TOHEROA ON ORETI BEACH:
Management to Minimize Threats of Local Extinction

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Abstract

Toheroa *(Paphies ventricosum)* is widely regarded as the national shellfish, yet since the early 1900s toheroa have been disappearing from the beaches of New Zealand. Despite 20 years of a ban on harvesting, the population of toheroa at Oreti Beach, Southland, shows little sign of recovery.

A particle size analysis was conducted on sediment from the inter-tidal zone of Oreti Beach. This involved taking samples every kilometre, at depths of 5, 10, 20 and 30 cm. In addition, vehicle surveys were conducted between the high and spring tide marks along the beach to indicate the distribution, density and overall health of toheroa at Oreti Beach.

Particle size analysis showed a trend of increasingly unsuitable sediment for toheroa towards the northwest end of Oreti Beach. This was especially evident close the Waimatuku Stream, were the majority of sediment particles were larger than 4 mm. Comparisons with the findings of a previous toheroa survey on Oreti Beach showed a strong mode of juvenile individuals in this area, with few adults. This indicates that sediment size could be an influencing factor in the population dynamics of toheroa and explain relatively high mortality amongst juveniles.

Surveys of vehicular traffic on Oreti Beach demonstrated a predominance of traffic within two kilometre of the entrance, and a concentration within 100 metres of the public access point. Vehicles were recorded primarily between the spring and high tide marks. Comparisons with the findings of a previous toheroa survey on Oreti Beach revealed a strong mode of juvenile individuals in this area, but only a few adults. This provided an indication that vehicle traffic could influence population dynamics by causing mortality in juveniles.

Other environmental influences, such as climate and stormy seas, are likely also to influence the population dynamics of toheroa on Oreti Beach.

On the basis of findings reported here and in previous surveys a management regime is suggested to ensure the survival of toheroa on Oreti Beach.

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Chapter 1

Toheroa' a Declining Resource

Once collected in their thousands around the country, toheroa, the national shellfish has fallen upon hard times. Toheroa are endemic to New Zealand, and valued by New Zealanders. The toheroa story is one of a dwindling resource about which surprisingly little is known. Since the early 1900s populations of this species have been disappearing from the beaches of New Zealand. Surveys have monitored this decline, yet little is known about why loss has occurred.

Toheroa *(Paphies ventricosum)* are large bivalve surf clams found inter-tidally on beaches fully exposed to surf with fine sediments and enough moisture to prevent desiccation at low tide (Rapson 1952). They are a distinctive element of the fauna in exposed surf beaches in several parts of New Zealand. Beaches that have historically supported abundant populations include Oreti Beach in Southland; Te Waewae Bay, Ninety Mile Beach, Muriwai and Dargaville Beaches on the west coast of Northland; and Foxton, Waitarere, Hokio, Otaki, and Waikanae along the Wellington coast (Parkinson & Morrison 2001, Redfearn 1974). Smaller populations have been recorded from Tom Bowling Bay and Spirits Bay (east coast North Island), Whangape, Mitimiti, Piha, and Pollok (west coast North Island), Ohope Beaches and Opotiki Beaches (Bay of Plenty), Waikouaiti, Hampden and Long Beaches (Otago) (Redfearn 1974). All those populations are strictly inter-tidal, yet it has been suggested (Cassie 1955, Waugh & Greenway 1967) that sub-tidal populations may exist. There is no direct evidence to support that statement.

Until 40 years ago, toheroa were intensively harvested. Since then harvesting has been prohibited throughout New Zealand due to concern about low and declining population numbers. Commercial harvesting of toheroa began in the late 1800s, but by 1969 commercial and recreational harvesting had been prohibited. Conservation regulations were introduced in the early 1900s to slow the decline in toheroa numbers.

Currently, the only permitted harvesting of toheroa are the customary Maori take and the occasional one-day harvest at Oreti Beach. The latest one-day open seasons at Oreti Beach were in 1972, 1973, 1974, 1980, 1981, and 1990. There is no indication when the next one-day season will be.

Twenty-nine surveys of toheroa have been carried out at Oreti Beach since 1969, and were done at least annually from then until 1990. The next surveys were in 1996, 1998 and 2002. They provide estimates of toheroa distribution, size composition and abundance. Estimates of the number of adult toheroa on Oreti Beach in the 1970s and early 1980s ranged between 1 and 2.5 million (Benntjes, Gilbert & Carbines 2003). Those surveys show a steady decline in the abundance of adult toheroa since 1985. The population almost halved in two years, from about 2 to 1 million, then continued to decline over the 11 years to 1996 when it was estimated at 400 000 individuals. Estimates from the latest Oreti Beach survey (2002) indicate 612 000 adult sized toheroa (Benntjes, Gilbert & Carbines 2003), which is low compared to the 1970s and 1980s values. A juvenile toheroa study was conducted on Oreti Beach in 1994 (McKinnon & Olsen 1994). Since then two further surveys have been conducted on all sizes of toheroa, the first in 1998 (Carbines & Breen 1999) and the second in 2002 (Benntjes, Gilbert & Carbines 2003). The process involves counting adult toheroa (100mm and over), sub-adults (40-99mm), and juveniles (under 40mm). The 2002 survey (Benntjes, Gilbert & Carbines 2003) showed a population of 298 000 sub-adults and 10 000 000 juveniles on Oreti Beach. It was concluded from inspection of data from the 2002 and 1998 surveys, that population size had been overestimated, compared to earlier surveys, and that the population of toheroa had remained low (Benntjes, Gilbert & Carbines 2003), the over-estimates being due to the sampling techniques used. Historical surveys show that mature, sub-adult and juvenile toheroa are concentrated in distinct areas up, as well as along, the beach profile. Mature toheroa tend to be clustered about low water mark, approximately 150 metres down the beach; sub-adult toheroa are clustered on the mid-water mark (100 metres); and juveniles tend to be near the high water mark (50 metres) (Benntjes, Gilbert & Carbines 2003).

The toheroa of Oreti Beach are of particular interest due to their distinctive population structure and geographical distribution. Analyses of historical distributions of toheroa on Oreti Beach indicate that the southeast end of the beach near the Oreti River mouth is where toheroa have consistently been found in greatest numbers. A previous study on tuatua (*Paphies donacina*) indicated similar frequency-distribution patterns (Cranfield, Michael & Dunn 2002). Several reasons for this have been hypothesized but no direct evidence is yet available for a formal conclusion to be made. One hypothesis is that sediment type has a profound influence on this organism, because the distribution of toheroa on Bluecliffs Beach is strongly correlated with substrate type (Benntjes, Gilbert & Carbines 2003). Another is that the population structure of toheroa at Oreti Beach is unbalanced. The 2002 population survey at Oreti Beach concluded that there is an over-abundance of juvenile and adult (i.e. legal size) toheroa but relatively few intermediate size individuals (sub-adults). This indicates that mortality amongst juveniles is high and that relatively few toheroa survive to the sub-adult size (Benntjes, Gilbert & Carbines 2003). Previous studies have suggested that vehicular traffic can have direct and indirect effects, on toheroa and surf clams (Cranfield, Michael & Dunn 2002, Morrison & Parkinson 2001). Hooker & Redfearn (1998) concluded from the results of their survey and an analysis of vehicle impacts on toheroa at Ninety Mile Beach that juvenile toheroa density was low due to vehicular traffic on the beach. A survey of juveniles on Ninety Mile Beach showed results comparable to those for juveniles on Oreti Beach. This raises the question: why, despite at least 30 years of controlled exploitation for commercial and recreational purposes, (with the exception of Maori customary takes) is the population of Toheroa on Oreti Beach showing scant sign of recovery?

The principal aims and objectives of the present research are as follows:

1. To determine whether vehicular compaction of beach sand could have a significant impact on the mortality of juveniles and affect the overall health of toheroa at Oreti Beach.

2. To determine whether the distribution of toheroa on Oreti Beach is related to sediment size distribution.

This dissertation will not provide empirical evidence to show why toheroa are declining on Oreti Beach. Instead, spatial comparisons will be made with the findings of vehicular surveys, sediment samples and previous surveys to propose reasons why the population is apparently not recovering after the decades of closely controlled off-take. This will involve analysing the general biology of the toheroa, to find areas of vulnerability in their life cycle. This information will be related to the population on Oreti Beach to find possible mortality agents. Then sediment samples shall be analysed, as well as vehicle surveys. Lastly, this dissertation proposes a management regime for toheroa on Oreti Beach.

Chapter 2

Overview

2.1. Reproductive Biology of Toheroa

The reproduction biology of toheroa has been described by Redfearn (1974), who examined individuals from all sizes groups from the southern end of Dargaville Beach over a 3 year period. Reproductive development of toheroa can be split into:

a) initial gonad development, and

b) subsequent phases of gonad development.

This chapter will describe the general characteristics, gonad development, and annual growth cycle of toheroa. Further, environmental preferences of toheroa by life cycle stage, mortality, and vulnerable points in its life history will be noted. Knowledge of the biology of toheroa is expected to provide insights into the factors causing mortality of this species on Oreti Beach, as well as information about the stages at which toheroa are evidently dying.

2.1.1. General Characteristics

Previous studies suggest that toheroa are primarily unisexual (Dawson 1950, Redfearn 1974). There are no external characteristics to distinguish male and female toheroa, but females are occasionally differentiated by the granular appearance of the gonads in section (Redfearn 1974).

2.1.2. Gonad Development

Various studies have concluded that toheroa and related species become sexually mature within three years. Rapson (1952) noted that *P. subtriangulata quoyi* become sexually mature within 3 years, but that some individuals have active gonads by their second year. Rapson (1952) conducted a study of the population and general biology of toheroa and found that the majority were under 3.8 cm in length (10 to 12 months old), and nearly all were sexually mature by their second year.

Redfearn (1974) provided evidence to suggest that toheroa are sexually mature in significantly less than 3 years. He concluded:

1. Three months after spat-fall, 20 percent of juveniles, have fully developed gonads: the females having follicles with ovocytes and free ova, and the males having follicles with spermatocytes, spermatids, and spermatozoa. Further, after three months the average length of the shell is 1.0 cm, with sexually developed individuals being larger at approximately 1.5 cm.

2. Nine months after spatfall, 75 percent of the population are sexually mature, with a mean shell length of 3.15 cm. By 15 months all toheroa are sexually mature, with a mean shell length of 4.7 cm.

From the findings noted above, it can be concluded that toheroa become sexually mature very early in their lifecycle (1 to 3 years). This is of importance for conservation, as juvenile toheroa at Oreti Beach vary in their recruitment to the population.

2.2. Annual Cycle

No long resting or inactive phase is apparent in the reproductive cycle of toheroa, at least under natural conditions. Free ova or spermatozoa are present in mature toheroa gonads throughout the year (Redfearn 1974). However, Redfearn suggests that there is a tendency for an increasing proportion of ova and spermatozoa to ripen when sea temperatures are rising. From July to October at Oreti Beach sea temperatures increase from 14 to 17 degrees. From September to October about 60-80% of the population shows ripening, with the rest of the population ripening shortly afterwards (October to November). Redfearn concluded that there is a second ripen phase from December to January, and that it is influenced by increasing temperatures. The period from September to February appears to be the major reproductive time during the annual cycle.

The annual reproductive cycle is important to population health of toheroa at Oreti Beach, especially when comparisons are made with vehicle use. Redfearn (1974) states that 80 – 90 percent of individuals are ripe for reproduction by September-October, which could be significant in regulating vehicle use as Oreti Beach tends to be heavily used over the summer months (December to February). This could be detrimental to the health of toheroa as the summer months see large vehicle numbers at the same time as spat are shed. That could result in enhanced mortality of juvenile toheroa.

2.3. Environmental Preferences of Toheroa by Stages in its Life Cycle Stage

2.3.1. Juvenile Toheroa

Juvenile toheroa are susceptible to predators and adverse environmental conditions. Juvenile toheroa settle during all stages of the tide, but especially during the interval of slack water just before a wave recedes. They quickly dig 1 to 2 cm into the sand (Redfearn 1974) where they are affected by wave fetch. For some weeks after metamorphosis the juveniles are continuously settled, washed out, and redeposited by the waves. This process gradually shifts the juvenile organisms' up-shore until they occupy a band just below high water mark. Juvenile toheroa tend to prefer this zone, due to their inability to burrow to a depth where pounding surf will not affect them.

