Taihoro Nukurangi

D
R
A
F
T
31/03/09

A literature review on the ecological health of Ninety Mile Beach, Northland

Ninety Mile Beach (Photo: C. Sim-Smith)

NIWA Client Report: AKL2009-11
March 2009

NIWA Project: MOJ09101

A literature review on the ecological health of Ninety Mile Beach, Northland

D
R
A
F
T
31/03/09

Author
Carina Sim-Smith

Prepared for

Office of Treaty Settlements, Ministry of Justice

NIWA Client Report: AKL2009-11
March 2009

NIWA Project: MOJ09101

National Institute of Water & Atmospheric Research Ltd
41 Market Place, Auckland Central 1010,
Private Bag 99940, Auckland 1149, New Zealand
Phone +64-9-375 2050, Fax +64-9-375 2051
www.niwa.co.nz

Contents

Executive Summary		iv
1.	Introduction	1
2.	Physical and biological environment	2
3.	Flora of Ninety Mile Beach	4
3.1	Sand dune flora	4
3.2	Macroalgae	4
4.	Fauna of Ninety Mile Beach	6
4.1	Toheroa	6
4.1.1	Toheroa biology	6
4.1.2	Commercial and recreational toheroa harvesting	9
4.1.3	Toheroa population monitoring	10
4.2	Green-lipped mussels	13
4.2.1	Mussel biology	13
4.2.2	Commercial harvesting of Green-lipped mussel spat	16
4.3	Other beach fauna	19
4.3.1	Intertidal beach fauna	19
4.3.2	Fauna of the sand dunes	19
4.4	Birds	20
5.	Human impacts on Ninety Mile Beach	21
5.1	Impacts of beach vehicle traffic	21
5.2	Pollution	23
6.	Conclusions	24
7.	References	26

Reviewed by: *Approved for release by:*

Michael Bruce *Michael Bruce*

Executive Summary

Ninety Mile Beach (Te Oneroa a Tohe), Northland, is recognised as an ecologically significant coastal area. The beach contains one of New Zealand's few remaining toheroa populations, and also supplies around 80% of the green-lipped mussel seed to New Zealand's aquaculture industry. Given the ecological importance of the beach there is concern, particularly amongst local Iwi, that the ecological health of the beach has changed over time. The Office of Treaty Settlements contracted the National Institute of Water and Atmospheric Research to conduct a literature review on the ecological health of Ninety Mile Beach. The aims of this literature review are; 1) to increase our understanding of the ecological health of the beach, 2) to ascertain whether or not the ecological health of the beach has changed over time, and 3) to identify any information gaps in the available research.

The sand dune flora and benthic macroinvertebrate communities on Ninety Mile Beach are characteristic of exposed sandy beaches of New Zealand. Important native sand-binding plants present on the beach include pingao, spinifex, sand sedge, sand coprosma, and sand pimelea. Dunes on the northern third of the beach have a higher conservation rating than the more modified dunes at the southern end of the beach. The beach and surrounding sand dunes are also inhabited by some uncommon native plants (*Pimelea arenaria* and *Hydatella inconspicua*) and rare birds (variable oystercatcher, northern NZ dotterel, and Caspian tern). The diversity and abundance of macroinvertebrate fauna on Ninety Mile Beach is very low, with only 13 species recorded from the intertidal sandy region. Tuatua are by far the most abundant macroinvertebrate on Ninety Mile Beach, with densities of up to 500 ind./m^2.

Toheroa were once abundant on Ninety Mile Beach but the population is now threatened and large toheroa have been rare on the beach since 1970. Population levels have fluctuated wildly over the past 80 years and no clear trend is obvious from historical population estimates. The largest toheroa population was recorded in 2000, with an estimated 51.6 million animals on Ninety Mile Beach, the majority of which were <35 mm in length. However, this extremely high recruitment did not lead to a detectable increase in the adult population in subsequent years, and by 2006 the population had dropped to 8.8 million animals. It appears that the toheroa population at Ninety Mile Beach has shifted from an adult-dominated population prior to 1970, to a juvenile-dominated population in 2000–2006. However, because of changes in sampling methodology over time it cannot be concluded for certain that there has been a shift in the population size structure. Little is known about the factors that affect toheroa recruitment, both onto the beach, and into the adult population. Large scale mortality events, disease, vehicle traffic on the beach, food availability, physical or chemical changes to the habitat, or poaching may have a significant impact on toheroa recruitment. Mass mortalities of toheroa populations have occurred on five occasions over the last 80 years. These mass mortalities are thought to be caused by high temperatures and calm surf conditions, which resulted in the tides not covering toheroa beds for several days.

Green-lipped mussel seed attached to drifting seaweed washes ashore at Ninety Mile Beach in vast quantities each year. This unique resource is commercially harvested from the surf zone of the beach and forms the basis of New Zealand's multi-million dollar aquaculture industry. The arrival of drifting seaweed and mussel seed is highly variable, and no scientific estimates are available on the quantity of spat that arrives at Ninety Mile Beach each year. The source of mussels and seaweed that are washed ashore is unknown, as are the ecological and physical processes that deliver the algae to Ninety Mile Beach. The combined reproductive output from known intertidal and subtidal mussel populations around the region is unlikely to be able to produce the vast quantities of seed that washes ashore each year. Intertidal populations of green-lipped mussels exist on the rocky headlands at Scott Point, The Bluff, and Tonatona Beach. The population at Scott Point is large and very dynamic, with almost 100% turnover each year. High winter mortalities, which are thought to be caused by low food availability and storm conditions, are followed by strong recruitment in spring. New recruits grow rapidly with an average growth of 72 ± 1.3 S.E. mm/year. In contrast, the populations at The Bluff and Tonatona Beach are much smaller and more static, with low levels of recruitment and mortality, and much lower growth rates of 32 ± 0.5 S.E. mm/year and 49 ± 1.0 S.E. mm/year, respectively. The differences in the population dynamics between the three intertidal populations are thought to be caused by natural physical and biological processes.

Ninety Mile Beach is a designated state highway and is subjected to high vehicle traffic. Little is known about the vehicle impacts on the beach flora and fauna of Ninety Mile Beach. International studies conducted on the vehicle impacts on the biota of sandy beaches generally conclude that while vehicle traffic above the high water mark is highly destructive, the impact of vehicles on the intertidal area appears to be minimal, if the level of vehicle usage is low and vehicles are only driven during the day. Low levels of vehicle impact do not cause any detectable mortality of tuatua living on Ninety Mile Beach, but there is good evidence that toheroa mortality can be caused by high levels of vehicle traffic. Repeated compressions by vehicles cause toheroa to emerge from the sand where they may be crushed or preyed upon by seabirds. In a pilot study conducted during a recreational fishing contest it was found that 14% of juvenile toheroa in a small bed were crushed by vehicles. Vehicle pressure may also cause toheroa to eject water from their mantle cavity, making them more prone to desiccation.

In summary, Ninety Mile Beach appears to be in relatively good ecological health, with the exception of toheroa populations. The beach and surrounding sand dunes have a moderate to high degree of natural character, and natural processes predominantly control the population dynamics of green-lipped mussels on the beach. Insufficient knowledge is available to determine whether there have been any changes in the ecological health of the beach over time, with the exception that large toheroa have been rare on the beach since 1970. Threats to the ecological health of the beach include the increasing usage of vehicles on the beach, the unknown impact of harvesting drift seaweed and mussel seed from the beach, pollution from residential areas, and unsustainable harvesting of shellfish. There is a lack of knowledge in a number of critical areas in the ecology of Ninety Mile Beach including:

- The factors that affect toheroa recruitment, such as spawning cues, effects of physical and chemical variables, and food availability.

- The factors that cause toheroa mortality, such as physical and chemical processes, disease, poaching, predation, and vehicle impacts.

- Growth rates on toheroa on Ninety Mile Beach

- The impact of vehicle traffic on the benthic biota of the beach, particularly on both juvenile and adult toheroa.

- The location of the parental sources of beach-cast green-lipped mussel seed and seaweed, and the sustainability of these sources.

- The physical and ecological processes that deliver the mussel seed and seaweed to the beach.

- The quantity of mussel seed and seaweed that washes ashore at Ninety Mile Beach each year.

- The impact of harvesting mussel seed and seaweed on the beach ecosystem, such as the impact on recruitment to intertidal mussel populations, the direct impact of harvesting activities on benthic fauna, and the cascading effect of removing a large nutrient source from the beach.

1. Introduction

Ninety Mile Beach (Te Oneroa a Tohe), Northland, is one of New Zealand's most renowned beaches and is a popular recreational destination for fishing, shellfish harvesting, diving, surfing, and sightseeing. The beach is a designated state highway and the intertidal region of the beach is subjected to regular vehicle traffic. Ecologically, the beach is of significance because one of the country's few remaining toheroa (*Paphies ventricosa*) populations is found within the intertidal region of the beach. Ninety Mile Beach also supplies around 80% of the green-lipped mussel (*Perna canaliculus*) seed used by New Zealand's mussel aquaculture industry (Jeffs, 1999). This seed is washed ashore attached to drifting seaweed and is commercially harvested from the surf zone. Given the ecological importance of the beach there is concern, particularly amongst local Iwi, that the ecological health of the beach has changed over time. The Office of Treaty Settlements contracted the National Institute of Water and Atmospheric Research Ltd (NIWA) to conduct a literature review of the ecological health of Ninety Mile Beach. Ecological health in this review is defined as the status of an ecosystem. Ecosystems that are in good ecological health have a high degree of natural character, which is defined as unmodified habitats that contain a high level of indigenous organisms whose populations are controlled by natural processes that would normally occur in an unmodified environment. In contrast, indicators of poor ecological health include the loss of keystone species, high mortality rates caused by disease, high abundance of invasive or introduced species, loss of habitats, and the proliferation of bacteria. The aims of this literature review are; 1) to increase our understanding of the ecological health of the beach, 2) to ascertain whether or not the ecological health of the beach has changed over time, and 3) to identify any information gaps in the available research. This literature review covers information on:

- the benthic fauna and flora of Ninety Mile Beach that inhabit the shallow subtidal, intertidal, and sand dune habitats of the beach.
- historical trends in population dynamics of toheroa and green-lipped mussels that inhabit Ninety Mile Beach.
- commercial harvesting of green-lipped mussel seed that occurs on the beach.
- research on the impact of vehicle traffic on the beach.

