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Potential impacts of vehicle traffic on recruitment of Toheroa (*Paphies ventricosa*) on Oreti Beach, Southland, New Zealand.

A report for Te Ao Mārama and Environment Southland

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He Kōhinga Rangahau is the research report series of *Te Tiaki Mahinga Kai*, a national coalition of tangata kaitiaki, researchers and mangers dedicated to sustained enhancement of the cultural, economic, social and environmental well being of Māori and New Zealand as a whole. This will be achieved through the application of mātauranga and science associated with mahinga kai to modern customary fisheries practices. *See* www.mahingakai.org.nz for a detailed description of the kaupapa. *He Kōhinga Rangahau* means "the gathering together of research findings". This report may be used and cited by anyone with due acknowledgement to *Tiaki Mahinga Kai* and its funders.

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Executive Summary

Historical declines of toheroa (*Paphies ventricosa*), an endemic surf clam and important customary food of Māori, are related to recruitment failure, habitat change and past harvest pressure. Many observers have expressed concern that population recruitment is also being disrupted by vehicles which crush juvenile toheroa when they are driven onto beaches, but comprehensive scientific assessment of this risk is not yet available. Our preliminary survey of damage to juvenile toheroa on Oreti Beach (Invercargill, Southland) measured the proportion of juvenile toheroa killed by: (a) motorbikes participating in the Burt Munro Challenge beach race on 28 November 2008; and (b) four test vehicles driven over experimentally placed toheroa on Oreti Beach in April 2009.

Best estimates suggest that around 53,000 juvenile (<40 mm) toheroa were killed on the 850 m-long race track used in the Burt Munro Challenge beach race, but statistical uncertainty means that the number of fatalities could have been as low as 31,000 or as high as 70,000. This indicates a minimum mortality rate of 72% (41 – 90%) amongst the toheroa living on the race track. On average the racing bikes ran over each toheroa on the track 11 times during the races in which some bikes reached speeds of 180-200Km/hr. Over 1700 additional vehicles drove onto the beach to carry spectators, competitors and race organisers to and from the event. The number of toheroa killed by this additional traffic was not quantified in our study, and the tide flooding the race track just after the race ended probably deposited newly drifting juvenile recruits and flushed away damaged specimens from the race track itself. We also used a conservative estimate of the size of the race track in our impact assessment. Our study therefore has underestimated the size of an intense local injury to the toheroa population.

Several ecological considerations ameliorate the wider impact of the race: (i) the race track area represents only around 5% of the 17Km stretch of Oreti Beach that has toheroa, and only covered the upper 100 m of the beach where around 55% of the juvenile toheroa occur; (ii) the majority of the juveniles would have died of natural causes even had they survived the race; (iii) very few subadults and no adults were put at risk by the bike race and these are the crucial stages for long-term sustainability of the toheroa population; and (iv) subsequent cohorts of juveniles within the 2008/09 breeding season and drifting juveniles will have re-populated the race track area to some degree after the race.

Impacts of future beach races on toheroa could be reduced by

- Minimising the use of a grader or leveller to smooth the sand before racing.
- Establishing the racing track closer to the main vehicle entrance on the beach.
- Positioning the race track where recruitment is naturally lowest.
- Having spectators park their vehicles off the beach and keeping the remaining vehicles as high on the beach as possible.
- Creating a vehicle track above high tide mark and directing all traffic along it rather than onto the intertidal area of the beach itself.

Trials in which we ran over experimentally translocated toheroa with test vehicles showed that the risk to toheroa was elevated in a 15m wide strip of comparatively soft, dry sand just below the high tide mark. However, this zone contains only 7% of the juvenile toheroa in the population and the sand hardens after one hour of each six hour tidal cycle, so this phenomenon poses comparatively little risk to overall recruitment. More importantly, the risk to juvenile toheroa from being run over by a four-wheeled vehicle, even in very soft saturated sand, was comparatively low over the rest of the beach. Around 5% of toheroa die when run over in this zone (the statistical margin of error for this risk was 1–7%). However, motorbikes posed a much greater risk than four-wheeled vehicles (18% mortality, margin of error 10-31%). The overall size and weight of a vehicle is less important in determining risk to toheroa than is the size of the gaps between the lugs of the tyres – high, well-spaced lugs displace sand and so are more likely to fracture the toheroa shells. Five trials in which we drove over toheroa five times in half an hour did not provide statistically reliable evidence of higher mortality than single passes with the same vehicle. However Northland studies suggest an increased risk of damage from multiple exposures to traffic, thus further research is needed to test cumulative effects from many vehicles. There is no evidence that smaller juvenile toheroa are less or more at risk of damage than larger juveniles. Probably the subadults, and definitely the adults, are not vulnerable to vehicle damage because they live much deeper in the sand and occur further down the beach where they are well supported by the hydrostatic properties of the saturated substrate.