2.3.2. Sub-adult Toheroa

As toheroa grow so their ability to burrow is enhanced (Redfearn 1974). This allows sub-adults to colonise sites in the mid-tidal zone.

2.3.3. Adult Toheroa

Adult toheroa can burrow to 30 cm (Redfearn 1974) and are typically found to greater depths compared with sub-adults and juveniles. They tend to be situated close to the low-tide mark on the beach profile where they are not usually disturbed by pounding surf.

2.3.4. Other Environmental Influences

Redfearn (1974) suggests that for most molluscs water temperature is the most important environmental factor controlling the emission of gametes. Molluscs that live in warm temperate or tropical environments are subject to a fairly narrow range of ambient temperatures.

According to Redfearn (1974), toheroa are virtually restricted to areas where the diatom *Chaetoceros armatum* is plentiful. The supply of nutriment affects their reproduction directly. The organism's reproductive cycle is continuous unless it is deprived of a plentiful supply of food (Redfearn 1974). As Rapson (1952) observed, "when toheroa in northern waters are fat they spawn".

Toheroa are particularly sensitive to changes in sediment conditions. McKinnon & Olsen (1994) attributed the drastic decline in toheroa at Bluecliffs Beach to changes in beach profile and sediment type. Frequent scouring events have been blamed for removing finer sediment from a beach, leaving behind a surface layer of coarse sand that toheroa spat and immature individuals are unable to burrow into. Beentjes & Carbines (2001) suggested that all sizes of toheroa at Bluecliffs Beach are to some extent restricted to relatively stable areas of soft substrate, notably sand and coarse sand. There is compelling evidence for concluding a causal relationship between substrate complexity and toheroa numbers in the inter-tidal zone of Bluecliffs Beach.

2.4. Mortality in Toheroa

2.4.1. Human Impact on Mortality

Harvesting

The taking of toheroa is currently banned throughout New Zealand, except for the traditional Maori take and occasional one-day seasons at Oreti Beach near Invercargill. This is mainly in response to previous over-exploitation by commercial and recreational harvesting. There are few records of the extent or intensity of Maori harvests of toheroa in pre-European times (Redfearn 1974). To traditional and contemporary Maori society, toheroa is a taonga: a valued possession to be managed as a treasure. In acknowledgment of the Treaty of Waitangi there is provision, via the Resource Management Act 1991, for the issuance of special permits for iwi to gather toheroa for specific occasions such as tangi and weddings.

Commercial exploitation of toheroa began in the late 1800s, with the opening of canneries throughout New Zealand. Commercial production peaked in 1940 when 77 tonne of toheroa were harvested. The commercial take seldom exceeded 20 tonnes (Redfearn 1974). Quotas were introduced in 1962 and the allowed take was based on annual population surveys. By 1969, decline in abundance had led to termination of all commercial harvesting permits.

Recreational exploitation has been implicated in the decline of toheroa numbers. In the past, recreational harvesting of toheroa was popular (Ackroyd 2002). By the early 1930s conservation regulations, such as harvest seasons, minimum legal size, and individual quotas, had been introduced to prevent over-exploitation (Redfearn 1974). Even so, populations declined to such an extent that recreational toheroa harvesting was prohibited at Ninety Mile Beach (North Auckland) in 1971, at Rangatira Beach in 1976, and at Ripiro Beach in 1980 (Ackroyd 2002), and these beaches have not since been re-opened to recreational toheroa gatherers.

The illegal taking of toheroa could also be a significant factor in the recent decline of numbers throughout the country. Little is known about illegal harvesting of toheroa, but Redfearn (1974) found that one rarely visits a toheroa beach without seeing some evidence of poaching.

Vehicles

Vehicles travelling along a beach are likely to be significant agents of mortality for organisms living a little below the surface. Heavy vehicular traffic semi-liquefies the sand, causing toheroa to float to the surface. This can result in the animals being swept out of the sand by the surf during the next high tide (Redfearn 1974). This phenomenon is likely to cause considerable losses to toheroa populations and is apparent in the numerous organisms seen stranded at the high tide mark (Redfearn 1974), rendering them susceptible to predation.

A study conducted by Hooker & Redfearn (1998) found mortalities, indicated by crushed shells, of 14 percent in juvenile and sub-adult toheroa (shell length 6-23 mm, mean 10-12 mm) following heavy use of the beach for a recreational fishing contest.

Further, Hooker & Redfearn (1998) noted that the majority of vehicle traffic was confined to the area between the high and spring tide marks.

Ackroyd (2002) stated that motorcycle traffic has the greatest impact on toheroa. The narrow tyres cut into surface layers and disturb the juveniles. Sandy beaches, such as Rangatira, Ripiro (North Island) and Oreti Beach are extensively used by motorcyclists. Ackroyd also suggests that heavy vehicles with small road tyres can have an adverse impact, especially during the first and last quarter tides when adult toheroa rise to the surface to breed.

Pollution

Pollution of a natural ecosystem, regardless of the cause, can have an adverse effect on flora and fauna. Pollution associated with coastal development can smother benthic communities and prove lethal to organisms that occupy shallow coastal habitats (Creese & Cole 1995, Creese & Kingsford 1998, Ackyrod 2002). This affects a number of shellfish species, including, toheroa.

2.5. Wildlife Factors on Mortality

The predators of toheroa include black-back gull *(Larus dominicanus*), red-billed gull *(Larus novaehollandiae)*, snapper *(Chrysophrys auratus)*, rough skate *(Raja australis)*, short-tail stingray *(Dasystis brevicaudatus)* and swimming crab *(Ovalipes catharus)* (Rapson 1952).

Gulls (black-backed and red-billed) are thought to be the most important predators of toheroa (Brunton 1978). Juvenile toheroa are eaten whole, while adult toheroa are carried into the air and dropped to crack the shell so the meat can be extracted. Toheroa up to 120-130 mm long can be carried into the air by a gull. Brunton (1978) noted consumption rates in excess of 20 toheroa a day and concluded that a resident gull population of 353 individuals could consume 1.5 million toheroa in a year.

Redfearn (1974) suggested that predation by fish, particularly, might be important. Toheroa siphon nipping by fish is commonly observed.

Street (1971) suggests that the rough skate and the short-tail stingray may also be predators of toheroa, as they are commonly found in shallow coastal waters adjacent to beaches occupied by toheroa. The swimming crab, occupies the shore zone just below low water mark and has been observed to attack toheroa if they are carried down shore by surf (Street 1971, Redfearn 1974).

2.6. Environmental Factors

Climate

Climatic factors are probably amongst the most important mortality agents. Mass mortality appears to be a regular feature in toheroa populations, especially during the summer. In 1930, a stretch of Ninety Mile Beach suffered heavy mortality when dry sand was blown from the sand hills on to the beach during an easterly wind storm, with "toheroas presumably being suffocated" (Rapson 1954). In 1954, Rapson (1954) reported a high summer mortality of toheroa in Northland beaches, which he explained as due to lack of oxygen and heat stress, resulting from wild surf conditions and tides not covering the toheroa with sediment for several days. High mortalities were also recorded at three northern beaches during the summer of 1970-71 (Greenway 1972). Strong inshore (southerly) winds, with an associated drop in air temperature, have caused enhanced mortality in toheroa populations on Bluecliffs Beach and Te Waewae Bay (Greenway 1972).

Toxic Algae *(Gymnodinium catenatum)*

Gymnodinium catenatum is a marine alga' and one of the dinoflagellates (Todd 2000). In 2000 this toxic alga invaded New Zealand waters, leading to widespread contamination of shellfish with PSP (paralytic shellfish poisoning) toxins along the west coast of the North Island. It had a detrimental effect on toheroa populations. Thousands of adult toheroa became stressed in January 2000, when the algal population was its peak and summer temperatures were high (Ackyrod 2002). The stressed toheroa surfaced, making them vulnerable to predators, such as gulls and oystercatchers.

Sub-adults living below low water mark

Beentjes & Carbines (2001) concluded from their survey at Bluecliffs Beach that variations in seasonal estimates of toheroa might reflect migration by the organism between the intertidal and sub littoral zones. The reasons for such migration are unknown but may be linked to winter storms and variations in the seasonal availability of suitable sediment for the organism to occupy.

Nutrient Cycles

Plankton provides the main food for toheroa (Redfearn 1974). In winter and early spring, the west coast waters of the South Island are dense with phytoplankton blown onshore by westerly winds and carried by ocean currents. During times of phytoplankton abundance toheroa thrive, feasting on the nutrient-rich cocktail (Redfearn 1974). In the early 1990s plankton blooms were virtually absent, near-shore currents were unpredictable, and unseasonable offshore winds prevented phytoplankton accumulation. All those factors may have led to recent declines in toheroa numbers on Ninety Mile Beach.

Salinity of the Interstitial Water

Stace (1992) investigated environmental issues raised during two open days in 1990 and on the 18th September 1993 at Oreti Beach. One concerned the lack of juvenile/adolescent individuals in the 3 harvests and the low density of toheroa in the shellfish beds on Oreti Beach. The burrowing ability of juveniles was investigated by video and compared to the behaviour of juvenile toheroa on Muriwai Beach. At Muriwai toheroa reburrowed immediately they were released and within minutes were completely buried. The Oreti toheroa simply remained on the surface. By the time the tide had reached the sample area only one individual had re-buried. The experiment was repeated several times each day, with similar results.

The salinity of interstitial water in sand deposits at Oreti Beach was analysed by Michael Liller. The salinity of the sample from near the surf club area, at the end of the entrance road, was 1.5 ppt, while that of a sample from the south end of the beach was 2 ppt (Stace 1992). In effect, proximity to fresh water had little impact. Several local people reported that it had been a very wet winter, with ponding in places where water had not been known to accumulate. Seepage onto the beach appeared to be at a maximum. Stace (1992) experienced difficulty locating toheroa with siphons exposed. They appeared to have withdrawn while the sand remained liquefied. He suggested that this was due to the low salinity of the interstitial water, the toheroa withdrawing their siphons as soon as they sensed the drop in salinity. They did not re-burrow in sediment with only mildly saline interstitial water, but did so when released on the beach with the incoming tide. This behaviour could result in high rates of mortality, whether by predation, dehydration or over-heating. Since toheroa do not occupy a low saline environment they would be subjected to predation for longer periods.

2.7. Vulnerable Stage in the Life History of Toheroa

2.7.1. Seasonal Phases

The condition of toheroa reaches a maximum in August or September, coinciding with rising sea and air temperatures. Their condition then drops to a minimum in January or February at the first major flush of spawning (Redfearn 1974). Their condition declines further during January and February, when vehicle traffic tends to be greatest. This could lead to enhanced mortality of toheroa when their condition is poor and ability to recover compromised.

2.7.2. Juvenile Stage

Although under constant threat, toheroa are most vulnerable in the first 1 to 3 years of their life. Juvenile toheroa face numerous obstacles before reaching adulthood. This shows in the relatively high abundances of juvenile and adult (legal sized) toheroa at Oreti Beach, few intermediate sized (sub-adult) organisms. Mortality amongst juveniles is clearly high, and relatively few individuals survive through to the sub-adult stage (Benntjes, Gilbert & Carbines 2003). Juveniles are vulnerable at several stages, listed below:

1. Due to their inability to burrow, very young individuals are at the mercy of the surf. This is particularly the case during neap and spring tides. Redfearn (1974) noted several occasions when juveniles were left stranded on dry sand above the high water mark by waves of greater than normal amplitude. Their chances of survival there appeared limited. During the

stranding period, juvenile toheroa are predated by gulls (black-backed and red-billed) and seriously affected by dehydration.