Information used in this review includes published and unpublished scientific literature from scientific journals, university theses, Waitangi Tribunal submissions, and reports commissioned or written by local regional authorities, research institutes, the Department of Conservation, Ministry of Fisheries, and other government agencies.

2. Physical and biological environment

Ninety Mile Beach is located on the west coast of the northernmost peninsula of North Island, and covers the area between Tauroa Point and Scott Point (Fig. 1). The exposed, open coast beach is actually only 55 miles (88.5 km) long and is part of a large tombolo[1] that connects an ancient rocky island with the mainland. The long, straight beach runs in a north-west direction and the beach has a low gradient. Extensive Pleistocene and Holocene sand dunes back the beach, which extend up to 10 km inland and reach heights of up to 150 m (Brook & Carlin, 2000; Walker, 2007). The fine, light coloured sands on the beach and dunes have a median grain size of between 0.14–0.18 mm, and primarily consist of quartz (52–71%), soda-calc feldspars[2] (11–21%), and potassium feldspars[3] (5–13%). The sand contains no detectable quantities of clay (Schofield, 1970). The beach is highly mobile and large storm events can move vast quantities of sand on and off the beach. South-westerly wind and wave conditions prevail, and the predominant current runs in a north-west direction up the beach, which generally facilitates the deposition of sediment onto the beach (Stanton, 1973; Hay & Grant, 2003; Walker, 2007). Water temperatures range between 14–21°C, inshore salinity is between 35.3–35.5 ppt, and the maximum tidal range is 3.2 m (Brook & Carlin, 2000).

Rocky headlands exist at Scott Point, The Bluff (Mangonui Rocks), and at Tauroa Point. The reef at Tauroa Point is extensive and extends out subtidally to at least 40 m water depth. Subtidal habitat types off Tauroa Point include bare rock, shallow *Carpophyllum* sp. zones, localised *Ecklonia radiata* forests, and deeper, complex topography reefs with extensive red algae beds, sponges, and other encrusting invertebrates (Morrison, 2005).

The surrounding land, which was originally covered in native broadleaf forests prior to human occupation (Coster, 1983), is now highly modified and is primarily covered

[1] A deposition landform in which an island is attached to the mainland by a narrow piece of land such as a sandspit.
[2] Sodium feldspar ($NaAlSi_3O_8$) is also known as Albite, and calcium feldspar ($CaAl_2Si_2O_8$) is also known as Anorthite.
[3] Potassium Feldspars is a generic name for three very closely related minerals; Orthoclase, Sanidine, and Microcline; that all have the same chemical composition, $KAlSi_3O_8$.

with pine forests, pasture, and exotic plants (e.g. marram grass (*Ammophila arenaria*) and lupins (*Lupinus arboreus*). A number of dune lakes and swamps are also present behind the beach, and these wetland areas are still considered to be a highly natural environment (Shaw & Maingay, 1990).

Figure 1. **Map of Ninety Mile Beach, Northland with an insert map showing the location of the beach in the North Island. (Map adapted from Land and Information New Zealand topographic map 242.1).**

3. Flora of Ninety Mile Beach

3.1 Sand dune flora

Sand dune flora of Ninety Mile Beach includes a mixture of native and introduced species (marked by an asterisk). Sand sedge (*Carex pumila*) is found on the strandline, while pingao (or pikao) (*Desmoschoenus spiralis*), spinifex (*Spinifex sericeus*), and marram grass (*Ammophila arenaria*)* are sand-binders that are commonly found on the foredunes, and less frequently, sand convolvulus (*Calystegia soldanella*) and ice plants (*Carpobrotus* spp.)*. Vegetation of the backdunes include; *Muehlenbeckia complexa*, bulrush (*Scirpoides nodosa*), *Cassinia retorta*, sand coprosma (*Coprosma acerosa*), toetoe (*Cortaderia splendens*), lupin (*Lupinus arboreus*)*, kikuyu (*Pennisetum clandestinum*)*, and harestail (*Lagurus ovatus*)*; while vegetation of the slack area between the dunes includes the uncommon sand pimelea (*Pimelea arenaria*), giant umbrella sedge (*Cyperus ustilatus*), raupo (*Typha orientalis*), *Zoysia pungens*, flax (*Phormium tenax*), buffalo grass (*Stenotaphrum secundatum*)*, and pampas (*Cortaderia selloana*)* (Partridge, 1992; Conning, 1998; Rawnsley, 2006). The rare *Hydatella inconspicua* in present in the wetland areas behind the dunes (Shaw & Maingay, 1990). Dune areas north of The Bluff have a higher conservation value (13/20) than the more modified dunes on the southern end of the beach (8–12/20) (Partridge, 1992). Marram, lupins, and pine, which were initially planted to control beach erosion, have largely displaced the native species in certain dune and inland areas on Ninety Mile Beach (Shaw & Maingay, 1990). However, in recent years local volunteer groups have been restoring the sand dunes and replanting them with pingao (Walker, 2007).

Pingao and spinifex are anecdotally reported to be important for toheroa settlement. Pingao stabilises the sand dunes and traps sea foam, which is though to facilitate the settlement of toheroa spat high on the shore, whereas, spinifex seed heads are thought to facilitate the dispersement of spat across the beach. Spat attached to spinifex seed heads are deposited across the beach when the seed heads are blown around (Department of Conservation, 2006). However, no information could be found that shows that these claims have been scientifically validated.

3.2 Macroalgae

Intertidal macroalgae is present on the lower regions of rocky headlands at The Bluff Scott Point, and Tonatona Beach. Species present include the red algae; *Corallina officinalis, Champia laingii, Melanthalia abscissa, Gigartina alveata, Osmundaria colensoi,* and *Plocamium costatum*; the brown alga *Scytothamnus australis*, and algal turf (Alfaro, 2006). Twenty one species of algae and five hydroid species have been identified from beach-cast seaweed on Ninety Mile Beach (Table 1), but the origin of these seaweeds is unknown. It is possible that large subtidal beds of macroalgae occur in deeper waters around the region.

Table 1. Species of drift algae and hydroids found with attached mussel spat on Ninety Mile Beach.

Algal Type	Species	Reference
RED ALGAE	*Champia laingii*	Alfaro (2001)
	Gigartina alveata	Hickman (1976)
	Gigartina marginifera	Alfaro (2001)
	Haliptilon roseum	Alfaro (2001)
	Laurencia thyrsifera	Alfaro (2001)
	Melanthalia abscissa	Alfaro (2001)
	Osmundaria (Vidalia) colensoi	Hickman (1976); Alfaro (2001)
	Pachymenia himantophora	Hickman (1976)
	Pachymenia lusoria	Alfaro (2001)
	Plocamium costatum	Alfaro (2001)
	Rhodymenia dichotoma	Alfaro (2001)
	Pterocladia lucida	Alfaro (2001)
	Pterocladia capillacea	Alfaro (2001)
BROWN ALGAE	*Carpophyllum maschalocarpum*	Hickman (1976)
	Carpophyllum angustifolium	Alfaro (2001)
	Cystophora retroflexa	Hickman (1976)
	Cystophora torulosa	Hickman (1976)
	Durvillaea antarctica	Hickman (1976)
	Ecklonia radiata	Hickman (1976)
	Lessonia variegata	Hickman (1976)
GREEN ALGAE	*Codium fragile*	Hickman (1976)
HYDROIDS	*Amphisbetia bispinosa*	Alfaro (2001)
	Dictyocladium moniliferum	Alfaro (2001)
	Crateritheca insignis	Alfaro (2001)
	Aglaophenia acanthocarpa	Alfaro (2001)
	Lytocarpia incisa	Alfaro (2001)

4. Fauna of Ninety Mile Beach

4.1 Toheroa

4.1.1 Toheroa biology

Toheroa (*Paphies ventricosa*) are large intertidal surf clams of the family Mesodersmatidae. They inhabit exposed, open coast, fine sand beaches, and are primarily found in the middle of the eulittoral zone, buried up to 20 cm below the surface. Toheroa were once abundant on Northland, Wellington, and Southland beaches, but populations have declined to such an extent that they are now rarely found and harvesting is prohibited.

Adults have separate sexes with a 1:1 sex ratio, and most animals reach sexual maturity when they are greater than 32 mm in length. Redfearn (1974) estimated that it would take toheroa between 9 and 15 months to reach sexual maturity, but recent growth estimates of South Island toheroa suggest that toheroa could reach sexual maturity in well under one year (Beentjes & Gilbert, 2006). Toheroa are broadcast spawners and mature females can release 15 to 20 million eggs during a single spawning event. Gametogenesis occurs over winter and the main spawning period is between September and March, though minor spawning peaks have been observed between May and July, and trickle spawning can occur at any time during the year. Histological studies show that gonads rapidly redevelop within one month following spawning, indicating that adults may spawn two or three times within the spawning season (Redfearn, 1974, 1982, 1997). Smith (2003) hypothesised that toheroa must have a spawning cue to synchronize their spawning, otherwise the chance of fertilization occurring in such a turbulent environment is likely to be very small. He studied the relationship between toheroa spawning and the lunar cycle, and his results suggest 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.

Larvae spend between 14 and 25 days in the plankton before metamorphosing and settling at around 270–300 μm length. Toheroa spat are washed ashore and settle on the beach just below 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, 1997). Although spat do not settle directly into adult beds, Smith (2003) found that juvenile (<32 mm length) densities on the upper shore were significantly higher in areas where adult beds were present lower on the shore, compared to areas where no adult beds were present. It is not known whether this adult/spat association is the result of a larval attraction to adult toheroa (e.g. by chemical cues), or whether onshore water currents regularly deposit planktonic larvae at the same sites along the beach.

Toheroa are filter feeders, consuming phytoplankton and organic debris up to 25 µm in size. Cassie (1955) observed that dense phytoplankton blooms were a common occurrence on all beaches where toheroa are present, and he hypothesized that toheroa relied on these blooms to obtain sufficient nutrients. The diatom, *Chaetoceros armatum*, is one of the predominant phytoplankton species at Ninety Mile Beach, accounting for 78–96% of the phytoplankton in the water during May (Rapson, 1954).