This preliminary research phase has demonstrated unequivocally that vehicles can damage toheroa. But this is not tantamount to having demonstrated significant impact on toheroa population recruitment. Even if vehicle impacts are removed, population increases may still be blocked by natural causes of poor recruitment in most years. Follow-up research is now needed to quantify the level and distribution of vehicle traffic on Oreti Beach, to match it to measures of recruitment success in different parts of the beach, to better understand the behaviour and seasonal survival of the juveniles, and to discover why recruitment to the toheroa breeding population is so sporadic. Establishment of a working party of beach users, kaitiaki (Māori environmental guardians), environmental managers, Ministry of Fisheries, and researchers to assess options for future research and management is recommended so that a collaborative approach to mitigation of public and ecological risks from vehicle traffic on Oreti Beach can begin. Education of beach users on ways to mitigate risks is likely to be slow and expensive, but it is overdue. The longer term solution to managing year-round traffic on the beach would be establishment of a network of roads, parking areas and pedestrian beach access points on the landward side of the main dune system. This would be expensive, presents several practical challenges and may not satisfy all beach users' needs. Therefore further research is needed to test whether vehicle damage is a significant threat to toheroa recruitment, and if so, to identify the most cost-effective solutions to secure toheroa restoration, protect beach ecology and sustainable recreational use of Oreti Beach for generations to come.

Contents

Introduction: the need for this research

Toheroa (*Paphies ventricosa* Gray) is an endemic bivalve found on sandy beaches that are fully exposed to surf[1]. Beentjes et al. (2006) describe the general ecology and history of toheroa as follows: "The largest beds are generally found midway between low and high water[2]. Toheroa are active burrowers, living from 10 to 20 cm beneath the sand where they extend siphons to the surface to filter feed and excrete waste during submergence[3]. The main toheroa populations are found in Northland, North Island (Ninety Mile Beach, Dargaville Beach, and Muriwai Beach), with smaller populations on the Wellington west coast, and in Southland on Oreti Beach and Bluecliffs Beach. Toheroa have been subjected to intensive exploitation both as a commercial and amateur fishery[4]. The main commercial fishery was based around Northland and continued until 1964 when it became uneconomic as the population declined. Toheroa populations also declined markedly throughout the country and by 1980 all fishing was prohibited except for Māori customary take and occasional one-day recreational seasons, the last of which was in 1980 at Bluecliffs Beach and 1993 at Oreti Beach".

The Southland populations of toheroa are of national conservation importance because of their outlying and limited distribution, long term declines of both northern and southern populations, general degradation of marine ecosystem health and the importance of toheroa as a customary food of Māori. Ongoing conservation concern for toheroa in Southland stems mainly from severe decline in the population at Bluecliffs Beach since the 1960s, primarily because the beach is eroding. Sand and vegetated sand dunes are being replaced by gravel and cobble substrates[5]. Beach erosion may relate to diversion of water from the Waiau River in 1969 for power generation, though this interpretation of its cause is disputed[6]. Declines at Bluecliffs force greater emphasis on securing the Oreti Beach and newly discovered[7] Orepuki Beach populations for customary use and ecological conservation. Numbers are lower now at Oreti Beach than in the 1970s, but the habitat appears

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[1] Good overviews of their biology and ecology are provided by Rapson (1952), Cassie (1955), Redfearn (1974) and Beentjes et al. 2006).

[2] Rapson (1952, 1954); Cassie (1955); Redfearn (1974); Morrison & Parkinson (2001); Beentjes & Gilbert (2006a,c); Beentjes et al. (2003, 2006).

[3] Redfearn (1974) ;Kondo & Stace (1995).

[4] Cassie (1955) ; Stace (1991)' McKinnon & Olsen (1994) ; Morrison & Parkinson (2001).

[5] Beentjes et al. (2006); Beentjes & Gilbert (2006a).

[6] See divergent views expressed by Gibb (1978), Kirk & Shulmeister (1994), Cranfield (1996), Futter & Moller (2009), and Moller et al. (in press).

[7] The population there has been well known to locals and apparently originated from translocation by the kaitiaki in the 1950s (Futter & Moller 2009). It was recently surveyed and found to have a dense though not extensive breeding bed, the overall population size being about a third of that remaining at Bluecliffs Beach.

relatively stable and toheroa numbers have been approximately steady or even increasing slightly in the past decade[8]. A recent proposal by the Waihopai Rūnaka to establish a mātaitai[9] on Oreti Beach in part reflects the importance placed on maintaining the health of toheroa, a taonga (treasured species) of the local kaitiaki (Māori environmental guardians).

Superbly thorough and standardised population monitoring at Oreti Beach has been conducted at 3-4 year intervals since 1998 by NIWA researchers and funded by Ministry of Fisheries[10]. These surveys provide excellent baselines from which the success of future restoration actions can be assessed. Now that robust monitoring techniques are in place and have quantified historical declines, the kaitiaki wish to identify the main threats to toheroa and consider options for intervention and restoration. In common with many shellfish populations, toheroa recruitment of the spat are sporadic and sometimes do not result in recruitment to the breeding population. The reasons for these cohorts' failed recruitment are poorly understood, but it has been suggested that poor growth and survival resulting from insufficient phytoplankton and other organic food particles[11] may contribute.