2. The physical nature of the sediment can influence where toheroa survive (McKinnon & Olsen 1994). If the spat are distributed over an area of small to coarse sands and gravel their chances of survival are minimal. Sediment features can also affect the density of toheroa beds, as on a beach with a shallow sand base that will only support a small population of toheroa compared to a beach with a deep sandy base.

3. Currents influence where toheroa become established. Rapson (1952) estimated an interval of at least 1 month between the first signs of spawning and accumulation of spat on the beach. During that time, spat are vulnerable to predation by several marine species. Near-shore currents may disperse spat to areas unsuitable for the species' establishment.

Generically, toheroa beds on all occupied beaches in New Zealand have vulnerable juvenile toheroa populations. This reflects the unstable coastal morphology that toheroa occupy and the biology of juveniles.

Chapter 3

Off-Take and Population Dynamics of Toheroa on Oreti Beach

3.1. Off-take by Commercial, Recreational and Maori Customary Harvesting on Oreti Beach.

3.1.1. Commercial Harvesting

No commercial harvesting of toheroa has ever occurred on Oreti Beach.

3.1.2. Recreational Harvesting

Before 1972, toheroa could be taken all year round by private individuals. Little is known about the off-take of toheroa on Oreti Beach before then, and issues of The Southland Daily Times contain little information. In 1972 one-day open seasons were introduced, and they were scheduled again in 1973, 1974, 1978, 1980, 1981, 1990, 1992 and 1993. Harvested numbers of toheroa were recorded for the last two of those one-day open seasons, when an estimated 30 000 toheroa were taken. There are no formal or informal estimates of numbers of toheroa taken during the other one-day open seasons.

3.1.3. Customary Harvest

Table 1 shows a total customary take of 47 330 toheroa on Oreti Beach since 1998. No estimates are available for the years before 1998, when the South Island Customary Fisheries Regulations came into force. The customary harvest before 1998 is thought to have been low, being for hui and tangi only.

Table 1: Estimated customary take of toheroa from Oreti Beach for calendar years 1998 to 2001. Data provided by Waihopai Runaka to the Ministry of Fisheries. Estimates of customary takes before 1998 are not available (Beentjes, Gilbert & Carbines 2003).

Year	Toheroa taken	Comment
1998	2257	
1999	2692	
2000	8853	
2001	6930	
2002	11910	
2003	14608	
2004	80	(January to June)

3.2. Historical abundance of toheroa on Oreti Beach

Millar & Olsen (1995) estimated the number of toheroa 80 mm and over from the findings of 22 surveys conducted between 1971 and 1990. They based their estimates on information from on-site surveys along the beach (Beentjies, Gilbert & Carbines 2002). The 1996 survey shows the lowest estimate to date, with 400 000 toheroa 80 mm and longer. Surveys between 1971 and 1996 only indicate abundance within the area surveyed (a 115 m wide swath along the length of beach) and do not include toheroa in sand below the mean water or above the mean high water marks. Population size was probably underestimated (Beentjies, Gilbert & Carbines 2003). The survey by Carbines & Breen (1999) in 1998 showed a recovery in population size, compared to 1996, with an estimated total of 1 million individuals. The 2002 survey showed that population size had declined to 700 000 individuals 80 mm long and longer. The historical abundance estimates are in Figure 1.

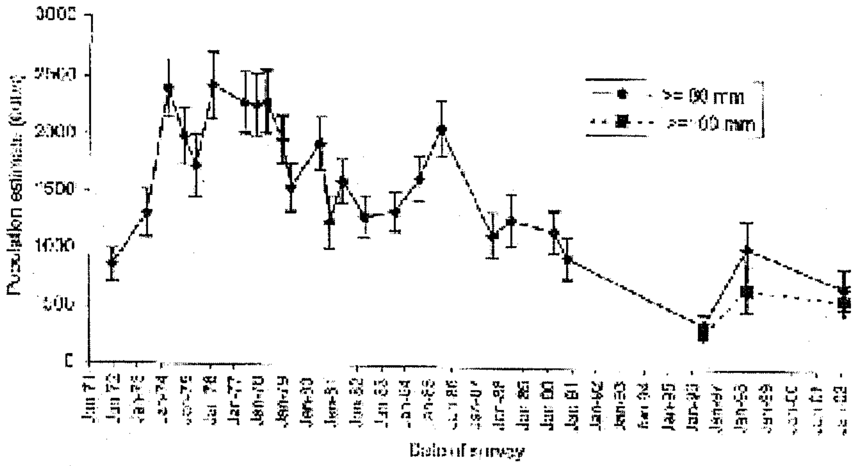


Figure 1: Changing history of abundance of toheroa on Oreti Beach, Beentjes, Gilbert and Carbines, (2003).

The data from published toheroa surveys show the variable, possibly unstable, nature of the Oreti Beach population. Furthermore, they indicate the species' inability to recover even after 20 years of prohibited harvesting, suggesting a mortality agent is responsible for the low rate of recruitment.

3.3. Present population structure at Oreti Beach

The most recent survey was conducted by (Beentjies, Gilbert & Carbines 2003) at Oreti Beach, between 25 February and 1 March 2002, and was for a 17 kilometre stretch of beach from the mouth of the Oreti River in the southeast to the Waimatuku River mouth in the northwest. The survey involved a two phase, stratified random, transect design with eight strata of various lengths in sections of Oreti Beach. Strata were situated in relation to the quantity of toheroa expected on the basis of previous surveys. For example, small strata were sampled where large numbers of toheroa were expected. The survey was timed to coincide with several days of low tides, allowing the maximum possible area of inter-tidal beach to be sampled. Each transect ran down the beach from high water mark (edge of the dunes) to low water mark. For each transect, quadrats 0.5 square metres in extent (1.0 x 0.5 m), and spaced at 5 m intervals, were excavated to a depth of 30 cm. All toheroa found in each quadrat were measured to the nearest 1 mm in length then returned to the substrate. To estimate the size, structure, abundance and distribution of juvenile toheroa (under 40 mm), samples of sand were sieved for two quadrats in each of the eight strata. Population size was estimated from the mean density of legal-sized toheroa in a stratum multiplied by surface area. Formulae were developed to allow estimation of population size.

Several statistics came from that survey. The population estimates for 2003 are 612 000 legal-sized toheroa (100 mm and over), 298 000 sub-adults (40-99 mm), and 10 000 000 juveniles (under 40 mm). The most populated section of the beach was the southeast end, with a clear trend of declining numbers of toheroa towards the northwest end. The largest mean number of toheroa per transect was at the southeast end of the beach, bordering the Oreti River, and that was true for all size groups. The different size groups were found to occupy different zones between the high and low water marks, with legal-sized toheroa from about 100 to 190 m (mean = 140 m) seaward of high water, sub adults 65 to 175 m away (mean = 120m), and juveniles 10 to 200 m away (mean 80 m). Juvenile toheroa were most abundant high on the beach, but larger toheroa were more abundant closer to low water mark. The size composition from historical surveys is characterised by a strong mode of juvenile toheroa and a second mode of adult toheroa, with relatively few individuals of intermediate size. This indicates that the mortality of juveniles is high, with relatively few individuals surviving through to the sub-adult stage (40-90 mm). That is significant in the population dynamics of toheroa on Oreti Beach.

Frequency analysis of shell length in sampled individuals shows a distinct trend across the surveyed region. Juveniles are distributed relatively evenly along the entire beach, but adults are mainly found at the south-east end. This indicates a high mortality of juveniles towards the north-west end of the beach, which could be due to substrate factors. No estimates can be made of population recruitment in toheroa on Oreti Beach, as only two surveys have been conducted.

3.4. Toheroa on Oreti Beach by size

Surveys between 1975 and 1990 show size distributions with a strong mode between 100 and 140 mm, few sub-adults, and even fewer juveniles (Beentjies, Gilbert & Carbines 2003). In April 1990, McKinnon & Olsen (1994) conducted the first comprehensive survey of juvenile toheroa on Oreti Beach. They suggested that juveniles had been present there between 1975 and 1988, but were probably not sampled. The surveys in 1998 and 2002 differed from early surveys in that juveniles were noted in non-sieved as well as sieved sand samples. The overall conclusion from the 1998 and 2002 surveys is that the size distribution of toheroa on Oreti Beach is characterised by a primary mode of juvenile toheroa and a second mode of adult toheroa, with relatively few immediate sized individuals.

3.5. Geographical patterns of species density on Oreti Beach

Surveys were made between 1975 and 1996, all of them based on regularly spaced transects, while those in 1998 and 2002 used a random stratified design (Beentjies, Gilbert & Carbines 2003). The latter were to provide higher precision in estimates of the abundance of toheroa, so the transects were concentrated where toheroa beds are most dense. Toheroa surveys from 1975 to 1996 only included the area of beach between the mean low water and mean high water marks, while the 1998 and 2002 surveys show the distribution of toheroa from the dune front down to low water mark (Beentjes, Gilbert & Carbines 2003).

Surveys made between 1975 and 1984 showed toheroa distributed along the entire length of the beach, although they were densest in the first 6 km from the southeast end of the beach and, within 50 m of mean low water. Beentjes, Gilbert & Carbines (2003) suggested that the large number of quadrats with no toheroa in the upper section of the beach is suspicious, given the spatial patterns evident in the 1998 and 2002 surveys. This suggests that not all transects were sampled up to mean high water mark, as several consecutive quadrats showed no signs of toheroa (Beentjies, Gilbert & Carbines 2003). Furthermore, the transect design used between 1975 and 1998 is based on the assumption that toheroa do not survive higher up the beach, hence zeros were allocated to the unsampled quadrats. Surveys from 1985 to 1996 provided contradictory evidence, compared to data from the 1975 and 1984 surveys, suggesting that toheroa are less common at the southeast end of the beach. By contrast, the 1998 and 2002 surveys, reflecting the randomly allocated transects, yielded results that agreed with the 1974 to 1984 surveys and suggested that toheroa were most dense at the southeast end of the beach.

Chapter 4

Possible Causes of Decline in Toheroa on Oreti Beach

No certain causes have been identified to explain the known decline in numbers of toheroa at Oreti Beach, but several possible explanations have been advanced.

4.1. Possible Causes

Comparisons with other beaches occupied by toheroa suggest at least 10 possible several causes for declining numbers of toheroa.

4.1.1. Vehicle movement

The main public access point lies between the Oreti Estuary and the Waimatuku Stream (Figure 2), and there are several minor access points to each side of it that can only be utilized by four wheel drive vehicles. They are seldom used. The road to Oreti Beach is popular and widely used by:

1. residents of Otara Township,
2. recreational users including members of Waihopi Rowing Club, Oreti Rugby Union and Rugby League Clubs, and the Surf Life Saving Club, and
3. others who want access to the Oreti Beach foreshore.

To obtain information about road access to the beach, the Southland City Council recorded traffic numbers in 1990. A road counter was set up on the Oreti River Bridge, and it showed an average of 1138 vehicles using the road each day, most of them heading toward Otara. The number of vehicles heading to the beach seems to have increased since 1990.

Oreti Beach is used extensively by vehicles (Figure 2). The implication is that toheroa could be significantly affected by vehicular traffic. There are days when 100 vehicles may occupy the foreshore, and others with no vehicles on the beach.