Growth rates of toheroa have been estimated by measuring shell rings, which are assumed to be laid down annually. If shell rings are annual, then North Island toheroa are estimated to reach 43 mm in one year and 100 mm in 4–5 years (Cassie, 1955; Redfearn, 1974). It should be noted that 'annual' shell rings of toheroa have not been validated and therefore these growth and longevity estimates may be inaccurate. Beentjes & Gilbert (2006) estimated the growth rates of South Island toheroa from mark and recapture data. Predicted growth rates were much faster than those of Cassie (1955) and Redfearn (1974), with toheroa predicted to reach 80 mm in one year and 100 mm in three years. Growth was substantially slower in larger animals with adults reaching a maximum size of 155 mm. It is not known whether the difference in growth rates between North and South Island toheroa are real differences, or whether growth estimates of North Island toheroa based on annual shell rings are inaccurate. Toheroa are estimated to live for more than 20 years (Cassie, 1955; Brunton, 1978; Beentjes & Gilbert, 2006).

Toheroa utilise the swash of waves to move up and down the beach, with movement mainly occurring at night. The shellfish emerge out of the sand with their siphons extended. 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). Entire adults beds are anecdotally 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). Tagging experiments have shown that while the majority of animals are sedentary, some tagged individuals move several miles from their release point (Greenway & Allen, 1962). Anecdotal reports state that adult toheroa are more common in areas where freshwater runs down the beach, and in small embayments. These embayments remain covered by the tide for longer than the rest of the beach, and thus, toheroa living there have a lower desiccation risk. Eddy currents may also concentrate phytoplankton and toheroa larvae within the embayments (Rapson, 1952; Cassie, 1955; Smith, 2003). Waugh & Greenway (1967) suggested that subtidal populations of toheroa exist after finding a number of toheroa shells that had been drilled by predatory gastropods. Given that predatory gastropods were not present on the beach the authors concluded that toheroa must also live subtidally. However, there is no direct evidence that subtidal populations of toheroa exists.

Mass mortalities of toheroa populations occur occasionally, especially during summer. In 1930 heavy toheroa mortality was reported on a 13–16 km stretch of Ninety Mile Beach after being suffocated by dry sand that was blown down from the dunes. High mortalities of approximately 15 to 20 million toheroa were also reported in the summers of 1932 and 1938 (Cassie, 1955), and again in 1945, and 1970–1971. These mortality events were thought to be caused by high temperatures and calm surf conditions which resulted in the tides not covering the toheroa beds for several days (Rapson, 1954; Greenway, 1972; Stace, 1991; Redfearn, 1997). Toheroa may be more susceptible to desiccation than the closely related tuatua (*Paphies subtriangulata*), as they live higher on the shore and they cannot completely close their shell. Instead, the gaps between the valves are covered by folds of the mantle (Redfearn, 1974, 1997). No specific diseases or parasites are known to affect toheroa, but this is likely to be because of a lack of knowledge, rather than a lack of diseases that affect toheroa.

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. However, given the currently depleted populations of toheroa on Northland beaches, the number of toheroa consumed by gulls is likely to be significantly less. Gulls also readily eat tuatua, which are extremely abundant on Ninety Mile Beach. Oystercatchers (*Haematopus* spp.) have been observed preying on toheroa by inserting their bill into the sand and twisting open the toheroa's shell (Stace, 1991). Fish, particularly snapper (*Pagrus auratus*), consume juvenile toheroa whole, but will just bite the siphons off adult toheroa, leaving them to die (Redfearn, 1974). Paddle crabs (*Ovalipes catharus*) also prey on toheroa; juvenile shellfish are eaten whole, while the muscles of adult toheroas are slowly snipped away until the shell opens (Stace, 1991).

Very large, dead toheroa shells that are much heavier and bulkier than shells of live animals can been found on Ninety Mile Beach. Carbon dating indicates that some of these shells are over 1000 years old, and it is speculated that these shells may be subfossils of a species (or sub-species) of toheroa that is now extinct (Cassie, 1955; Stace, 1991). There are also anecdotal reports of giant toheroa presently living in subtidal populations (Stace, 1991), but no one has ever caught a live giant toheroa.

4.1.2 Commercial and recreational toheroa harvesting

Commercial harvesting for toheroa began in the late 1800s with the vast majority of the commercial harvest canned. Very little fresh toheroa was sold, as the shellfish cannot survive long out of water owing to its inability to completely close its valves (Mestayer, 1921). Total commercial production for Northland beaches (Dargaville, Ninety Mile Beach, and Murawai) was typically around 20 tonne per annum of canned product, with a record production of 77 tonnes in 1940 (approximately 1.5 million toheroa (Cassie, 1955)) (Fig. 2). In 1923 a toheroa cannery opened on Ninety Mile Beach that operated for three months of the year and processed around 576,000 toheroa per annum. The cannery closed in 1945 because poor harvest levels made production uneconomic, but it reopened briefly between 1962 and 1964 when the toheroa population at Ninety Mile Beach briefly resurged to an estimated 25 million animals. Commercial quotas were introduced in 1962 based on annual population surveys, but this was insufficient to stop the rapid decline in population numbers and all commercial harvesting ceased in 1969 (Redfearn, 1974, 1997).

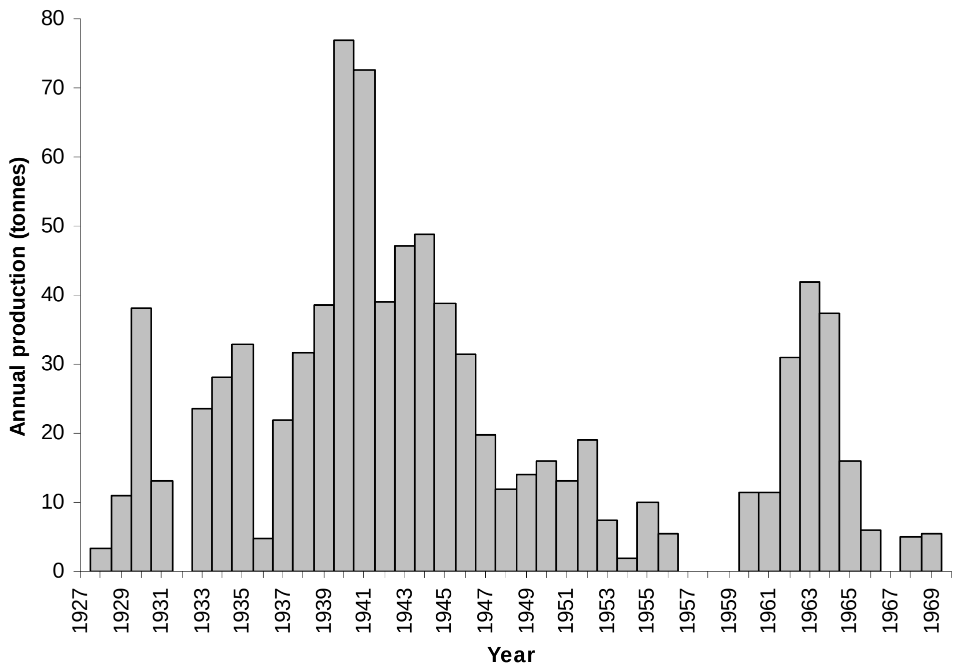

Figure 2. Commercial production of canned toheroa from Northland canneries (Dargaville, Ninety Mile Beach, and Murawai Beach) from 1928 to 1969. (Data from Rapson, 1954; Cassie, 1955; Redfearn, 1974).

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 to; 1) a daily limit of 50 toheroa for Europeans, 2) a minimum size limit of 76 mm, and 3) a 2 month closed season from October to November. Despite the harvest restrictions the rate of exploitation continued to increase, and 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. In 1968 the harvest restrictions were further amended 10 toheroa per person per day with harvesting only permitted during two weeks in September. However, toheroa population numbers continued to decline and in 1971 Ninety Mile Beach was closed to all toheroa harvesting (Greenway, 1972; Redfearn, 1974). Adult populations have still not recovered to a level that would allow any sustainable harvest, and no toheroa harvesting is permitted within New Zealand, with the exception of limited customary harvests. Illegal fishery of toheroa may have a significant impact on population levels. No recent estimates are available on the size of illegal or customary toheroa harvests.

4.1.3 Toheroa population monitoring

Monitoring of toheroa populations has been carried out sporadically since 1933. Historically, population sizes have varied greatly for year to year as populations appear to be susceptible to major mortality events, and large spatfalls are irregular and unpredictable. Toheroa populations at Ninety Mile Beach are also anecdotally reported to have disappeared in 1888, 1900, and 1917, prior to the commencement of population monitoring (Cassie, 1955).

Figure 3A shows estimated toheroa population size at Ninety Mile Beach between 1939 and 2006. No overall trend in population levels is apparent; instead the toheroa population at Ninety Mile Beach has oscillated wildly over the last 70 years. Toheroa numbers were very high in 1941 with an estimated 35 million animals present on Ninety Mile Beach. However, a mass mortality event occurred in 1945 and by 1946 the population had dramatically declined to around 6 million animals. Population levels continued to decline, and by 1948 the population was estimated at zero, as only one toheroa was found in the 1948 survey of 53 km of the beach (Cassie, 1955). The toheroa population resurged in 1962 with an estimated 25 million animals on the beach, but it crashed again in 1965. Similarly, there was a brief resurgence in the population in 1970 to 29.7 million animals, but a mortality event in the summer of 1970–1971 caused the population to drop to 3.7 million animals in 1972. Between 1973 and 1986 numbers of toheroa at Ninety Mile Beach remained very low (<3 million animals). No toheroa surveys were conducted at Ninety Mile Beach between 1986 and 2000. In 2000 there were an estimated 51.6 million toheroa on Ninety Mile Beach, the largest population recorded on the beach since surveys began in 1933. The vast majority of the population were juveniles, with around 66% of the population less than 35 mm in length. However, the extremely high recruitment in 2000 did not increase the number of adult toheroa in subsequent years, and by 2006 the population had dropped to 8.8 million. The majority of the 2006 population consisted of new recruits (<50 mm), with only one animal found that was over 75 mm in length (Morrison & Parkinson, 2008).

