Tunbridge, B.R. 1965. Toheroa Survey – Wellington Beaches – May 1965. Fisheries Division, Wellington

Waugh G.D. and Greenway, J.P.C., 1967. Further evidence of sub-littoral populations of Toheroa, *Amphisdesma ventricosum* Grey (Eulamellibranchiata) of the west coast of New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 1. 407-441.

Wear, R.G. Haddon, M. 1987. Natural diet of the crab *Ovalipes catharus* (Crustacea, Portunidae) around central and northern New Zealand. *Marine Ecology Progress Series*, 35: 39-49.

Woodin, S. A. 1976. Adult-Larval interactions in dense infaunal assemblages: Patterns of abundance. *Journal of Marine Research* 34(1): 25-41.

Yu, J.H., Song, J.H., Choi, M.C. and Park, S.W. 1999. Effects of water temperature change on immune function in surf clams, Mactra veneriformis (Bivalvia: Mactridae). *Journal of Invertebrate Pathology*. 102, 1, 30-35.

# 7. APPENDICES

Appendix 1. Estimates of toheroa abundance on the Horowhenua Coast (Wellington West Coast).

| Period | Researcher | Beach surveyed | Beach length | Est number of legal toheroa | Est number of undersized toheroa | Est total number of toheroa |
|---|---|---|---|---|---|---|
| 1940 | Rapson (1952) | Waitarere to Waikanae | 36 km | 2.4 million | 200,000 | 2.6 million |
| 1951 | Cassie (1955) | Waitarere and Hokio | | | | 325,800 |
| 1961 | Tunbridge (1965) | Waitarere | 12.8km | | | 45,760 |
| 1948 | Cassie (1955) | Hokio | 8km | | | 700,000 |
| 1961 | Tunbridge (1965) | Hokio | 8km | | | 16,720 |
| 1965 | Tunbridge (1965) | Hokio | 8km | | | 311,520 |
| 1965 | Tunbridge (1965) | Foxton | 9.6km | 81,840 | 55,440 | 137,280 |
| 1965 | Tunbridge (1965) | North Waitarere | 8km | 274,560 | 111,180 | 385,740 |
| 1965 | Tunbridge (1965) | South Waitarere | 4.8km | 63,360 | 64,400 | 89,760 |
| 1965 | Tunbridge (1965) | Otaki | 8km | 80,520 | 51,480 | 132,000 |
| 1965 | Tunbridge (1965) | Te Horo | 8km | 5,280 | 0 | 5,280 |

Appendix 2. Estimates of toheroa abundance on Northland's western beaches.

| Period | Researcher | Beach surveyed | Beach length surveyed | Est number of legal toheroa (millions) | Est number of undersized toheroa (millions) | Est total number of toheroa (millions) |
|---|---|---|---|---|---|---|
| 1930 | Hefford (1945) | **Ninety Mile** | 87.2km | | | Significant mortality |
| 1933 | Hefford (1945) | " | 87.2km | 11-12 | | 11-12 |
| 1938 | Rapson (1954) | " | 87.2km | | | 12 |
| 1944/45 | Hefford (1945) | " | 87.2km | | | Scarce |
| 1946 | Rapson (1954) | " | 87.2km | | | 6 |
| 1948 | Cassie (1955) | " | 52.8 | | | 0 |
| 1957 | Morrison & Parkinson (2006) | " | | | | 6.2 |
| 1962* | " | " | | | 24 | 24 |
| 1963* | " | " | | | 22-37 | 22-37 |
| 1964* | " | " | | | 15-22 | 15-22 |
| 1965* | " | " | | | 3.9-1.4 | 3.9-1.4 |
| 1966* | " | " | | | 2.3-1.9 | 2.3-1.9 |
| 1967* | " | " | | | 0.54-0.83 | 0.54-0.83 |
| 1968* | " | " | | | 6.9-1.9 | 6.9-1.9 |
| 1969* | " | " | | | 7.1-9.3 | 7.1-9.3 |
| 1970* | " | " | | | 41-18 | 41-18 |
| 1971* | " | " | | | 10.4 | 10.4 |
| 1972* | " | " | | | 3.7 | 3.7 |
| 1973* | " | " | | | 0.7 | 0.7 |
| 1974* | " | " | | | 0.3 | 0.3 |
| 1975* | " | " | | | 0.03 | 0.03 |
| 1976* | " | " | | | 0 | 0 |
| 1977* | " | " | | | 0.18 | 0.18 |
| 1978* | " | " | | | 0.03 | 0.03 |
| 1979* | " | " | | | 0 | 0 |
| 1980* | " | " | | | 0 | 0 |
| 1981* | " | " | | | 0.05 | 0.05 |
| 1982* | " | " | | | 0.02 | 0.02 |
| 1983* | " | " | | | 0.76 | 0.76 |
| 1984* | " | " | | | 2.6 | 2.6 |
| 1985* | " | " | | | 0.78 | 0.78 |
| 1986* | " | " | | | 1.8 | 1.8 |
| 2000 | Morrison & Parkinson | " | 87.2km | | 51 | 51 |
| 2006 | Morrison & Parkinson | " | 87.2km | | 8.8 | 8.8 |

* Data are from unpublished records.