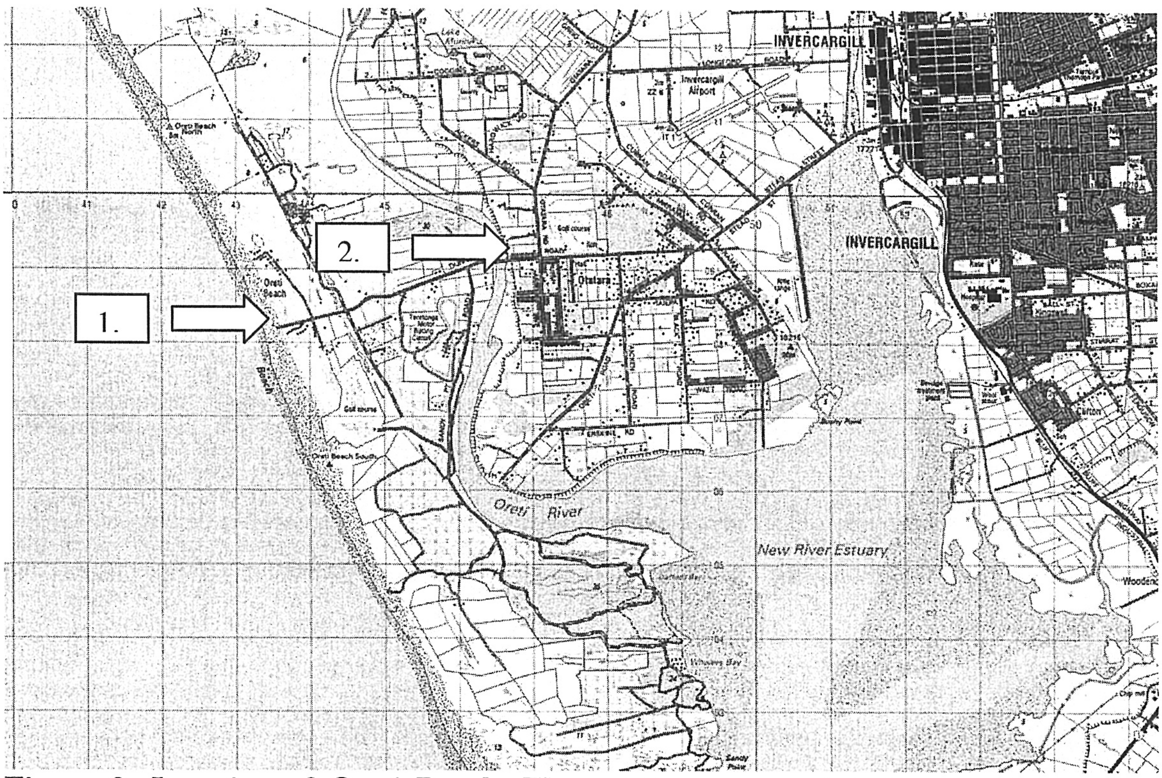


Figure 2: Location of Oreti Beach. The public access point (1) and the road counter (2) are noted.

4.1.2. Beach sediment

As noted in Chapter Two a particular type of beach sediment ensures an environmental niche for toheroa. At Bluecliffs Beach in the South Island, recent population declines in toheroa have been attributed to changes in beach profile and sediment type (Carbines & Breen 1998). Episodes of scouring removed finer sediment from the beach leaving a layer of coarse sand unsuitable for toheroa to burrow in (McKinnon & Olsen 1994, Carbines & Breen 1998). Bluecliffs Beach is approximately 200 km around the coast from Oreti Beach, but it is possible that the latter is suffering from the same phenomenon. Beentjes & Carbines (2001) suggest that much of the suitable substrate at Oreti Beach has been removed by enhanced wave action and transported away by the strong currents that flow from west to east. Beentjes, Gilbert & Carbines (2003) analysed sediment on Oreti Beach and concluded that 95 percent of the foreshore can be considered suitable habitat for toheroa. Previous analysis of Oreti Beach sediments by Beentjies, Gilbert & Carbines (2003) involved observations on sample quadrats. Substrate type was classified as follows: sand, coarse sand, sand and moderate gravel/stone, sand and frequent gravel/stone, sand and abundant rocks, and virtually solid rock (Beentjies, Gilbert & Carbines 2003). To date that is the only such research that has been conducted at Oreti Beach. As the area's morphology changes markedly with the season, and between sections of the beach, changes in sediment constitution cannot be ruled out. The depth of suitable sediment may also be a determining factor in the distribution and mortality of juvenile toheroa on Oreti Beach. The highest densities of toheroa in 2002 were found at the southeast end of Oreti Beach, but juveniles were fairly evenly distributed along the entire shore line (Beentjies, Gilbert & Carbines 2002). This suggests that juvenile toheroa are dying prematurely, due to the lack of a suitable substrate, at the northwest end of Oreti Beach.

It may also be significant that at the southeast end of Oreti Beach estuarine conditions ensure the fine sand/silt deposits that toheroa apparently prefer.

Beentjes, Gilbert & Carbines (2003) concluded that the highest densities of toheroa were at the southeast end of Oreti Beach. This could be due to two factors. Firstly, density could reflect environmental conditions at the time of recruitment and mass mortality of individuals in the northeast, and storm conditions could have been the cause. Secondly, density of toheroa could vary with depth of suitable sediment, with mass mortality in areas having only shallow deposits of fine sand. Data from the 2002 survey indicate that lack of suitable sediment may be the leading cause of mortality amongst juveniles at the northwest end of Oreti Beach. Beentjes, Gilbert & Carbines (2003) found virtually no adult toheroa in the last 2-3 km of the northwest extent of Oreti Beach. This suggests that juvenile toheroa at the northwest end have been dying off for at least 15 years (i.e. longer than the normal life expectancy of a toheroa).

Rennie (1980) investigated recent shoreline trends in Oreti Beach, Colac Beach and Kawakaputa Beach, Southland, and concluded that the geometry of the area's beaches is predominant swash aligned and symptomatic of partially impeded sediment transport. Sediment movement was described as being in an easterly direction in response to the Southland Current (Rennie 1980). Observations on wind and wave regimes supported that conclusion. Westerly winds and the southwest swell environment were described as the two most important influences on sediment transport. Bardsley (1972) suggested that the Waiau River is the chief supplier of sediment to the area, which supports the conclusions of Carbines & Breen (1998).

4.1.3. Toxic algae

Oreti Beach has not been affected by the toxic alga, *Gymnodinium catenatum* that caused widespread mortality of toheroa on North Island beaches.

4.1.4. Climate

Like Bluecliffs Beach, Oreti Beach has strong onshore (southerly) winds and a highly seasonal temperature regime. Wind chill and low air temperatures could be significant causes of mortality of toheroa on Oreti Beach. Although there is no evidence to support this statement, it seems likely that juvenile toheroa could be affected by wind chill, due to the shallow depths to which they burrow and their thin shells.

4.1.5. Wildlife factors on mortality

Snapper are not found in South Island waters. Also, the short-tail stingray is uncommon in the South, which rules out these two predators. The swimming crab rough skate, and gulls are found in Southland, and could possibly be causes of mortality in young toheroa at Oreti Beach.

4.1.6 Pollution

Air pollution is unlikely to be a significant mortality agent at Oreti Beach due to its isolated location and the prevailing south-westerly winds. Non-point pollution could be a detrimental factor as the toheroa beds boarder on intensive dairy and sheep farms, which are recognised sources of nitrates, organic compounds, and micro bial pollutants.

4.1.7. Nutrient availability and currents that disperse spat

Nutrients and currents could explain spatial and temporal patterns in toheroa on Oreti Beach. Surveys during the past two decades show that the majority of toheroa are consistently found at the southeast end of the beach near the Oreti River mouth. That may also be related to ocean currents. A strong offshore current runs parallel to the Beach and is responsible for the movement of materials of marine and terrestrial origin. This could mean that the majority of plankton during winter months is deposited at the southeast end of Oreti Beach, with populations at the northwest end effectively starved of a major food source, thus explaining the observed pattern. This effect could be magnified by discharge from the Oreti River replenishing toheroa at the southeast end of the beach with nutrients, by pushing plankton to the southeast.

Beentjes, Gilbert & Carbines (2003) agree that this could explain spatial variations in the density of mature toheroa, with currents dispersing the spat. The reasons for the geographically variable spat density are unknown but may result from alongshore currents depositing spat preferentially at the southeast end of the beach (Beentjes, Gilbert & Carbines 2003).

4.1.8. Salinity of the interstitial water

As described in Chapter Two, low interstitial water salinity could be a significant mortality agent of toheroa on Oreti Beach.

4.1.9. Other factors

Some local observers suggest that the best toheroa beds coincide with zones of fresh water seepage from lakes behind the sand dunes. Run-off and seepage may keep the beds moist and cool, protecting the toheroa from desiccation (Stace 1992). No evidence has been advanced to support this relationship, although reclamation of dunes for forestry has lessened the amount of fresh water seeping on to the beaches (Stace 1992).

Climatic conditions could also have led to the recent decline and low density of toheroa beds at Oreti Beach, with unusually cold sea temperatures and blooms of the toxic alga, *Gymnodinium mikimotoi* possibly responsible for the decline in numbers noted in 1996 (Carbines 1997a, Beentjes, Gilbert & Carbines 2003). Comparison of the population structures of toheroa on Oreti and Bluecliffs Beaches suggests that toheroa on Bluecliffs Beach have long shown a similar size distribution to those on Oreti Beach. This could be the result of large-scale climatic episodes wiping out juveniles in Southland. This size distribution contrasts to that for North Island toheroa populations, which usually show a strong mode of sub-adult individuals and few legal-size organisms. Although climatic factors may be responsible for mortality, it is unlikely that weather alone explains the low density of toheroa on Oreti Beach.

4.2. Some Initial Conclusions

Juveniles are especially susceptible to human and natural impacts. They occupy a critical region of the beach profile, between the high and spring tide marks. This suggests seven possible impacts:

1. Vehicle traffic appears likely to cause enhanced mortality in juvenile toheroa on Oreti Beach, due to their location on the beach profile. That follows the conclusions of Hooker & Redfearn (1998) on the effect of traffic movement on Ninety Mile Beach, Northland. A vehicle survey can be expected to offer insights into the likely effects of vehicle traffic.

2. Climatic conditions could have a detrimental effect on toheroa on Oreti Beach, particularly amongst juveniles. For this to be conclusively tested, a number of years of observations would be needed, but even a limited amount of data may provide suggestive results.

3. Sediment size is important to toheroa. Little is known about the substrate on Oreti Beach, so particle size analysis can be expected to provide indications of the distribution, size and frequency of toheroa on Oreti Beach.

4. Oreti Beach has not recently been affected by the toxic alga, *Gymnodinium catenatum* that caused enhance mortality of toheroa on North Island beaches.

5. Predation by marine animals could have a significant effect on toheroa at Oreti Beach, but time constraints meant that I could not assess this factor.

6. A reliable food supply is important if toheroa are to persist. There is the possibility that toheroa at Oreti Beach are deprived of a constant food supply. Again, for this to be tested the observations of a number of years are needed.

7. Salinity of the interstitial water could be a critical issue for toheroa on Oreti Beach, but this would require a minimum of two full years of observation to obtain conclusive results.

Chapter 5

Methodology

5.1. Vehicle Survey

Surveys of vehicular traffic on Oreti Beach were conducted on the 15th of March and the 20th of June, 2004. The 15th of March was chosen to represent vehicular traffic on a normal summer's day at Oreti Beach. On the shortest day of the year (June 20) many Southlanders participate in the "mid winter swim" at Oreti Beach, an event that attracts numerous participants. For coding purposes, vehicles on Oreti Beach were assigned to the most appropriate of 12 separate blocks 12 kilometres apart, with place on the beach categorised as between the high, spring and storm tide marks (Figure 3).