Figure 3B shows the estimated number of toheroa >76 mm and <35 mm. Numbers of large toheroa fluctuated between 0 and 12 million between 1933 and 1971, but have remained consistently low since 1971. Examination of the percentage of recruits (<35 mm) in the toheroa populations suggests that populations prior to 1970 were dominated by adult toheroa, whereas, toheroa populations in 2000 and 2006 were dominated by new recruits. It should be noted that this apparent shift in population dynamics may be a sampling artifact. It is most likely that the number of juvenile toheroa on the beach was underestimated in surveys conducted prior to 2000 because quadrats were dug out with a potato fork and sorted by hand. In later surveys juveniles down to 5 mm length were reliably detected by sieving the quadrats (Morrison & Parkinson, 2001). Furthermore, early surveys only sampled the mid-tide level where adults mainly lived, while the 2000 and 2006 surveys sampled a cross section of the beach from the high water mark to the low water mark, which encompassed both the juvenile and adult habitats.

Toheroa recruitment on Ninety Mile Beach appears to be sporadic and unpredictable, and the factors that influence recruitment are poorly understood. Historically beds of newly settled juveniles extended for many kilometres along the beach (Redfearn, 1974). There appears to be some correlation between high spatfalls and the occurrence of dense phytoplankton blooms (mainly *Chaetoceros armatum*) that occur in late winter and early spring (Redfearn, 1997), but these observations have not been vigorously tested. Large numbers of recruits (<35 mm) do not necessarily lead to high numbers of adult toheroa in subsequent seasons, such as in 1970 and 2000. Conversely, population resurgences are not always preceded by high numbers of recruits, such as in 1962, 1963, and 1970 (though the number of juveniles in these years is likely to have been underestimated). Recruitment into the adult population may be limited by large scale mortality events, poaching, mortality caused by vehicle traffic, physical or chemical changes to the habitat, or changes in food availability (Morrison & Parkinson, 2008).

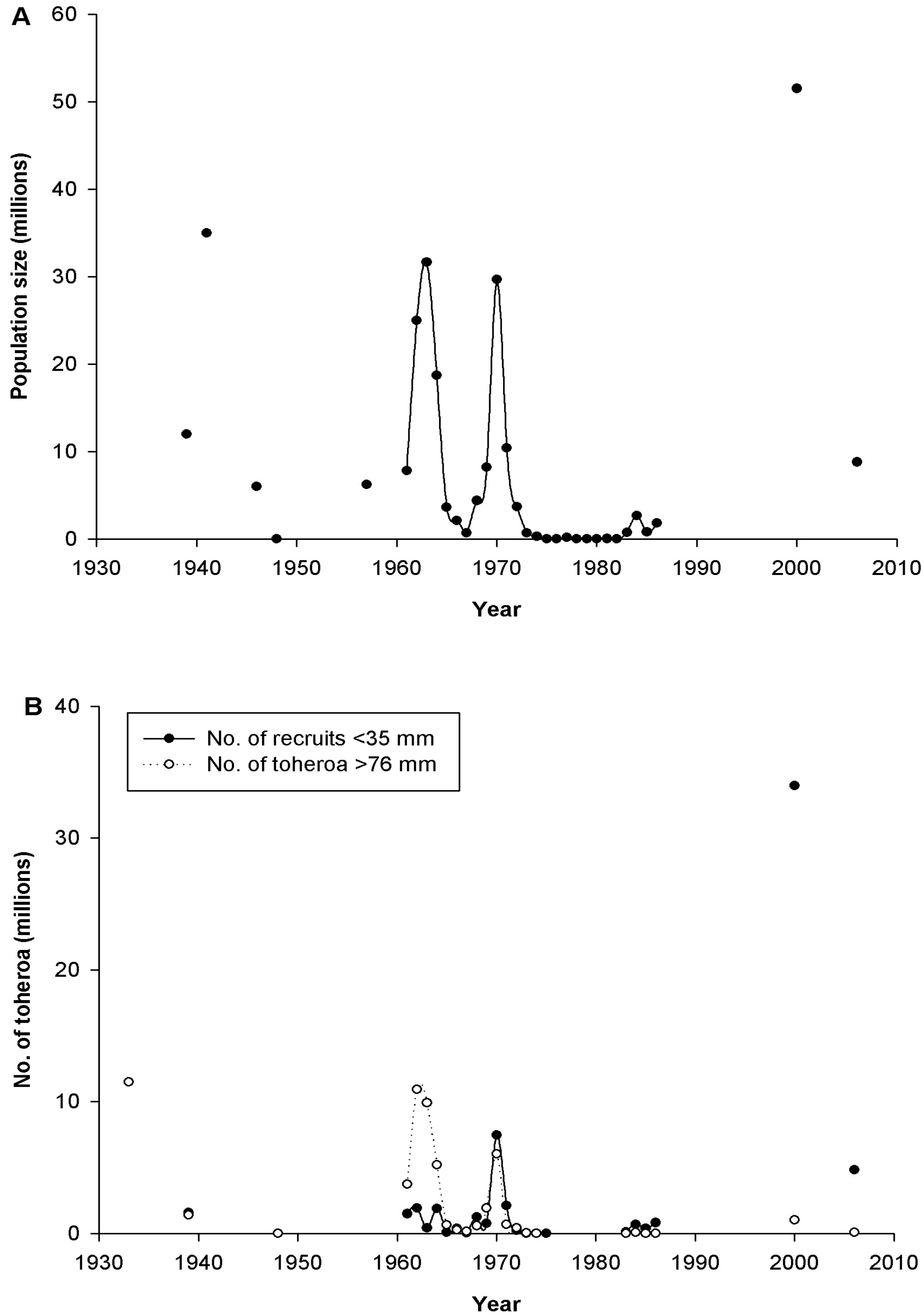

Figure 3. **A) Estimated population size of toheroa at Ninety Mile Beach between 1933 and 2006, and B) Estimated number of toheroa >76 mm and <35 mm. Numbers of toheroa in each size class were calculated from length-frequency data. Between 1963 and 1970 population surveys were conducted before and after the harvesting season. The average of these estimates is given here. (Data from Rapson, 1952; Cassie, 1955; Greenway & Allen, 1962; Greenway, 1969, 1972, 1974; Redfearn, 1974; Morrison & Parkinson, 2001, 2008).**

4.2 Green-lipped mussels

Green-lipped mussels (*Perna canaliculus*) are New Zealand's primarily aquaculture product generating US$342 million in sales in 2007 (FAO Fisheries Department, 2009). Mussel aquaculture in New Zealand is based on a unique resource — the vast quantity of mussel seed attached to drift seaweed that only washes ashore on Ninety Mile Beach. Locally known as "Kaitaia spat", the mussel seed and seaweed are collected from the surf zone of the beach, shipped to the mussel farms around the country, and attached to suspended culture ropes using biodegradable mesh stockings. Aquaculture production has increased from 300 tonnes in 1977 to 99,500 tonnes in 2007 (FAO Fisheries Department, 2009), of which, around 80% originates from Kaitaia spat (Jeffs, 1999).

4.2.1 Mussel biology

Green-lipped mussels have separate sexes with a 1:1 sex ratio. Mussels can reach sexual maturity within their first year, from 27 mm shell length, and the majority of mussels are mature by 40–50 mm length (Alfaro, 2001). Mussels are broadcast spawners and females can produce up to 10 million eggs per season (Jenkins, 1985). Histological studies show that mussels have an annual, synchronised reproductive cycle, with gametogenesis occurring in later autumn/winter and spawning occurring from June to December, with peak spawning occurring in late winter/spring (June–October). Gonads rapidly redevelop after spawning, indicating that mussels are likely to spawn multiple times throughout the year (Buchanan, 1994; Alfaro, 2001). Mussels may trickle spawn anytime throughout the year, and consequently minor settlements of spat may occur all year round (Buchanan, 1994). Northern mussel populations appear to have a much longer spawning season than southern populations, probably because of the higher water temperatures (Alfaro, 2001).

Larvae spend between 28 and 42 days in the plankton before metamorphosing and settling at a length of 220–350 μm (Booth, 1977). Green-lipped mussels exhibit primary and secondary settlement behaviour, that is, larvae initially prefer to settle on fine, filamentous substrata such as filamentous algae, where they stay until they are about 6 mm long, before moving to adult mussel beds. The spat facilitate their transport into adult beds by producing long mucus threads that increases the viscous drag on the mussel allowing them to drift in the currents. Known as "bysso-pelagic drifting", small spat may use this technique to resettle numerous times before finally settling in adult mussel beds (Buchanan, 1994; Buchanan & Babcock, 1997).

Field studies at Ninety Mile Beach show that the abundance of green-lipped mussel larvae in the plankton correlates to the reproductive cycle of adults mussels. Late-stage mussel larvae were most abundant in July with a mean abundance of 506 ± 90 S.E. larvae/1000 L. Larvae abundance decreased with time over spring and early summer to less than 60 larvae/1000 L in January. Larvae densities were generally higher at the southern end of the beach where substantial intertidal and subtidal mussel populations are present. It is possible that current eddies retain larvae in this region (Alfaro *et al.*, 2004).

Abundance of spat on beach-cast seaweed, intertidal rocks, and on suspended spat collecting ropes at Ninety Mile Beach also correlates to both the reproductive cycle of adult mussels and larval abundance (Alfaro & Jeffs, 2003; Alfaro *et al.*, 2004; Alfaro, 2006). Beach-cast spat was available throughout the year with highest abundances recorded in August (1.5 million mussels/kg wet material). Spat abundance gradually decreased over spring/summer to reach minimum levels in March (21,000 mussels/kg wet material). Spat range in size from <0.1 mm to >3 mm in length, with the majority of spat between 0.7–1 mm. The mean mussel size increased steadily with time, with the smallest mussels (<0.5 mm) most abundant in August and the largest mussels (>2 mm) most abundant in January. This increase in mussel size with time indicates that the majority of spat originated from a major spawning event that occurred in June–July, and were just washed ashore at different times of the year (Alfaro *et al.*, 2004; Jeffs *et al.*, 2005). Similar abundance patterns were observed for spat that settled on intertidal rocks and on suspended spat collecting ropes deployed off Ninety Mile Beach. Analysis of the distribution of spat on seaweed washed ashore at Ninety Mile Beach show that spat preferentially settle on hydroids (57 ± 4% S.E. mussels/cm^2), followed by fine-branching algae (28 ± 2 % S.E. mussels/cm^2), then medium-branching algae (8 ± 2% S.E. mussels/cm^2), and finally, coarse-branching algae (7 ± 2% S.E. mussels/cm^2). A significant inverse relationship was found between mussel size and the coarseness of the substrata, i.e., small mussels preferred to settle on fine substrata while larger mussels preferred to settle on coarse-branching algae (Alfaro & Jeffs, 2002).