Appendix 2. Estimates of toheroa abundance on Northland's western beaches-*continued*.

| Period | Researcher | Beach surveyed | Beach length surveyed | Est number of legal toheroa | Est number of undersized toheroa (millions) | Est total number of toheroa (millions) |
|---|---|---|---|---|---|---|
| 1930 | Stace (1991) | **Ripiro Beach** | | | | 30 |
| 1938 | Rapson (1954) | " | | | | 9 |
| 1948 | Morrison & Parkinson (2006) | " | | | | 5 |
| 1957 | " | " | | | | 10 |
| 1962* | " | " | | | 20 | 20 |
| 1963* | " | " | | | 18-10 | 18-10 |
| 1964* | " | " | | | 14.8 | 14.8 |
| 1965* | " | " | | | 11.7-15.3 | 11.7-15.3 |
| 1966* | " | " | | | 14.5-3.2 | 14.5-3.2 |
| 1967* | " | " | | | 5 | 5 |
| 1968* | " | " | | | 6.3-3.4 | 6.3-3.4 |
| 1969* | " | " | | | 8.1-6.5 | 8.1-6.5 |
| 1970* | " | " | | | 11-8 | 11-8 |
| 1971* | " | " | | | 3.2 | 3.2 |
| 1972* | " | " | | | 29.9 | 29 |
| 1973* | " | " | | | 4.3 | 4.3 |
| 1974* | " | " | | | 10.7-4.4 | 10.7-4.4 |
| 1975* | " | " | | | 6.1-3.9 | 6.1-3.9 |
| 1976* | " | " | | | 15.5-5.6 | 15.5-5.6 |
| 1977* | " | " | | | 12.8-12.8 | 12.8-12.8 |
| 1978* | " | " | | | 4.7-3.7 | 4.7-3.7 |
| 1979* | " | " | | | 3.2 | 3.2 |
| 1980* | " | " | | | 5.5-3.7 | 5.5-3.7 |
| 1981* | " | " | | | 4 | 4.6 |
| 1982* | " | " | | | 6.3 | 6.3 |
| 1983* | " | " | | | 2 | 2 |
| 1984* | " | " | | | 7 | 7 |
| 1985* | " | " | | | 10.3 | 10.3 |
| 1986* | " | " | | | 5.9 | 5.9 |
| 1990 & 1993 | MAF | " | 72.4km | | | 0 |
| 1993 - 1999 | Akroyd *et.al.* (2002) | " | 72.4km | | | General increasing numbers |
| 1999 | Akroyd *et.al.* (2008) | " | 72.4km | 3.3 million | 110m | 113m** |
| 2008 | Akroyd *et.al.* (2008) | " | | | 24m-58m | 24m-58m |

* Data are from unpublished records.
** This high number may be due to improved sampling methods and has a high standard error (33 million).

Appendix 2. Estimates of toheroa abundance on Northland's western beaches-*continued*.

| Period | Researcher | Beach surveyed | Beach length surveyed | Est number of legal toheroa | Est number of undersized toheroa | Est total number of toheroa (millions) |
|---|---|---|---|---|---|---|
| 1937 | Cassie (1955) or Redfearn (1974) | **Rangatira Beach** | | | | 15 |
| 1938 | " | " | | | | 4 |
| 1940 | " | " | | | | 5 |
| 1941 | " | " | | | | 5 |
| 1942 | " | " | | | | 5 |
| 1947 | " | " | | | | 3 |
| 1948 | " | " | | | | 13-10 |
| 1949 | " | " | | | | 15 |
| 1950 | " | " | | | | 1 |
| 1952 | " | " | | | | 8 |
| 1962* | Morrison & Parkinson (2006 | " | | | | 5.1 |
| 1963* | " | " | | | | 8.3-4.7 |
| 1964* | " | " | | | | 12.4-0.6 |
| 1965* | " | " | | | | 3.6-1.6 |
| 1966* | " | " | | | | 5.4-3 |
| 1967* | " | " | | | | 2.3-2.8 |
| 1968* | " | " | | | | 6.7-2.2 |
| 1969* | " | " | | | | 2.6 |
| 1970* | " | " | | | | 2.5-0.7 |
| 1971* | " | " | | | | 1.4-0.7 |
| 1972* | " | " | | | | 2.1 |
| 1973* | " | " | | | | 6.7 |
| 1974* | " | " | | | | 6.7 |
| 1975* | " | " | | | | 1 |
| 1976* | " | " | | | | 3.3-0.88 |
| 1977* | " | " | | | | 0.4 |
| 1978* | " | " | | | | 0.4 |
| 1979* | " | " | | | | 0.8 |
| 1980* | " | " | | | | 0.2 |
| 1981* | " | " | | | | 0.02 |
| 1982* | " | " | | | | 0.04 |
| 1983* | " | " | | | | 0.9 |
| 1984* | " | " | | | | 0.7 |
| 1985* | " | " | | | | 0.4 |
| 1986* | " | " | | | | 1.4 |
| 2000 | Akroyd et al. (2008) | | | | | 0.5 |
| 2008 | Akroyd *et.al.* (2008) | | | | | 0.7 |

* Data are from unpublished records.

Appendix 3. Estimates of toheroa abundance at Te Waewae (Bluecliffs Beach).

| Period | Researcher | Beach surveyed | Beach length surveyed | Est number of legal toheroa (millions) | Est number of undersized toheroa | Est total number of toheroa (millions) |
|---|---|---|---|---|---|---|
| 1966-1970 | Street (1971) | **Te Waewae Bay** | 11.25km | 12 | Not assessed | 1-2 |
| 1971-1982 | McKinnon & Olsen (MAF study 1994) | " | ? | 0.5-0.7 | Not assessed | 0.5-0.7 |
| 1990 | McKinnon & Olsen (MAF study 1994) | " | | <0.08 | | <0.08 |
| 2001 | NIWA Abundance survey (chc01/107) | " | 5km | 0.04-0.16 | | 0.33 |