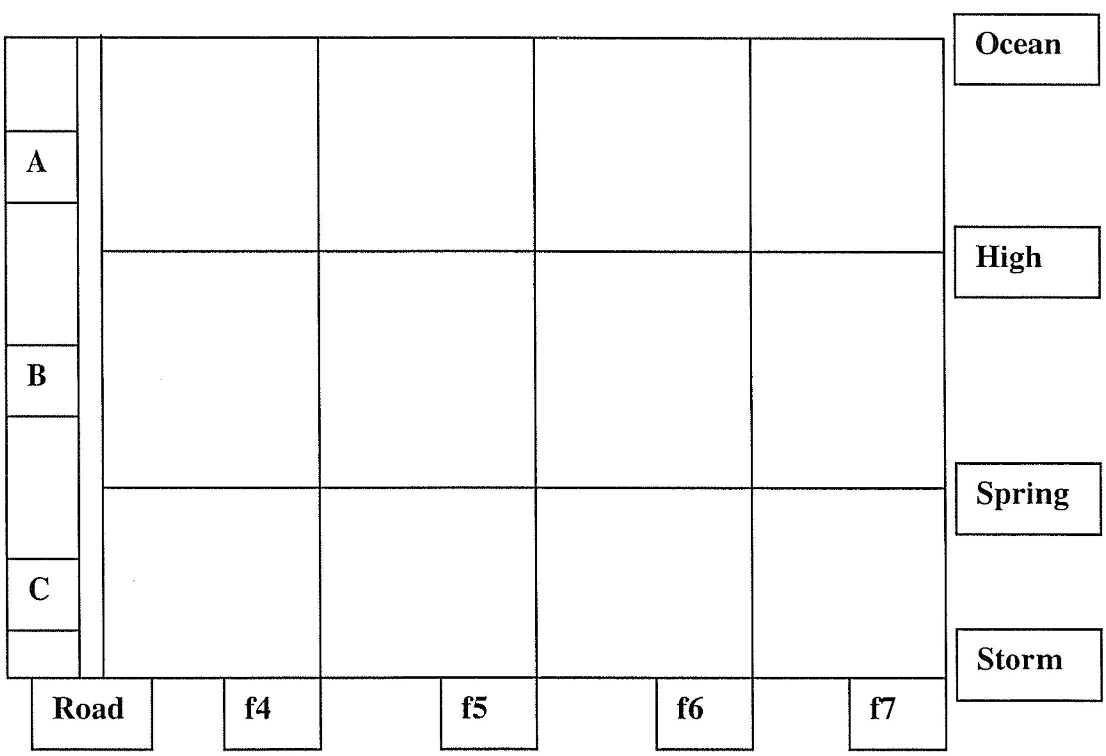


Figure 3: The coding matrix, representing the profile of Oreti Beach, used for a survey of vehicle traffic. The matrix comprises three bands: A, B and C. "A" is the area closest to the ocean, "B" lies between the high and spring tide marks, and "C" is the spring to storm area of Oreti Beach. Oreti Beach was split into 1 km sections, labelled F4, F5, F6, and F7. NB – Figure 3 only shows the west of Oreti Beach, from the access road.

Car journeys on to Oreti Beach were noted. This involved mapping the journeys of individual vehicles on the coding matrix (Figure 3). When a vehicle moved into a section of the matrix it was recorded. For example F4, A, is within 1 kilometre from the public access road and between the high-tide and the spring tide marks. Vehicles that moved to other sections of the beach were recorded in that section as well. For example, a vehicle that had parked in F4, B then moved on F5, B would be recorded twice as in F5, B and twice in F4, B, because it moved over the latter part of the beach twice. If the vehicle followed a different return path then that was recorded. For example, if a vehicle was parked in F4, B then travelled back through F4, C to the public access, then it would be recorded in F4, B once and in F4 once. This routine records movement along, up and down the beach. All vehicles would be were recorded: 4 wheel drive, cars, vans, motor bikes and tourist coaches. Motor bikes included 2, 3 and 4 wheel vehicles. Vehicular traffic was recorded in car units as below:

<u>Vehicular Equivalents:</u>

1 Car	-	1 Car
1 Van	-	1 ½ Cars
1 4WD	-	1 ½ Cars
1 Bus	-	3 Cars

Prohibited activities, such as speeding and dangerous driving, were also recorded.

The aims of this survey were to:

1. show the areas of Oreti Beach where pressure is exerted by vehicular traffic on the sand. The data will be related to the findings of previous surveys to provide an indication whether or not vehicle traffic on Oreti Beach is having an effect on toheroa.

2. indicate if special events may be expected to have a greater impact on toheroa in comparison to ordinary times at Oreti Beach.

3. allow comparisons with the distribution of juveniles on the beach profile and density of vehicle traffic. This should hopefully indicate whether or not the juveniles are significantly affected by vehicular traffic.

4. indicate if prohibited or illegal behaviour on Oreti Beach is likely to affect toheroa.

5.2. Beach Sediment

Particle size analyses were conducted on samples of sand from Oreti Beach. Samples were collected from the Oreti Estuary (southeast) to the Waimatuku (northwest) ends of the beach, over a distance of 12 km (Figure 1). Four sand samples were taken every kilometre, with sub-samples 5 cm, 10 cm, 20 cm and 30 cm below the surface in the inter-tidal zone of each site (Figure 2). The aims were to show:

1. differences in sediment size distribution along Oreti Beach and to identify possible influences on toheroa;

2. change in sediment type with depth along Oreti Beach. A deep sample was expected to have more sand, and a shallow sample more gravel and small stones. Shallow stony sediments are undesirable for juvenile as well as adult toheroa as they limit their burrowing capacity.

5.2.1. Laboratory Analysis

For particle size analysis, sediment samples were placed in an oven and dried for 24 hours at 98 degrees C. Samples then sieved (8 mm, 4 mm, 2 mm and 1 mm) by shaking for approximately 10 minutes. The contents of each sieve were weighed. The data were then used to give cumulative percentages for each site and the four sampled depths.

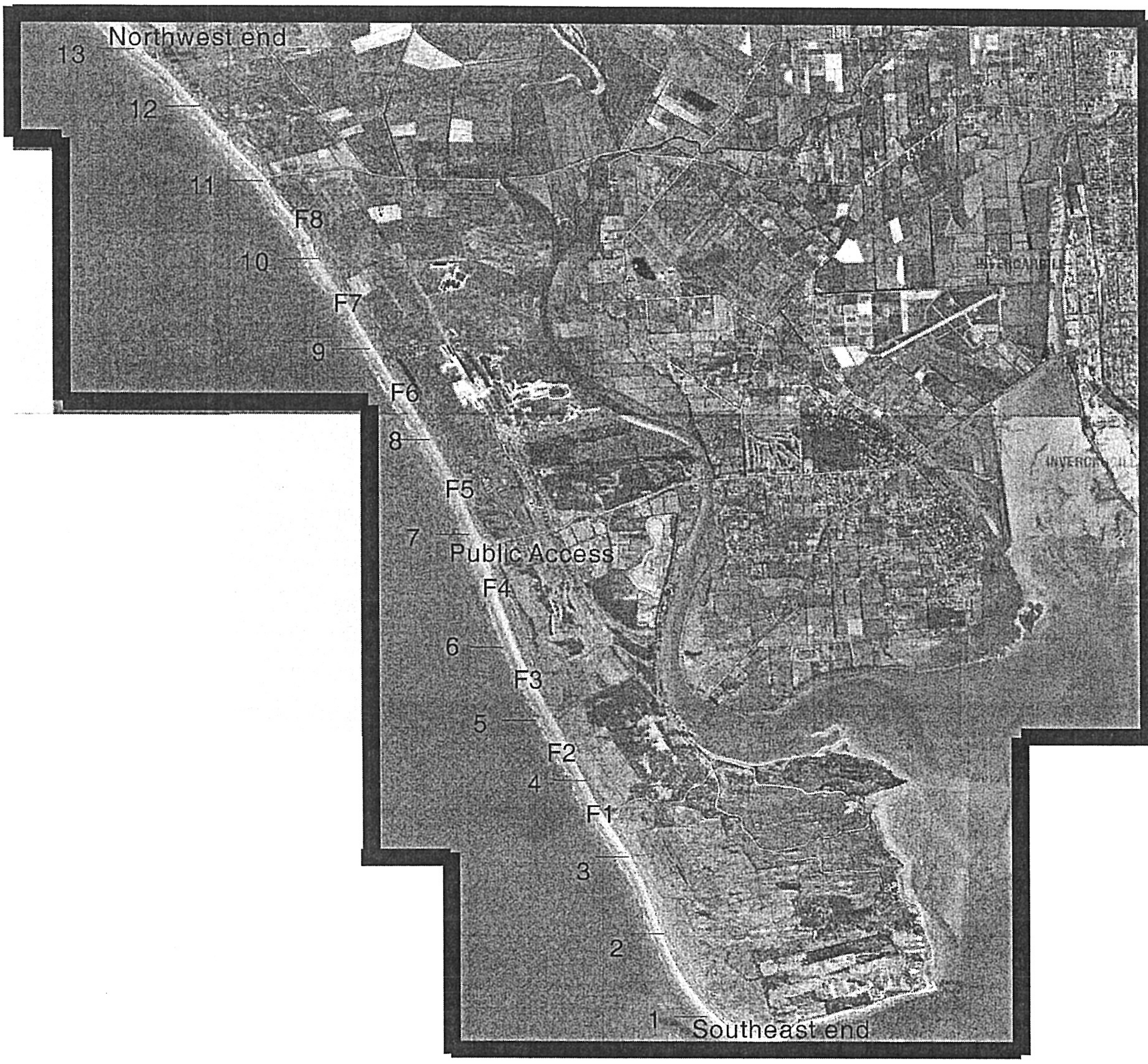


Figure 4: The study area at Oreti Beach. 1-13 represents sediment sample sites, and F1-F8 represents the vehicle survey area.

Chapter 6

Sediment Size Distribution on Oreti Beach

6.1. Sediment Samples

This chapter outlines results of analyses of sediment samples collected from Oreti Beach. The main findings are shown in Figure 5, which depicts cumulative percentages by size class: larger than 8 mm, 5 mm to 7 mm, 2 to 4 mm, 1 to 2 mm, and smaller than 1 mm. The Figure shows values for the four sampled depths and the 13 sites along the beach.

6.2. Sediment Type

The sediment ranged from large gravel and pebbles (8 mm and bigger) to sand grains smaller than 1 mm. When viewed under a dissecting microscope at 10 and 15 magnification the following features were observed:

1. The finer sediment was markedly different from the larger sediment in its angular shape and sharp edges, indicating a mobile environment. It was also almost entirely quartz, with less than one percent other minerals.

2. The larger material was either shell fragments or the much more common oblate (disk or tabular) particles, all of which were of metamorphic origin. Classification of the shape of sediment particles was according to Zingg (1935).