The location of adult mussel beds that produce Kaitaia mussel spat is unknown. Historical records show that large mussel populations existed at Tauroa Point (Reef Ponit) at the southern end of Ninety Mile Beach, and at Herekino, Whangape, and Hokianga harbours (Hickman, 1979). The current status of the populations in the Herekino, Whangape, and Hokianga harbours are unknown, but two subtidal mussel populations were found at Tauroa Point in 1999. In addition, four intertidal populations were also found at Tonatona Beach, Ungaunga Bay, The Bluff, and Scott Point in 1999 (Alfaro 2001) (see Fig. 2 for locations). The subtidal mussel populations at Tauroa Point are localised, high-density beds that occur both in very shallow waters (from intertidal down to 3–5 m), and in deeper waters (15–30 m) (Jeffs, 2003; Morrison, 2005). However, the combined reproduction output of the known mussels beds around Ninety Mile Beach is unlikely to be able to produce the vast quantities of spat stranded on the beach each year (Jeffs *et al.*, 2005). A comprehensive side scan sonar survey conducted along the length of Ninety Mile Beach failed to detect any other subtidal populations (Jeffs, 2003). Furthermore, the source of macroalgae that is washed ashore with the spat is also unknown. Twenty one species of algae and five hydroid species have been found on Ninety Mile Beach with attached mussel spat (see Table 1). A search of the rocky intertidal areas around Ninety Mile Beach failed to find significant quantities of live algae of these species, and thus, it is most likely that drift algae originate from subtidal beds (Alfaro, 2001).

The population dynamics of the intertidal mussel populations on Ninety Mile Beach varied greatly with location. The population at Scott Point was very dynamic with almost 100% turnover each year. Average population density was 1133 ± 140 S.E. mussels/625 cm^2, but density varied from 1946 mussels/625 cm^2 in August 1999 to 56 mussels/625 cm^2 in July 2000, back to around 1800 mussels/625 cm^2 in August 2000. These large fluctuations were caused by high mortalities of adults mussels in winter followed by very strong recruitment in spring. During winter great quantities of adult mussels were observed dying off, with diminished tissues and gaping valves. Strong wave action also detached whole sheets of mussels off the rocks. Alfaro (2006) hypothesized that the mass mortality of mussels observed at Scott Point was the result of localised limited food availability, caused by the accumulation of vast quantities of drifting Kaitaia spat near Scott Point. In contrast, the mussel populations at The Bluff and Tonatona Beach were much smaller and more static, with mean densities of 119 ± 5 S.E. and 308 ± 34 S.E. mussels/625 cm^2, respectively, and moderate recruitment and mortality (Alfaro, 2001, 2006). The smaller populations at The Bluff and Tonatona Beach may be caused by recreational harvesters continually removing mussels from the populations, as these two lower sites are more accessible to residents. This hypothesis is supported by the fact that recovery rates of tagged mussels was lower at The Bluff (19%)and Tonatona Beach (35%), than Scott Point (63%), despite Scott Point have the highest population turnover (Alfaro, 2008).

Mussels grown in suspended culture reach 111–115 mm in their first year, and 195 mm in three and a half years (Ministry of Fisheries, 2008). However, growth of intertidal mussels at Ninety Mile Beach is significantly slower. Alfaro *et al.* (2008) compared the growth of mussels in intertidal beds at Scott Point, The Bluff, and Tonatona Beach. Growth was found to vary significantly with site, with young mussels (20–30 mm length) at Scott Point growing the fastest (72 ± 1.3 S.E. mm/year), mussels at Tonatona Beach showing intermediate growth (49 ± 1.0 S.E. mm/year), and mussels at The Bluff growing the slowest (32.0 ± 0.5 S.E. mm/year). Similarly, Hickman (1979a) found that intertidal mussels at Ahipara Bay grew approximately 35 mm in their first year. It should be noted that Hickman's growth estimates may be inaccurate as they were based on cohort analysis of length-frequency data. The large variances in growth rates between intertidal mussel populations at Ninety Mile Beach indicate that environmental conditions that are important for mussel growth vary significantly along the beach, with the most favourable conditions present at the northern end of the beach (Scott Point).

Green-lipped mussels have several natural parasites including; the digeneans *Cercaria haswelli* (Jones, 1975b) and *Bucephalus* sp. (Alfaro *et al.*, 2001), the protozoan *Nematopsis* spp. (Jones, 1975a), the pea crab *Pinnotheres novaezelandiae* (Jones, 1975b), and the copepods *Pseudomyicola spinosus* and *Lichomolgus uncus* (Jones, 1976); however, infection rates are generally low and none of the parasites are known to cause serious mortalities. Very little information is available on bacterial or viral diseases that affect mussels. High mortalities in wild mussels from the west coast of South Island and recently reseeded mussel spat from the Marlborough Sounds have been associated with an RNA virus (Jones *et al.*, 1996), but there have been no reports on diseases that affect mussels on Ninety Mile Beach.

Harmful algae blooms are a sporadic problem at Ninety Mile Beach for the mussel industry, mainly because of transfer bans and negative publicity, though intense blooms are capable of killing mussels (Wear & Gardner, 2001). In the summer of 1992–1993 a major *Gymnodimium breve* bloom occurred in northern New Zealand, and a second harmful alga, *Alexandrium* sp., was found in algae associated with Kaitaia spat (Lupi, 1993). As a result, the Ministry of Fisheries temporarily banned all transfer of bivalves between the North and South Island to prevent *Gymnodimium breve* from being transferred to the Marlborough Sounds (MacKenzie *et al.*, 1995). A similar ban was implemented in 2000–2001 when a *Gymnodinium catenatum* bloom occurred in Northland, which resulted in a serious shortage of spat for the mussel industry for almost a year (Taylor, M.D. & MacKenzie, 2001).

4.2.2 Commercial harvesting of Green-lipped mussel spat

The appearance of Kaitaia spat on Ninety Mile Beach was first recorded in 1974 in a routine survey of the beach. It was estimated that more than 1000 kg of seaweed and spat were washed ashore on Ninety Mile Beach with an average density of 210,000 mussels/kg (Hickman, 1975, 1982). The possibility of using Kaitaia spat for mussel aquaculture occurred immediately, but it was uncertain how frequently spat strandings occurred (Hickman, 1976). A second stranding of approximately 50,000 kg of seaweed and spat was recorded in 1978 and 500 kg of this material was used for aquaculture trials (Hickman, 1979b). Since 1978 the beach has been regularly monitored for spat strandings and the mussel spat commercially harvested. Spat can arrive at any time of the year but strandings are most frequent in spring (Aug–Dec), and to a lesser extent, autumn (May–Jun) (C. Hensley, Kaitaia Spat, pers. comm.). Strandings occur most years but the timing and quantity of strandings are highly variable, from a few kilograms to tens of tonnes (Hickman, 1982; Bartrom, 1983; Alfaro *et al.*, 2004). The spat and seaweed appear to be brought ashore under easterly winds and low swell conditions, and generally travel northwards along the beach. There also appears to be a relationship between storm events and strandings, which may be because storms increase the detachment of algae from the sea bed (Alfaro, 2001; Jeffs *et al.*, 2005; Alfaro, 2006).

Mussel spat harvesters collect the spat material from the surf zone using hand-held nets, pitch forks, rakes, and tractors. The material is loaded onto tractors, trailers, and trucks, which are frequently driven into the water, and towed off the beach, to be sorted, packed, and transported in refrigerated trucks to mussel farms around the country (Sim-Smith *et al.*, 2007). Prior to 2004 the mussel spat fishery was managed by limiting the number of fishery permits, which permitted the hand gathering of spat material between high water springs and 100 m beyond low water springs. Six fisheries permits were issued by the Ministry of Agriculture and Fisheries between 1984 and 1997 (Walshe, 1997). On 1 October 2004 green-lipped mussel spat was introduced into the Quota Management System (QMS), with a total allowable commercial catch (TACC) of 180 tonnes of mussel spat (which equates to 360 tonnes of spat and seaweed). Current harvest levels are below the TACC, with 136.9 tonnes of spat harvested in 2006–2007 (Ministry of Fisheries, 2008).

Figure 4 shows the quantity of Kaitaia spat harvested from Ninety Mile Beach between 1989 and 2007. Harvest quantities increased between 1989 and 1999, and then suddenly decreased in 2000 because of restrictions placed on spat transfers around the country to prevent the transfer of *Gymnodinium catenatum* from North Island to South Island. Harvest totals in 2001 were unusually high because the mussel industry compensated for the shortfall in supply from the previous year. Since 2001 harvest quantities have fluctuated between 90 and 270 tonnes of spat material. Spat collectors harvest on demand owing to the very limited time that spat can remain out of the water, and therefore, the harvest totals are more likely to be a reflection of demand rather than the quantity of spat available on the beach. No scientific estimates are available on the quantity of spat washed ashore on Ninety Mile Beach each year. There is little agreement amongst spat harvesters have as to whether the quantity of spatfall has changed over the years. Some harvesters believe that less spat has arrived in recent years, whereas other harvesters believe that the same amount of spat is available, but that competition for the material had increased. However, all spat harvesters are in agreement that in most years the quantity of spatfall is in excess of harvest demands. It is also likely that a sizeable quantity of spat material remain offshore and never get washed onto the beach (Jeffs *et al.*, 2005).

Although mussel spat has been harvested from Ninety Mile Beach for over 40 years little is known about the fishery and its impact on the environment, such as the source of the spat and algae that compose Kaitaia spat, the ecological and physical processes that deliver Kaitaia spat to the beach, the effects of harvesting on the recruitment to local mussel populations, and the effects of removing seaweed and spat from the beach ecosystem. Overseas studies have shown that beach-cast seaweed plays an important role in the beach ecology, providing a source of nutrition for shore invertebrates e.g. sand hoppers, and in turn seabirds which may feed on the invertebrates (Stephenson, 2001), but this has not been studied at Ninety Mile Beach.