3. There were no silt or clay-sized particles visible, and even the finest sand lacked a coating of finer sediment.

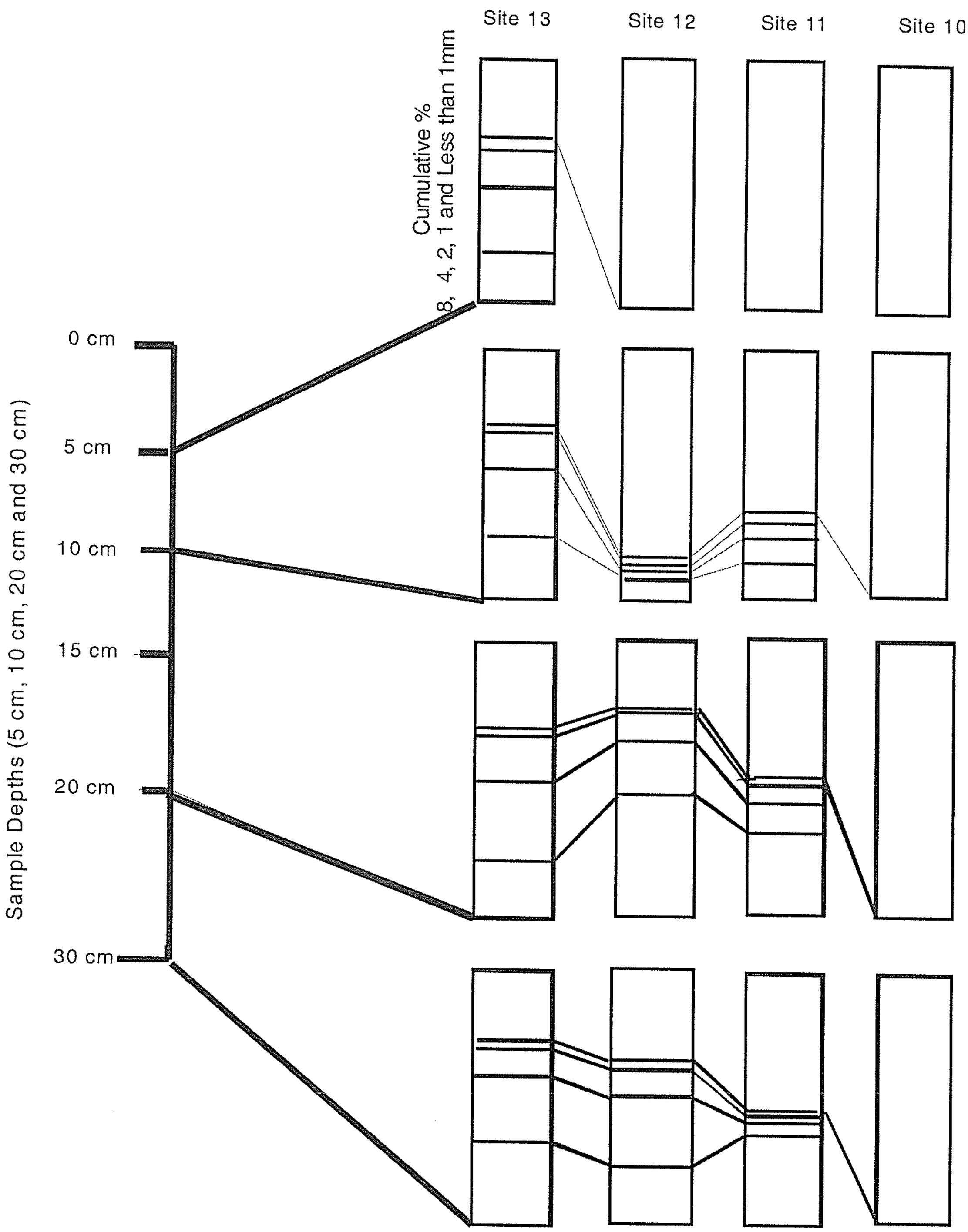


Figure 5: Cumulative percentages of particle sizes on 8, 4, 2 and 1 mm sieves for each of four depths (5, 10, 20 and 30 cm below the surface) by sample site. At sites 9 to 1, all sediment in each of the four sample bands is smaller than 1 mm.

6.3. Near-Surface Sediment

Particle size analysis of near-surface sediment (5 cm below the surface) showed little change along the beach. The prime exception was at site 13, at the western end of Oreti Beach. The 1 mm sized material consisted of small sand and shell fragments. Nineteen percent of the sediment in the near surface sample from site 13 was 8 mm or larger in size, and was made up of large gravel and small pebbles, all of which were smooth and tabular with rounded edges. One percent of the sediment at site 13 was between 4 and 8 mm in size. Thirteen percent was 2 to 4 mm, and included small gravel. The remaining thirty-five percent was smaller than 1 mm, and consisted of fine sand.

All other sediment samples, regardless of depth below the surface, from sites 1 to 12 along the beach comprised particles smaller than 1 mm but larger than 0.25 mm.

6.4. At Ten Centimetres

Particle size analyses of sediment from 10 cm below the surface showed clear trends, the proportion of larger sediment declining from the northwest to the southeast end of Oreti Beach (Figure 2). The sediment at 10 cm had particles 8 mm or bigger, between 7 mm and 5 mm, between 4 mm and 2 mm, 1 mm and sediment less than 1 mm for sites 11, 12 and 13.

At site 13 there was a similar size distribution to that for the 5 cm deep sample, being mostly 8 mm or bigger. Thirty-one percent ranged between 8 and 4 mm, identical to what was found in the 5 cm deep sample for site 13. Fourteen percent of sediment was between 2 and 4 mm in size. The bulk of the sediment (thirty-five percent) was smaller than 1 mm, and the remaining two percent was between 1 and 2 mm.

At site 12, ninety-three percent of the sediment was smaller than 1 mm, with larger size material, accounting for the balance. Three percent of the sediment ranged from 1 to 8 mm, and the remaining twenty percent was 8 mm or more.

The results for site 11 are similar to those for site 12. Seventy-nine percent of the sediment was smaller than 1 mm, more than twice the corresponding value for site 13.

The remaining twenty-one percent was split over the other sizes classes (8 mm and bigger, 7 to 5 mm, 4 to 2 mm, and 1 mm: eleven, six, three and one percent, respectively).

For the remaining sites (1 to 10) samples from 10 cm below the surface were identical, with one hundred percent of the sediment in each sample smaller than 1 mm.

6.5. At Twenty Centimetres

Particle size analysis of sediment from 20 cm below the surface showed several clear features. There was a decline in the relative amount of larger sediment from the northwest to the southeast end of Oreti Beach. There were also strong modes at 8 mm and larger, between 7 and 4 mm, and less than 1 mm. Nineteen percent of the sediment was 8 mm and larger, which compares with sediment samples from depths of 10 and 5 cm. Thirty percent of the sediment from site 13 was between 8 mm and 4 mm in size. This is almost identical to the value for 10 cm below the surface, and one percent less than the value for 5 cm. Relatively little sediment was between 4 and 1 mm, which follows the trend for other depths, as seen in site 13.

Site 12 contained a relatively large amount (forty-three percent) of sediment 8 mm and larger. Eighteen percent was between 7 and 4 mm, which differs markedly from all other sites. A small proportion of the sediment at site 12 was between 2 and 1 mm, being seven and two percent respectively. The remaining thirty percent was 1 mm or less.

Site 11 had a strong mode at 1 mm, comprising fifty-five percent of the sediment. This is higher than for sites 13 and 12. Thirty percent of the material was 8 mm or larger. The remaining sediment was between 8 and 1 mm.

The remaining samples from 20 cm below the surface at sites 1 to 10 were all less than 1 mm in size.

6.6. At Thirty Centimetres

Thirty centimetres was the deepest sample for each site, and the values compared with those from twenty centimetres below the surface. The amount of larger sediment shows a clear decline from the northwest to the southeast ends of the beach.

Site 13 has a relatively large amount of sediment 8 mm and larger (thirty-one percent). Further, there is a strong mode at 7 to 4 mm (thirty percent) for the sediment sample. Sediment smaller than 1 mm comprised twenty-seven percent of the sample.

At site 12, sediment 1 mm and smaller, or between 8 and 4 mm, was well-represented. Sediment 8 mm and larger contributed twenty percent of the total, with the remaining fifteen percent comprising sediment between 4 and 1 mm.

The sample from site 13, consisted of sediment mostly smaller than 1 mm, or larger than 8 mm, being fifty-eight and thirty-three percent respectively. This is different from the situation at sites 13 and 12, were there was a more even spread over the size ranges. Six percent of the sediment was between 7 and 4 mm, with the remaining three percent of sediment was in the range of 4 to 1 mm.

6.6.1. Broad Trends

1. Sites 11, 12 and 13 were the only places on Oreti Beach with a reasonably broad suite of sediment sizes. By contrast sites 1 to 10 contained sediment smaller than 1 mm.

2. Site 13 has different proportions of the various sediment size classes than the other 12 sites. At 5 cm below the surface, site 13 was the only one with particles larger than 1 mm, making up sixty-five percent of the sediment. The remaining sites all had particles smaller than 1 mm. Site 13 had relatively more sediment 8 mm or larger at that depth, as well as sediment between 7 mm and 4mm. Site 13 had less fine sediment, compared with sites 11 and 12.

3. Finally, there was a declining abundance of large particles from the northwest to the southeast end of Oreti Beach, with particularly rapid change from site 13 to site 11.

Chapter 7

Primary Findings

7.1. Vehicular and Related Traffic: Late summer

The first traffic survey was conducted between 12:00 pm and 2.30 pm on Saturday 20th March 2004. During this period the tide was high, peaking at approximately 1.30 pm and retreating soon afterwards. There was a light north-easterly breeze, with high cloud and an ambient temperature of 12 degrees Celsius. A total of 24 car units were recorded: 6 four wheel drive vehicles, and 15 cars.

7.2. Vehicular Traffic and Related Usage: Mid-Winter

A traffic survey was conducted for two and half hours, being the duration of the mid winter swim, on Sunday 13th June 2004. It ran from 12 pm to 2.30 pm and during this period the tide was incoming. High tide peaked at 2.05 pm. Strong southerly breezes prevailed for the duration of the survey and there were intermittent showers. The air temperature was 7 degrees Celsius.

A total of 10 four wheel drive vehicles and 45 cars were on the beach at that time. The following formula was used to express the effect of four wheel drive vehicles in car equivalents, the multiplier being the average weight relationship between the two:

Car Units	=	Total 4WD	x	1.5
	=	10	x	1.5
	=	25 Car Equivalents		

No mini vans, buses or motorcycles were observed on the beach during the survey. The eastern side of the access track (Fig 2) had the majority of vehicles, although a large proportion of the total was found on the western side of the access track. A total of 54 car equivalents were found between the high tide and storm tide marks, with 15 car equivalents between the storm beach and the dunes.

7.3. Late Summers Day

The results accumulated on the late summer's day are shown below (Figure 6).

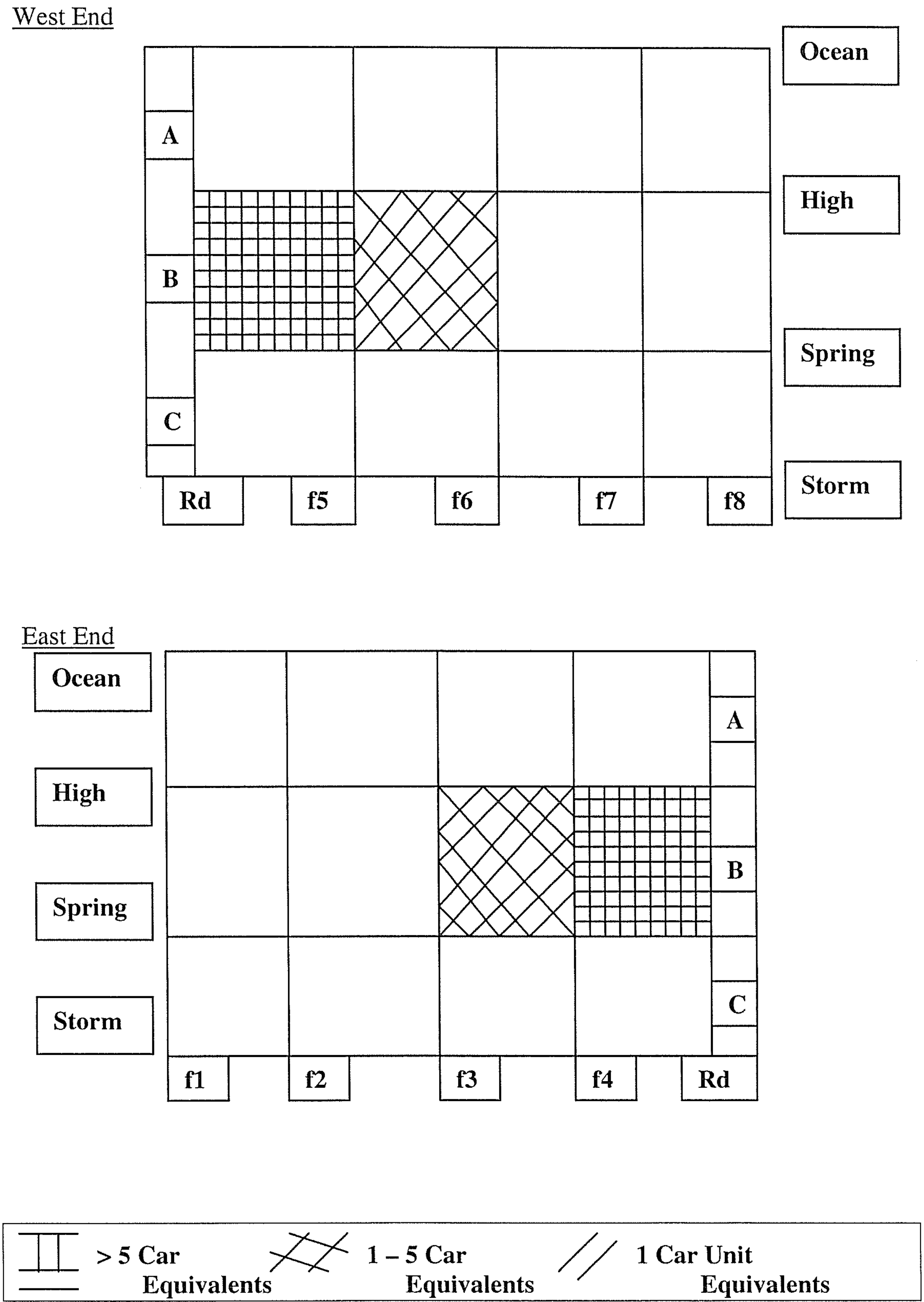


Figure 6: Vehicular and related traffic on Oreti Beach on a late summers day: Saturday 20th March 2004.

West of the Public Access Point

Fifteen car equivalents were recorded west of the public access point on Oreti Beach: 6 four wheel drive vehicles and 9 cars.

The majority of vehicular traffic was within 100 metres of the public access point, with vehicles only in F5 and F6 (see Figure 6). In F5 there were 10 car equivalents, while F6 recorded the remaining 5 car equivalents. All the traffic was in those areas.

A number of traffic journeys were made in zone B. Three car units in total travelled from F5 to F6, then back to F5. This effectively doubled the traffic in F5. The remaining vehicles stayed in F5 and F6.

East of Public Access Point

A total of 9 car equivalents were seen east of the public access point: 2 four wheel drives and 6 cars.

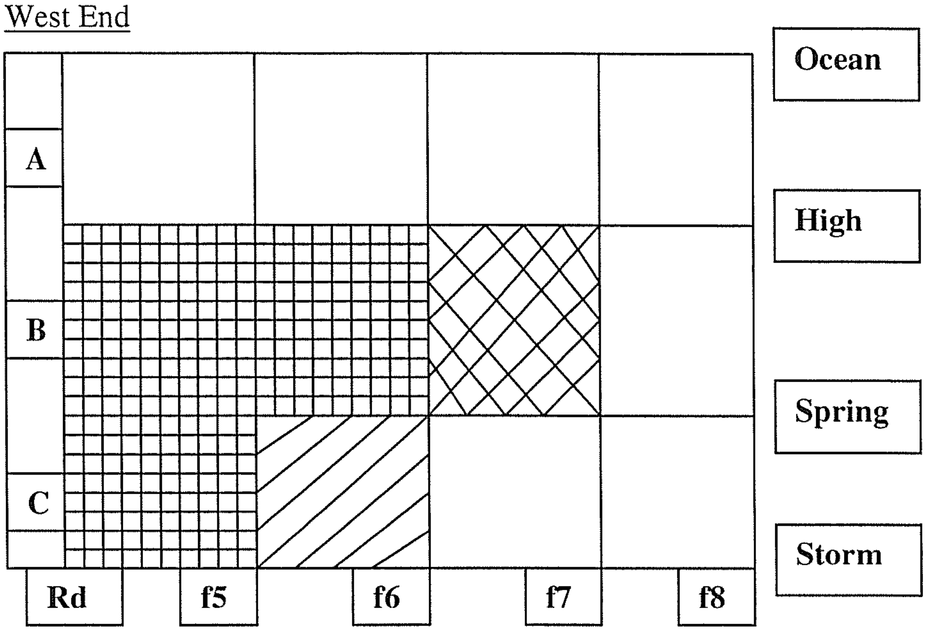
The majority of that traffic was within 100 metres of the public access point, and moved to F5 and F6 (see Figure 6). F5 had 6 car units and F6 the balance. Itemisation of vehicle traffic on the beach zone illustrated (Figure 6) that profile B had all the majority of vehicle traffic.

Several journeys were observed in the band between the high and spring tide marks. Three car equivalents travelled from F5 to F6, then back to F5.

7.4. Shortest Day

The results accumulated on the shortest day are shown below (Figure 7).

West End



East End

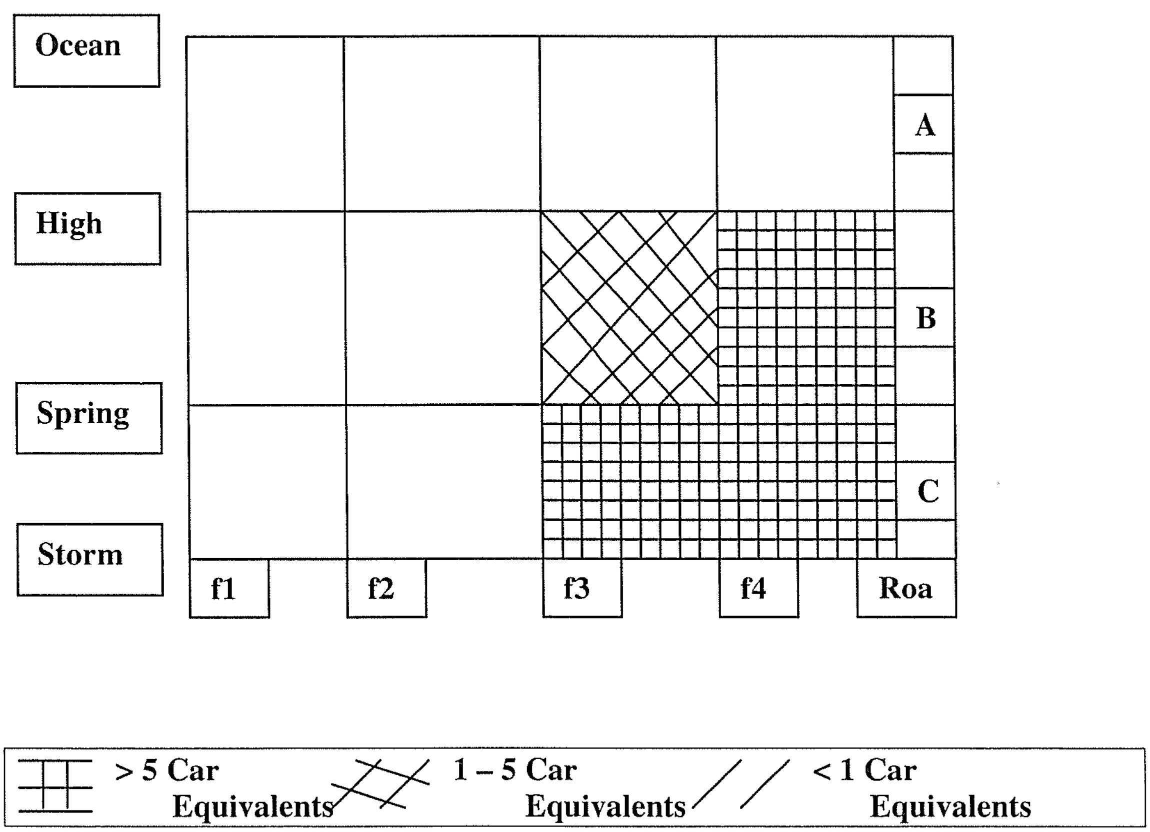


Figure 7: Vehicular and related traffic on Oreti Beach: 13 June 2004.

West of Public Access

A total of 32 car equivalents were parked along the public access road. Of the total, four were wheel drive vehicles and 26 were private cars.

The majority of vehicular traffic was clustered around the point of entry to the public access track (see Figure 2). The area between the high and spring tide line (Figure 7) had the majority of traffic (21 car units). The area between the spring and the storm marks had 11 car equivalents, but the area below high tide had no vehicle traffic. All but 2 car equivalents were found in F5 and F6, with the outlier in F7 of zone B.

The majority of vehicle movement was between the high and spring tide lines, with three cars travelling from F5 to F6, then from F6 to F5, effectively doubling usage. The remaining vehicles stayed in only one section of Oreti Beach.

The 4 four wheel drives were found in zone B, yet all remained stationary within F5.

East of the Public Access Point

A total of 38 car equivalents were recorded east of the public access. The total of 38 cars included 6 four wheel drives and 31 cars.

The majority of traffic was clustered around the public access point (see Figure 7), with vehicles in the first three strata (F5, F6 and F7). F5 contained 25 car equivalents, with the remaining 13 in strata F4 and F3. The area between the high and spring tide marks contained the majority of the traffic (28 car equivalents). The area below the high tide mark had no vehicle traffic, and the remaining 10 car equivalents were present in between the spring tide mark and the edge of the dune system.

Several visitors made journeys along the beach to the east of the public access way, with the majority in the area between the high and spring tide marks. The greatest density of vehicular traffic occurred in the beach zone, with 5 car equivalents travelling from F5 to F4 then to the public access via F4, hence doubling the number of car equivalents (Appendix 1). Vehicles were seen in C, but only two cars moved between F4 and F3. The remaining vehicles did not move from where they were first parked until their owners were ready to leave the beach.

Chapter 8

Discussion

8.1. Sediment

Particle size analysis provided valuable insights into influences on the population dynamics of toheroa at Oreti Beach, particularly when compared with the findings of previous surveys on juvenile, sub-adult and adult toheroa. It confirmed a significant decline in amount of fine sediment towards the northwest end of Oreti Beach. The last three kilometres contain a full suite of sediment sizes, in contrast to the first ten kilometres that comprise only of sediment smaller than 1 mm.

As stated by Mckinnon & Olsen (1994), toheroa are particularly sensitive to changes in sediment conditions. They attributed the drastic decline in toheroa numbers at Bluecliffs Beach to changes in beach profile and sediment type. Frequent scouring events have been blamed for removing finer sediment from the beach, leaving behind a layer of coarse sand that toheroa spat and immature individuals are unable to burrow into. Beentjes & Carbines (2001) suggested that all sizes of toheroa at Bluecliffs Beach are to some extent restricted to persistent areas of soft substrate (notably fine and coarse sand), and there is compelling evidence for a causal relationship between substrate complexity and toheroa numbers in the inter-tidal zone. A similar relationship is evident at Oreti Beach. Sediment larger than 4 mm is unlikely to provide a suitable habitat for toheroa. All surface sediment in sites 1 to 10 was between 0.25 mm and 1 mm in size. Despite being angular, it is likely to be suitable for all life stages of toheroa. That view is congruent with the Beentjes, Gilbert & Carbines (2003) visual analysis of sediment on Oreti Beach. At the northwest end of Oreti Beach the coarse sediment is generally of an oblate shape. Over half the sediment in the 3 western most sites was 4 mm and larger, except at the surface, meaning that toheroa will experience difficulty becoming established there. Further, sites 11 to 13 represent a stretch of 2 kilometres, which is significant in terms of the young organism's ability to move to a more suitable sediment. Little is known whether or not the sediment trend identified in this study has developed over a long or short time, as this is the first particle size analysis study conducted at Oreti Beach.

The results indicate a narrow niche for toheroa on Oreti Beach, and it lies between sites 1 and 10. Beentjes, Gilbert & Carbines (2003) concluded that adult toheroa are not found beyond the 12 km mark on Oreti Beach, which is approximately 2 kilometres before the Waimatuku Stream. Juvenile toheroa on Oreti Beach are relatively evenly spread throughout the 15-kilometre beach (Beentjes, Gilbert & Carbines 2003), sub-adults are effectively confined to the first 10 kilometres. This points to enhanced mortality of sub-adults and adults in the vicinity of the Waimatuku Stream, presumably due to the lack of a suitable sediment for them to occupy. This pattern is also shown in the findings of Beentjes, Gilbert & Carbines (2003). They divided Oreti Beach into eight strata, with my site 13 corresponding with their eight stratum. The mean number of juveniles found in stratum eight was 40.5, and the mean numbers of sub-adults and adults were 1.3 and 1.1 respectively. Clearly very few juveniles are reaching maturity in this region.