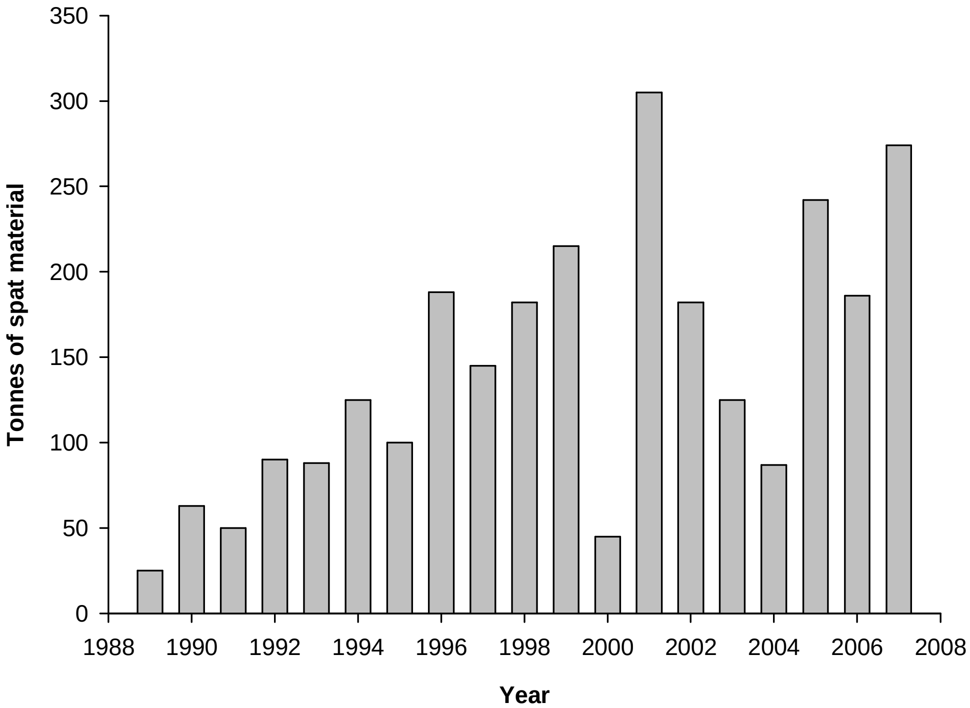

Figure 4. Total quantity of spat material harvested from Ninety Mile Beach between 1989 and 2007. Note that for 2005–2007 the data actually corresponds to the year between 1 Oct and 30 Sep, e.g. for 2005 the actual period is 1 Oct 2004 to 30 Sep 2005. (Data from Jeffs *et al.*, 2005; Ministry of Fisheries, 2008).

4.3 Other beach fauna

4.3.1 Intertidal beach fauna

The diversity of macroinvertebrate fauna on Ninety Mile Beach is very low. Sim-Smith *et al*. (2007) conducted a survey of the macroinvertebrate fauna of the beach and only found 13 species within the sandy intertidal region; three bivalves (tuatua, toheroa, and triangle shell (*Spisula aequilatera*)), three crustaceans (ghost shrimp (*Callianassa filholi*), mantis shrimp (*Squilla armata*), and swimming crab (*Ovalipes catharus*), two echinoderms (brittle star (*Ophionereis fasciata*) and sand dollar (*Fellaster zelandiae*), three unidentified polychaetes, and two unidentified nermertean worms. Of these species, only tuatua had a density above 1 individual (ind.)/m^2 on the beach.

Tuatua (*Paphies subtriangulata*) are by far the most abundant macroinvertebrate on Ninety Mile Beach. Closely related to the toheroa, this surf clam inhabits the lower intertidal to shallow subtidal regions of the beach, down to water depths of 4 m (Morley, 2004). Tuatua have a very patchy distribution, forming discrete beds along the beach, with densities of up to 500 ind./m^2 (Hooker & Redfearn, 1998; Sim-Smith *et al.*, 2007). In 2006 there were an estimated 486 million tuatua on Ninety Mile Beach, the majority of animals between 30–60 mm in length (Morrison & Parkinson, 2008).

No information is available on the meiofauna or microfauna (animals <1 mm in size) that inhabit Ninety Mile Beach.

4.3.2 Fauna of the sand dunes

Very little specific information is available on the fauna of the sand dunes at Ninety Mile Beach. Two crustaceans, the sand hopper (*Talorchestia quoyana*) and the sea slater (*Scyphax ornatus)* are common on the upper shore and dunes (Shaw & Maingay, 1990), and the coastal tiger beetle, *Neocicindela pehispida*, is present in the sand dunes. Coastal tiger beetles prefer to inhabit open sand dunes, rather than vegetated areas, and their distribution is often restricted by the growth of marram grass on the sand dunes (Wise, 1988).

The introduced yellow flower wasp (*Radumeris tasmaniensis*) was first discovered in New Zealand in 1999 and is now well established in the Far North region. It is a parasitoid of scarab beetle (Family: Scarabaeidae) and its primary host in the Far North region is the sand scarab (*Pericoptus* spp.). Thousands of yellow flower wasps have been observed at Waikoropupunoa Stream (Butlers Creek) at the northern end of

Ninety Mile Beach. The wasps are mainly confined to the inner dune region with 96% of wasp sightings recorded from the inner dune region. The potential impact that yellow flower wasps may have on native species, particularly scarab beetles, is currently unknown (Rawnsley, 2006).

4.4 Birds

Numerous species of seabirds have been sighted around Ninety Mile Beach including thin-billed prions (*Pachyptila belcheri*), broad-billed prions (*Pachyptila vittata*), fairy prions (*Pachyptila turtur*), blue petrels (*Halobaena caerulea*), mottled petrels (*Pterodroma inexpectata*), common diving petrels (*Pelecanoides urinatrix*), short-tailed shearwaters (*Puffinus tenuirostris*), sooty shearwaters (*Puffinus griseus*), grey-headed mollymawks (*Diomedea chrysostoma*), light-mantled sooty albatrosses (*Phoebetria papebrata*), Arctic skua (*Stercorarius parasiticus*), white-fronted terns (*Sterna striata*), Australasian gannets (*Morus serrator*), banded dotterels (*Charadrius bicinctus*), bar-tailed godwits (*Limosa lapponica*), wrybills (*Anarhynchus frontalis*), turnstones (*Arenaria interpres*), great knots (*Calidris tenuirostris*), pied shags (*Phalacrocorax varius*), little black shags (*Phalacrocorax sulcirostris*), black shags (*Phalacrocorax carbo*), reef herons (*Egretta sacra*), white-faced herons (*Ardea novaehollandiae*), pied oystercatchers (*Haematopus ostralegus*), pied stilts (*Himantopus himantopus*), black-backed gulls (*Larus dominicanus*), red-billed gulls (*Larus novaehollandiae*), kingfishers (*Halcyon sancta*), and blue penguins (*Eudyptula minor*) (Watola, 1986; Powlesland, 1987; Shaw & Maingay, 1990; Burger *et al.*, 1994; Taylor, G.A., 2004). The migration route of many of these birds travels over Ninety Mile Beach and huge flocks are sometimes observed. For example, an estimated 50,000–70,000 thin-billed prions and around 4000 short-tailed shearwaters were observed off Ninety Mile Beach in May 1986 by G. Watola (Watola, 1986).

Ninety Mile Beach is an important feeding area for three rare seabirds; the variable oystercatcher (*Haematopus unicolor*), the Northern New Zealand dotterel (*Charadrius obscurus aquilonius*), and the Caspian tern (*Sterna caspia*) (Shaw & Maingay, 1990). The variable oystercatcher and the NZ dotterel both feed on intertidal molluscs, worms, and crustaceans, while the Caspian tern primarily feeds on small fish (Heather & Robertson, 2005). Rare or unusual birds sighted or found dead around Ninety Mile Beach include the Oriential dotteral (*Charadrius veredus*) (Ogle, 1984), Leach's storm petrel (*Oceanodroma leucorhoa*)[4], New Caledonian petrel (*Pterodroma leucpttera caledonica*) (Taylor, G.A., 2004), red-tailed tropic bird (*Phaethon rubricauda*) (Powlesland & Pickard, 1992), White-bellied Storm petrel (*Fregetta grallaria*)

[4] Only six Leach's storm petrels have been recorded from New Zealand

(Powlesland, 1987), and Southern Royal Albatross (*Diomedea epomophora epomophora*) (Taylor, G.A., 1999).

Occasionally large mortality events occur that 'wreck' huge numbers dead seabirds on the beach. In September 1985 2992 dead fairy prions were found on Ninety Mile Beach. Wrecks of fairy prions are relatively common in Northland and it appears that the birds are susceptible to rough seas and poor food supplies (Powlesland, 1987). Similarly, in July 1998 989 common diving petrels and 378 blue penguins were wrecked upon Ninety Mile Beach. This mortality event occurred throughout the Northland and Auckland regions and was thought to be caused by a lack of food during winter (Taylor, G.A., 2004).

5. Human impacts on Ninety Mile Beach

5.1 Impacts of beach vehicle traffic

Little research has been conducted on the impact of vehicles on the benthic fauna of Ninety Mile Beach. Possible adverse effects of vehicle beach traffic include direct crushing of animals and vegetation, disturbance of seabird breeding and feeding behaviour, increased erosion of the sand dunes, and changes to the physical characteristics of the beach and dunes. In a review on the vehicle impacts on the biota of sandy beaches Stephenson (2001) generally concluded that vehicle traffic above the high water mark is highly destructive, but the impact of vehicles on the intertidal area during the day appeared to be minimal. However, the study highlighted the need for more research in the area, and certain species are likely to be more affected by vehicle traffic than others.

Ninety Mile Beach is a designated state highway and is subjected to high vehicular traffic. Up to 35 tourist buses per day drive along the beach in summer (Stace, 1991) and nearly 400 vehicles were counted travelling along the beach during one day of a recreational fishing contest[5] (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. The majority of vehicles are driven around mid-tide level where the sand is firm, but if the tide is high vehicles will travel higher on the shore where the sand is softer.

[5] The Snapper Classic Ninety Mile Beach surfcasting fishing competition is an annual 5 day event that attracts up to 1000 entrants (http://www.snapperclassic.co.nz/index.html).

There is good evidence that toheroa mortality can be caused by vehicle traffic along Ninety Mile Beach (Redfearn, 1974; Brunton, 1978; Hooker & Redfearn, 1998), though the percentage of toheroa mortality caused by vehicles is unknown. 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). Hooker and Redfearn (1998) found that 14%[6] of juvenile toheroa (6–23 mm) in a small bed were crushed after particularly heavy vehicle use of the beach during a large recreational fishing contest. It is thought that low levels of vehicle traffic on the beach do not cause significant mortality of adult toheroa, but may cause much higher mortalities in newly-settled toheroa, which live high on the beach and are only buried a few centimetres below the surface (Redfearn, 1997). Vehicle pressure may also cause toheroa to eject water from their mantle cavity as they contract, making them more prone to desiccation (Hooker & Redfearn, 1998), however, this hypothesis has not been tested.