Redfearn (1974) states that juvenile toheroa occupy the top 5 cm of beach sand so the 2-kilometre area between sites 10 and 12 should contain them (Beentjes, Gilbert and Carbines 2003). In that area a suitable sediment is found, but below the surface layer (i.e. > 5 cm) the majority of particles are coarser than 4 mm and, hence, unsuitable for toheroa. Redfearn (1974) found that sub-adults and adults preferentially occupy the band 10 cm to 30 cm below the surface. There is a lack of suitable sediment in this band, so sub-adults and adults are unlikely to survive there. Further evidence from Beentjes, Gilbert & Carbines (2003) supports the proposal of an abrupt stop to the distribution of adult toheroa at the 10-kilometre point. This could explain the apparent lack of recruitment in that part of Oreti Beach. Additionally, the generally coarse sediment in sites 13, 12 and 11 is likely to be a significant cause of mortality in toheroa despite the large amount of spat reaching this area. Yet the juvenile population in sites 13, 12 and 11 is apparently disappearing. That could either mean toheroa migration towards the southeast end, or a juvenile population dying due to the lack of suitable sediment for them to occupy. Due to the extensive area and the small mean number of toheroa found within stratum eight, juvenile toheroa are likely to be dying. That implies lack of recruitment, and may explain why the population has not recovered after 20 years of prohibited harvesting.

8.2. Vehicle

The results of traffic surveys conducted on the 20^{th} of March and 13^{th} of June 2004 point to a serious mechanical or other impact on toheroa.

Traffic numbers varied between the shortest day (13^{th} of June) and a normal summer's day (20^{th} of March 2004). Both surveys were conducted for two and half hours, yet the survey for the shortest day recorded a total of 70 car equivalents, where as the normal summer's day only recorded a total of 24 car equivalents. The users of Oreti Beach were primarily involved in recreational activities, such as swimming, surf life saving and surfing. With this in mind, and reflecting on results gathered from the survey on a late summer day (20^{th} of March), one might assume that vehicle traffic during a normal winter's day must be minimal, due to cool temperatures and prevailing southerly winds. Although there is no evidence to support this claim it is a fair hypothesis and damage to toheroa during winter is likely to be minimal. Special events, such as the mid winter swim (13^{th} of June) which attracts many participants, pose particular problems for toheroa.

The distribution of vehicular traffic on Oreti Beach was predominately within 100 metres of each side of the public access point. Most of the vehicles recorded were within 2 kilometres of the public access point, with only a few outliers beyond this region. For both traffic surveys, traffic was slightly greater to the east of the public access, although the difference was so minor as to have little effect on the toheroa population. With knowledge of the concentration of vehicular traffic on Oreti Beach comparisons can be made with the 2002 Oreti Beach toheroa survey conducted by Beentjes, Gilbert & Carbines (2003).

They investigated toheroa numbers on Oreti Beach in February 2002 and their plots were designed for adult, sub-adult and juvenile toheroa. Beentjes, Gilbert and Carbines (2003) stated that a region 7 kilometres from the estuary (southeast end) of Oreti Beach held no toheroa. Seven kilometres from the estuary, directly in line with the public access, is where most of the traffic is concentrated. Redfearn (1974) stated that sub-adult and adult toheroa are notable for moving along beaches at will. That being the case, a possible hypothesis is that adult and sub-adult toheroa are becoming distressed by the traffic movement and vacating the area most popular with car drivers. For their part, juvenile toheroa are dying due to their inability to establish in coarse sand and move from areas of high traffic density. The survey by Beentjes, Gilbert & Carbines (2003) was conducted in February 2002 and lends evidence to that hypothesis. February is when sub-adult toheroa might be expected to have moved to the southeast or northwest ends of Oreti Beach. However, most juvenile toheroa, in this area are likely to be already dead or dying, thus explaining the lack of a viable toheroa population for that section of Oreti Beach.

In addition to the concentration of vehicle traffic on Oreti Beach is the position on the beach profile that vehicles are occupying. Surveys on the 13th of June and the 20th of March 2004 both recorded highest densities and greatest movements of traffic between the spring and the high tide marks. Redfearn (1974) stated that juvenile toheroa occupy the area between the spring and the high tide marks until they can burrow deep enough to occupy areas between the high tide and low tide marks. This statement concurs with findings from the Oreti Beach 2002 toheroa survey (Beentjes, Carbines & Gilbert 2003). Beentjes, Carbines & Gilbert (2003) found that the majority of toheroa were clustered around the spring the and high water marks. This comparison points to issues of the impact motorised vehicles are having on juvenile toheroa on Oreti Beach.

Comparisons can be made between vehicle traffic and movement on the beach profile and the mean number of juvenile toheroa on Oreti Beach. When conducting the 2002 survey Beentjes, Gilbert & Carbines (2003) divided Oreti Beach into strata to account for age-specific distributions of toheroa. Mean numbers of toheroa were calculated for adults, sub-adults and juveniles. Beentjes, Gilbert & Carbines (2003) found for strata 4 and 5 (which is the 2-kilometre section in line with the public access point) that mean numbers of juvenile toheroa were, 58.5 and 42.5 respectively. This contrasts with the average number of sub-adult and adult toheroa found (3.0 and 0.7 respectively). The adult toheroa were finer in strata 4 and 5, being 2.3 and 3.0 respectively. This suggests significant mortality preventing juveniles from maturing.

Due to the complex nature of coastal areas and toheroa population dynamics, firm conclusions cannot be offered about the effect of vehicle traffic, although there is evidence to suggest that juvenile toheroa on Oreti Beach, are being adversely affected by motorised vehicles.

The mid-winter swim on the shortest day (13^{th} of June 2004) produced the highest densities of vehicle traffic, in comparison with numbers recorded on the late summer's day. The mid-winter swim may have the greatest impact on toheroa beds at Oreti Beach, because of its intensity. During the early summer months the warm weather periodically lures recreational users to Oreti Beach, but the gradual influx of visitors to the Beach may give sub-adult and adult toheroa time to move areas where traffic that would not however, save the juveniles as they lack the ability to move far and burrow more than a few centimetres below the surface.

The mid-winter swim is a major event at Oreti Beach, although there may be other events that could affect toheroa. There could include motorcycle club members riding along the foreshore of Oreti Beach. It has been suggested by Ackroyed (2002) that motorcycles have an especially detrimental effect on juvenile toheroa, because narrow tyres can overturn and liquefy large amounts of sand. Although not recorded in this study, prohibited or illegal behaviour could also be affecting toheroa on Oreti Beach. The speed limit is 30 kilometres per hour, yet when observing the journeys of vehicles it was obvious to me that the majority of traffic was exceeding this limit. Secondly, many people were driving in a dangerous or reckless manner, and performing prohibited stunts.

Chapter 9

A Management Regime

Definitive management recommendations are not possible at this stage. There are, never-the-less, factors that seem important for the management of toheroa on Oreti Beach. They relate to proscribed activities under the proposed regional coastal plan.

9.1. Extracts from The Proposed Regional Coastal Plan for Southland

Issue 14.2.2: Some recreational activities can have adverse impacts on indigenous fauna for example, toheroa at Oreti Beach and Hector's Dolphin at Porpoise Bay.

Rule 14.2.13: Vehicle restrictions on Oreti Beach

On that area of Oreti Beach below Mean High Water Mark, between the New River Estuary mouth and the Jacob's River estuary mouth, the use of the foreshore by vehicles where

a they do not exceed 30 kilometres per hour' and

b they do not exceed 3.5 tonne in gross weight, is prohibited.

Explanation – Speed is controlled for safety reasons and vehicle weight is controlled to prevent damage to biota, in particular juvenile toheroa. A 3.5 tonne vehicle may be occasionally used for recreational purposes but anything heavier is likely to have an adverse effect on toheroa beds. This rule, however, does not prohibit use of the area between the mean high water mark and the mean high water spring by heavier vehicles. From a safety viewpoint, 30 kilometres per hour is considered the acceptable maximum on the beach.

Rule 14.2.14: Vehicles prohibited on Oreti Beach

On that area of Oreti Beach below Mean High Water Mark, between the New River Estuary mouth and the Jacobs River Estuary mouth, the use of the foreshore by vehicles other than those used for the disposal of dead marine animals or recovery purposes where

a they exceed 30 kilometres per hour' or

b exceed 3.5 tonne in gross weight is prohibited

Explanation - This Rule seeks to prohibit heavy vehicles (more than 3.5 tonne) and vehicles travelling in excess of 30 kilometres per hour. From a safety viewpoint, 30 kilometres per hour is considered the acceptable maximum speed limit. A beach is a public road and the Police can control breaches of traffic regulations. Vehicles weighing in excess of 3.5 tonne on sand below mean high water mark are likely to have an adverse effect on toheroa beds. This rule, however, does not prohibit the use of the area between mean high water mark and mean high water springs by heavier vehicles.

The author concurs with the intent of rules 14.2.13 and 14.2.14 in the Proposed Regional Coastal Plan for Southland. In addition, the following management proposals are important and should be integrated into the Regional Coastal Plan to ensure that human impact on the toheroa beds of Oreti Beach is minimised.

1. A public access track for pedestrians only is needed on the foreshore of Oreti Beach. All vehicle access, including cars, buses and motor cycles should be prohibited, especially when spat are being released.

2. Efforts will be needed to prevent unauthorised vehicle use on Oreti Beach. Such moves will require integrated management with Invercargill Police Department, and may involve preventive actions.

3. Traffic on the beach should be restricted to designated areas during "special events" and vehicles should not be permitted to circulate in the area between the low and spring tide marks.

Chapter 10

Conclusion

The population of toheroa at Oreti Beach is under severe threat. The growth and population dynamics of this valued shellfish are showing worrying signs, with a run of surveys showing marked variations in population size and structure. The author's findings do not provide definite answers to explain these fluctuations in population dynamics. Rather, the research findings offer indications and insights into possible environmental influences and human impacts on toheroa. The following findings, implications, and research recommendations may prove important for the conservation and management of toheroa on Oreti Beach.

1. Particle size analysis on foreshore deposits at Oreti Beach showed a trend of declining suitable substrate towards the northwest end of Oreti Beach. This was especially prominent around the Waimatuku Stream, where the majority of particles were larger than 4 mm. Comparisons with the findings of an earlier survey on Oreti Beach revealed relatively many juveniles in this area, but few adults. This indicates that sediment quality could influence population dynamics through enhanced mortality of juvenile toheroa.

2. Surveys on Oreti Beach demonstrated a predominance of vehicular traffic within two kilometres of, and concentrated 100 metres around, the public access point. Most of those vehicles were between the spring and high tide marks. Comparisons with the findings of a previous survey on Oreti Beach revealed an abundance of juveniles in this area, with only small numbers of adults. This indicates that vehicle traffic could influence the species' population dynamics through enhanced mortality of juveniles.

3. Sections of the foreshore at Oreti Beach where little vehicle traffic was seen and where most sediment was smaller than 1 mm showed similar population

features to those outlined above. This points to the susceptibility of juvenile toheroa to macro-environmental conditions.

4. The management regime for toheroa substantially conforms to the Proposed Regional Coastal Plan, but access should be restricted to pedestrian traffic, especially when spat are dispersing. In particular, events that bring may vehicles on to the beach should be prohibited.

5. This research points to the serious threats to toheroa on Oreti Beach, but it should be repeated. In particular surveys need to be conducted annually to monitor the growth, survival and distribution of this vulnerable shellfish species.

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Appendix

Sediment Data

Layer	8 mm	%	4mm	%	2 mm	%	1 mm	%	Pan (g)	%
13										
D	196.87	31	189.5	30	54.3	9	20.51	3	169.05	27
C	65.6	19	105.1	30	48.55	14	5.35	2	122.34	35
B	96.03	22	129.36	30	59.88	14	50.05	1	138.99	33
A	76.93	19	126.61	31	55.2	13	8.54	2	143.95	35
12										
D	63.54	20	97.43	30	43.56	13	4.98	2	114.2	35
C	155.59	43	66.37	18	23.91	7	8.65	2	106.85	30
B	13.06	4	4.37	1	3.99	1	1.03	1	284.03	93
A	-	0	0	0	-	0	-	0	286.78	100
11										
D	161.48	33	27.57	6	13.24	2	5.72	1	285.75	58
C	176.57	30	55.62	9	22.71	4	8.92	2	327.69	55
B	26.97	11	13.25	6	5.83	3	1.03	1	197.02	79
A	-	0	-	0	-	0	-	0	240.2	100
10										
D										
C										
B										
A										