The commercial harvesting of Kaitaia spat from Ninety Mile Beach involves extensive use of vehicles on the beach. During peak season the length of the beach is checked daily for the arrival of spat, and harvesting activities involve vehicles, which are sometimes heavily laden with spat, repeatedly driving on the lower half of the beach. Sim-Smith *et al.* (2007) investigated the ecological impact of mussel spat harvesting activities on the infauna that inhabit the low tide region of the beach. Of the species present in the samples (see Section 4.3.1), only tuatua were present in significant numbers to be analysed statistically. All other animals were present at densities of less than 1 ind./m^2. The results show that in the 24 hours after sampling an equivalent 3% mortality was observed in the control treatment (no vehicle pressure), and the experimental treatments (direct pressure from a tractor laden with ~550 kg). This 3% mortality was likely to be the result of accidental crushing of shellfish by spades during sampling, and thus the simulated harvesting activity had no effect on short-term mortality of tuatua. It should be noted that this study was specifically designed to compare the impact of two harvesting methods in the surf zone, and thus did not test the impact of vehicles on the middle and upper beach, the long-term impact of vehicle traffic, or the effect of numerous vehicle passes on benthic animals, as would be

[6] 26 out of 160 toheroa were crushed

experienced on the beach during certain event days e.g., recreational fishing contests. A similar study on South African macrofauna found that the intertidal gastropod, *Bullia rhodostoma*, was unaffected by five passes with a 4-wheel drive vehicle, but showed up to 8.6% mortality after 50 passes with the vehicle (Van der Merwe & Van der Merwe, 1991).

Further research is needed on the impact of vehicles on the benthic fauna of sandy beaches, particularly the impact of vehicles on juvenile toheroa, the effect on long-term survival of infauna, and the impact of vehicles on the upper shore.

5.2 Pollution

There are two residential settlements along Ninety Mile Beach, one at Ahipara and one at Waipapakauri. In recent years there has been substantial growth in the residential development at Ahipara, which puts increasing load on the stormwater system. Stormwater is a potential source of pollution to the beach and thirteen stormwater drains in the Ahipara area directly flow into streams or onto the beach. The Wairoa River, which has become polluted over the years, also spills out onto the beach at Ahipara (Walker, 2007).

Burger *et al.* (1994) compared the levels of six heavy metals in the feathers of Australasian gannets collected from Ninety Mile Beach, Muriwai Beach, and Pakiri Beach (see Burger *et al.*, 1994 for locations). Birds can remove heavy metals from their blood and tissues by sequestering the metals in their feathers, making birds potentially useful tools for monitoring heavy metals in the environment. Burger *et al.* (1994) found that levels of lead, cadmium, selenium, manganese, and chromium were significantly lower (up to 3.5 fold less) in birds from Ninety Mile Beach compared to birds from either Muriwai or Pakiri Beach. There was no significant difference in levels of mercury between the three sites. These results suggest that levels of heavy metals in the marine environment around Ninety Mile Beach are lower than levels of heavy metals around Muriwai or Pakiri Beach, both beaches being within 100 km of Auckland City. However, these results need to be interpreted with caution as both the gannets and their prey (pelagic fish) are capable of travelling large distances, and thus, levels of heavy metals in their body may not necessarily reflect the levels of heavy metals in the environment from which they are caught.

6. Conclusions

In summary, Ninety Mile Beach appears to be in relatively good ecological health in terms of natural character. The sand dune and beach flora and benthic macroinvertebrate communities on Ninety Mile Beach are characteristic of exposed sandy beaches of New Zealand (Morton & Miller, 1973; Partridge, 1992; Stephenson, 2001), and the beach is an important habitat for three species of rare seabirds. Sand dunes on the northern third of the beach have a high conservation rating and the wetland areas behinds the dunes are considered to be a highly natural environment. However, introduced plants have largely displaced native species for much of the inland area behind the dunes and some of the southern dune areas.

There is a paucity of information on most of the species that inhabit Ninety Mile Beach, particularly the meifauna and microfauna, and the factors that affect their population levels. Only 13 macroinvertebrate species have been recorded from the intertidal sandy region of Ninety Mile Beach, of which, tuatua are by far the most dominant animal.

Toheroa were once abundant on Ninety Mile Beach but the population is now threatened and large toheroa (>75 mm) have been rare on the beach since 1970. Large fluctuations in toheroa population levels have occurred relatively frequently since monitoring began on Ninety Mile Beach in 1933, but it is unknown whether these fluctuations are caused by natural or human-mediated processes. Little is known about the factors that affect spawning, recruitment, growth, and mortality of toheroa on Ninety Mile Beach.

The population dynamics of intertidal green-lipped mussel populations at Ninety Mile Beach vary with location. The population at Scott Point shows strong annual recruitment, rapid growth, and rapid turnover of the population. In contrast intertidal populations at the southern end of the beach show low recruitment, slow growth, and low mortality. These differences in population dynamics between the sites are thought to be caused by natural physical and biological processes. Little is known about the mussel spat fishery at Ninety Mile Beach. For example, the parental source of Kaitaia spat and its sustainability is unknown, and no research has been conducted on the impact of harvesting mussel seed on the beach ecosystem.

Threats to the ecological health of Ninety Mile Beach include the increasing usage of vehicles on the beach, the unknown impact of harvesting spat material from the beach, pollution from residential areas, and unsustainable harvesting of shellfish. Currently, we have a poor level of knowledge on these areas and future research should focus on these areas. No current research is being conducted on Ninety Mile Beach by the Northland Regional Council (J. Reed, NRC, pers. comm.), Department of Conservation (V. Kerr, Northland Conservancy, pers. comm.), or the University of Auckland's Faculty of Science (http://www.science.auckland.ac.nz/). NIWA is currently conducting a review for the Ministry of Fisheries on toheroa biology and population levels around New Zealand that is due September 2009.

In summary, insufficient knowledge is available on the species that inhabit Ninety Mile Beach to determine whether there have been any changes in their ecological health over time, with the exception that large toheroa have been rare on the beach since 1970. There is a lack of knowledge in a number of critical areas in the ecology of Ninety Mile Beach including:

- The factors that affect toheroa recruitment, such as spawning cues, effects of physical and chemical variables, and food availability.
- The factors that cause toheroa mortality, such as physical and chemical processes, disease, poaching, predation, and vehicle impacts.
- Growth rates on toheroa on Ninety Mile Beach
- The impact of vehicle traffic on the benthic biota of the beach, particularly on both juvenile and adult toheroa.
- The location of the parental sources of beach-cast green-lipped mussel spat and seaweed, and the sustainability of these sources.
- The physical and ecological processes that deliver the spat material to the beach.
- The quantity of spat material that washes ashore at Ninety Mile Beach each year.
- The impact of harvesting spat material on the beach ecosystem, such as the impact on recruitment to intertidal mussel populations, the direct impact of harvesting activities on benthic fauna, and the cascading impact of removing a nutrient source from the beach.

7. References

Alfaro, A.C. (2001). Ecological dynamics of the green-lipped mussel, *Perna canaliculus*, at Ninety Mile Beach, Northern New Zealand. PhD Thesis. University of Auckland, Auckland, New Zealand.

Alfaro, A.C. (2006). Population dynamics of the green-lipped mussel, *Perna canaliculus*, at various spatial and temporal scales in northern New Zealand. *Journal of Experimental Marine Biology and Ecology 334*: 294-315.

Alfaro, A.C. (2008). Variability of growth, health, and population turnover within mussel beds of *Perna canaliculus* in northern New Zealand. *Marine Biology Research 4(5)*: 376-383.

Alfaro, A.C.; Jeffs, A.G. (2002). Small-scale mussel settlement patterns within morphological distinct substrata at Ninety Mile Beach, Northern New Zealand. *Malacologia 44(1)*: 1-15.

Alfaro, A.C.; Jeffs, A.G. (2003). Variability in mussel settlement on suspended ropes placed at Ahipara Bay, Northland, New Zealand. *Aquaculture 216*: 115-126.

Alfaro, A.C.; Jeffs, A.G.; Creese, R.G. (2004). Bottom-drifting algal/mussel spat associations along a sandy coastal region in northern New Zealand. *Aquaculture 241*: 269-290.

Alfaro, A.C.; Jeffs, A.G.; Hooker, S.H. (2001). Reproductive behaviour of the green-lipped mussel, *Perna canaliculus,* in northern New Zealand. *Bulletin of Marine Science 69(3)*: 1095-1108.

Bartrom, A. (1983). No spatfall this season. *Catch 10(8)*: 15.

Beentjes, M.P.; Gilbert, D.J. (2006). Bluecliffs Bleach 2005 toheroa survey: yield per recruit and review of historical surveys. *New Zealand Fisheries Assessment Report 2006/37*. 48pp.

Booth, J.D. (1977). Common bivalve larvae from New Zealand: Mytilacea. *New Zealand Journal of Marine and Freshwater Research 11(3)*: 407-440.

Brook, F.J.; Carlin, G. (2000). A biogeographical ecological classification system for the near coastal environments of Northland. *Unpublished report by the Northland Conservancy, Department of Conservation*. Whangarei. 13pp.

Brunton, P.M. (1978). Toheroa predation by black-backed gulls on Dargaville Beach, North Auckland, New Zealand. *Notornis 25*: 128-140.

Buchanan, S. (1994). The settlement behaviour and recruitment of *Perna canaliculus*. MSc thesis. University of Auckland, Auckland, New Zealand. 112pp.

Buchanan, S.; Babcock, R. (1997). Primary and secondary settlement by the Greenshell™ mussel. *Journal of Shellfish Research 16(1)*: 71-76.

Burger, J.; Veitch, C.R.; Gochfeld, M. (1994). Locational differences in metal concentrations in feathers of Australasian gannet (*Morus serrator*) in New Zealand. *Environmental Monitoring and Assessment 32*: 47-57.

Cassie, R.M. (1955). Population studies on the toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata). *Australian Journal of Marine and Freshwater Research 6*: 379-382.

Conning, L. (1998). Natural areas of Ahipara Ecological District. *New Zealand Protected Natural Areas Programme no. 39*. Department of Conservation, Whangarei. 94pp.

Coster, J. (1983). The Aupoiri sand dunes archaeological study: an interim report. *New Zealand Archaeological Association Newsletter 26(3)*: 174-191.

Department of Conservation (2006). Northland's wild west coast. http://www.doc.govt.nz/upload/documents/about-doc/concessions-and-permits/conservation-revealed/northland-west-coast-lowres.pdf (Accessed March 2009).

FAO Fisheries Department (2009). FISHSTAT Plus: Universal software for fishery statistical time series. Version 2.3, 2000. http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp (Accessed March 2009).

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: Eulammellibranchiata) on northland beaches, 1962-1971. *Fisheries Technical Report 85*. Marine Department Fisheries Division, 8pp.

Greenway, J.P.C. (1974). Population surveys of toheroa on northland beaches, 1972-1973. *Fisheries Technical Report 128*. Ministry of Agriculture and Fisheries, 7pp.

Greenway, J.P.C.; Allen, K.R. (1962). Toheroa survey - Ninety Mile Beach October 1961. *Special Fisheries Report no. 13*. 11pp.

Hay, B.; Grant, C. (2003). Marine Resources of Te Tai Tokerau. *Unpublished report by Aquabio Consultants for the James Henare Maori Research Centre*. Auckland. 83pp.

Heather, B.; Robertson, H. (2005). The field guide to the birds of New Zealand. 2nd ed. Penguin Books Ltd, Auckland. 440pp.

Hickman, R.W. (1975). New source of seed mussels. *Catch 2(7)*: 10-12.

Hickman, R.W. (1976). Potential for the use of stranded seed mussels in mussel farming. *Aquaculture 9*: 278-293.

Hickman, R.W. (1979a). Allometry and growth of the green-lipped mussel *Perna canaliculus* in New Zealand. *Marine Biology 51*: 322-327.

Hickman, R.W. (1979b). Second stranding of seed mussels. *Catch 6(2)*: 26-27.

Hickman, R.W. (1982). Watch kept on mussel seed. *Catch 9(8)*: 15.

Hooker, S.; Redfearn, P. (1998). Preliminary survey of toheroa (*Paphies ventricosa*) populations on Ninety Mile Beach and possible impacts of vehicle traffic. *NIWA Client Report AK98042 for the Northland Regional Council*. 32pp.

Jeffs, A.G. (1999). Overview and bibliography of research on the Greenshell mussel, *Perna canaliculus*, from New Zealand waters. *Journal of Shellfish Research 18(2)*: 347-360.

Jeffs, A.G. (2003). Ninety Mile Beach Spat Research. *In*: Biosecurity and spat research workshop, Havelock Bowling Club, Havlock, 2 May 2003. p. 2-11. New Zealand Mussel Industry Council Ltd.

Jeffs, A.G.; Sim-Smith, C.; Alfaro, A.C. (2005). Development of the Green-lipped mussel spat resource in Northern New Zealand. *NIWA client report for the NZ Mussel Industry Council*. Auckland. 55pp.

Jenkins, R.J. (1985). Mussel cultivation in the Marlborough Sounds. 2nd ed. New Zealand Fishing Industry Board, Wellington. 77pp.

Jones, J.B. (1975a). *Nematopsis* n. sp. (Sporozoa: Gregarinia) in *Perna canaliculus*. *New Zealand Journal of Marine and Freshwater Research 9*: 567-568.

Jones, J.B. (1975b). Studies on animals closely associated with some New Zealand marine shellfish. PhD thesis. Victoria University, Wellington.

Jones, J.B. (1976). *Lichomolgus uncus* n. sp. (Copepoda: Cyclopoida): an associated of the mussel *Perna canaliculus* Gmelin. *Journal of the Royal Society of New Zealand 6*: 301-305.

Jones, J.B.; Scotti, P.D.; C, D.S.; Wesney, B. (1996). Virus-like particles associated with marine mussel mortalities in New Zealand. *Diseases of Aquatic Organisms 25*: 143-149.

Lupi, P. (1993). Will a shortage of spat be the next problem for the mussel industry? *Aquaculture Update 5*: 5.

MacKenzie, L.A.; Rhodes, L.; Till, D.; Chang, F.H.; Kaspar, H.; Haywood, A.; Kapa, J.; Walker, B. (1995). A *Gymnodinium* sp. bloom and the contamination of shellfish with lipid soluble toxins in New Zealand, Jan-April 1993. *In*: Lassus, P.; Arzul, G.; Erard, E.; Gentien, P.; Marcaillou, C. (eds). Harmful Marine Algal Blooms. Proliferations D'algues marines nuisibles. Proceedings of the sixth international conference on toxic marine phytoplankton, October 1993, Nantes, France, pp. 795-800. Intercept Ltd, England.

Mestayer, M.K. (1921). Notes on the habits and uses of the toheroa. *The New Zealand Journal of Science and Technology 4(2)*: 84-85.

Ministry of Fisheries (2008). Report from the Fisheries Assessment Plenary, May 2008: stock assessments and yield estimates. Ministry of Fisheries, Wellington. p.306-309.

Morley, M.S. (2004). Seashells of New Zealand. New Holland Publishers (NZ) Ltd, Auckland. 143 pp.

Morrison, M. (2005). An information review of the natural marine features and ecology of Northland. *NIWA client report for the Department of Conservation*. Auckland. 162pp.

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*. 27pp.

Morrison, M.; Parkinson, D. (2008). Distribution and abundance of toheroa (*Paphies ventricosa*) on Ninety Mile Beach, 2006. *New Zealand Fisheries Assessment Report 2008/26*. 27pp.

Morton, J.; Miller, M. (1973). The New Zealand seashore. Collins, Auckland. 651pp.

Ogle, C.C. (1984). Wildlife and wildlife values of Northland. *New Zealand Wildlife Service fauna survey unit report no. 30*. 272pp.

Partridge, T.R. (1992). The sand dune and beach vegetation inventory of New Zealand. I. North Island. *DSIR Land Resources Scientific Report no. 15*. Christchurch. 253pp.

Powlesland, R.G. (1987). Seabirds found dead on New Zealand beaches in 1985, and a review of *Pterodroma* species recoveries since 1960. *Notornis 34*: 237-252.

Powlesland, R.G.; Pickard, C.R. (1992). Seabirds found dead on New Zealand beaches in 1988, and a review of *Puffinus* species recoveries, 1943-1988. *Notornis 39*: 27-46.

Rapson, A.M. (1952). The toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata), development and growth. *Australian Journal of Marine and Freshwater Research 3*: 170-198.

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

Rawnsley, V. (2006). Observation of yellow flower wasp activity at Bulters Creek, Ninety Mile Beach. *DOC Research and Development Series no. 242*. Department of Conservation, Wellington. 14pp.

Redfearn, P. (1974). Biology and distribution of the toheroa *Paphies (Mesodesma) ventricosa* (Gray). *Fisheries Research Bulletin no. 11*. New Zealand Ministry of Agriculture and Fisheries, 51pp.

Redfearn, P. (1982). Larval shell development of the toheroa, *Paphies ventricosa* (Gray, 1843) (Mactracea: Mesodesmatidae). *New Zealand Journal of Marine and Freshwater Research 16*: 241-252.

Redfearn, P. (1997). Statement of evidence by Peter Redfearn concerning toheroa. *Document D8 in the Muriwhenua Land Report (Wai 45) Record of Inquiry*.

Schofield, J.C. (1970). Coastal sands of Northland and Auckland. *New Zealand Journal of Geology and Geophysics 13*: 767-824.

Shaw, T.; Maingay, J. (1990). Coastal resource inventory - First order survey. Northland Conservancy. Department of Conservation,

Sim-Smith, C.; Jeffs, A.G.; Cole, R. (2007). Assessment of the impact of mechanical harvesting of mussel spat on the infauna of Ninety Mile Beach. *Unpublished NIWA Client report AKL2007-21*. 17pp.

Smith, S. (2003). The reproduction and recruitment of toheroa, *Paphies ventricosa*. MSc thesis. University of Auckland, Auckland. 105pp.

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

Stanton, B.R. (1973). Hydrological investigations around northern New Zealand. *New Zealand Journal of Marine and Freshwater Research 7*: 85-110.

Stephenson, G. (2001). Vehicle impacts on the biota of sandy beaches and coastal dunes. A review from a New Zealand perspective. *Science for Conservation, no. 121*. Wellington. 48pp.

Taylor, G.A. (1999). Seabirds found dead on New Zealand beaches in 1996. *Notornis 46(4)*: 434-445.

Taylor, G.A. (2004). Beach patrol scheme: Seabirds found dead on New Zealand beaches, 1997-1999. *Notornis 51*: 176-191.

Taylor, M.D.; MacKenzie, L.A. (2001). Delimitation survey of the toxic dinoflagellate *Gymnodinium catenatum* in New Zealand. *Cawthron report no. 661 for the Ministry of Fisheries*. Nelson. 12pp.

Van der Merwe, D.; Van der Merwe, D. (1991). Effects of off-road vehicles on the macrofauna of a sandy beach. *South African Journal of Science 87*: 210-213.

Walker, S. (2007). Coastal sand dune management of Ninety Mile Beach. BPlan research project. University of Auckland, Auckland.

Walshe, K. (1997). Statement of evidence by Kim Walshe, Regional Manager, MAF Fisheries North. *Document D7 in the Muriwhenua Land Report (Wai 45) Record of Inquiry*.

Watola, G. (1986). Petrels off Ninety Mile Beach. *Notornis 33*: 258.

Waugh, G.D.; Greenway, J.P.C. (1967). Further evidence for the existence of sub-littoral populations of toheroa, *Amphidesma ventricosum* Gray (Eulamellibranchiata), off the west coast of New Zealand. *New Zealand Journal of Marine and Freshwater Research 1*: 407-411.

Wear, R.G.; Gardner, J.P.A. (2001). Biological effects of the toxic algal bloom of February and March 1998 on the benthos of Wellington Harbour, New Zealand. *Marine Ecology Progress Series 218*: 63-76.

Wise, K.A.J. (1988). Sand-dune tiger beetles of northern New Zealand coasts (Coleoptera: Cicindelidae). *Records of the Auckland Institute and Museum 25*: 147-180.