Crushing by vehicle traffic has been mooted as a potential threat to toheroa, but reliable scientific measures of its putative importance are lacking. An extremely brief study of a small toheroa bed on Ninety Mile Beach (Northland/Taitokerau) in 1998 estimated that 14% of the juveniles were crushed by vehicles[12]. However, only three 1 m^2 quadrats were sampled during that study, and the traffic at the time was unusually heavy because of a fishing competition. The researchers considered that there was sufficient evidence of damage to toheroa to warrant further investigation of mortality in relation to the volume of traffic, type of vehicles and distribution of the vehicles on the beach. No such follow up study has been reported. Interviews with the kaitiaki and knowledgeable locals in Southland recently also identified vehicle traffic, especially on Oreti Beach, as potentially posing a threat to population recruitment[13]. Oreti is the most important beach for recreation in Southland – the average number of visitors per day between 16th December 1998 and 10th February 1999 was

[8] Beentjes & Gilbert (2006b)

[9] Mātaitai are Māori community led customary fishing reserves that were created under the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992 (better known as the 'Sealord's Deal'). However, reserves could not be established until the South Island Customary Fishing Regulations were gazetted in 1998.

[10] Carbines & Breen (1999); Beentjes et al. (2003); Beentjes & Gilbert (2006b).

[11] Marine ecologists call these particles the 'seston' (Gardner 2008)

[12] Hooker & Redfearn (1998).

[13] Futter & Moller (2009); Moller et al. (in press).

961, carried to the beach in approximately 374 vehicle visits per day (Wilson 1999[14]). All vehicles drive at least part way onto the beach by the main (Dunns Rd.) entrance, but a minority travel more than a kilometer either side of the entrance. In another (2004) study, two extremely brief (2.5 hour) surveys[15] of vehicle traffic on Oreti Beach were used (very inappropriately) to assert evidence of vehicle impacts on toheroa[16]. Certainly, large numbers of people from Invercargill and Riverton and surrounding areas drive vehicles onto the beach to picnic and party, surf, kite surf, swim, paddle, fish, exercise themselves and their dogs. A minority also race their motorbikes and cars along the beach. Since the 1920s there have been regular organised beach races of motorbikes on Oreti Beach[17]. In the last three years beach motorcycle races have been marketed as the 'Burt Munro Challenge', an important part of a three-day motorcycle racing festival[18]. Participation in the festival is growing rapidly, in part due to the profile given to Burt Munro's racing success featured in the 2005 film, *The World's Fastest Indian*[19]. Apart from being fun for motorcycle enthusiasts, the festival is of growing economic importance to Southland's tourism and hospitality industry.

The importance of Oreti Beach for local recreation, tourism and the maintenance of a strong toheroa population raise the prospect of potential conflict concerning the use of the beach. It is therefore paramount that reliable scientific estimates of the impact of vehicle traffic on toheroa recruitment are made as a first step to considering mitigation options should significant risk to toheroa recruitment be demonstrated. Our preliminary investigation was funded by Environment Southland at the request of Te Ao Mārama[20] to assess whether more detailed scientific studies should follow.

[14] This was calculated by adjusting the estimated number of visitors by 94% (the estimated proportion that arrived by car – others walked, cycled or rode a horse) and dividing by the estimated average number of people in each car visit (calculated as 2.41 after weighting by weekend and week days from the data presented in Table 4.1 of Wilson 1999).
[15] Counts on Saturday 20th March 2004 and Sunday 13th June 2004 (the latter during a public mid-winter swim event)
[16] Gray (2004).
[17] David Morris, President of the Invercargill Motorcycle Club, pers. comm.
[18] See URLs: http://burtmunrochallenge.southlandnz.com/ and http://www.aa.co.nz/motoring/news/Pages/2008-Burt-Munro-Challenge.aspx
[19] http://www.imdb.com/title/tt0412080/
[20] Te Ao Mārama is an incorporated society set up by the four Murihiku Rūnanga Papatipu for the purpose of providing iwi input into the processes required by the RMA and other relevant legislation. The four Rūnanga Papatipu are Te Rūnanga o Oraka-Aparima, Waihopai Rūnaka, Te Rūnanga o Hokonui and Te Rūnanga o Awarua.

Aims of this research

The specific aims of the preliminary research were to:

1. Measure the risk posed to toheroa by the Burt Munro Challenge beach race on Oreti Beach on 28th November 2008.
2. Measure the risk posed by different grades of vehicle on individual toheroa during normal public use of Oreti Beach.
3. Recommend potential ways that any risks found could be mitigated and priorities for follow-up research in the 2009/10 year.

A fourth aim was to provide a rapid response protocol for stakeholders (Te Ao Mārama, Environment Southland, Invercargill City Council, Department of Conservation, the Waihopai Rūnaka) to sample any future toheroa die-back events. Die-back events (i.e. mass mortalities) have been noted occasionally on Oreti and Bluecliffs Beaches over the past decades[21]. These events kill a large number of adults, some of which might otherwise live and breed for 20 years[22]. They can therefore be classed as "ecological catastrophes" (rare, high impact events)[23] that are particularly important threats to small or fragmented populations like toheroa. A scientifically robust sampling procedure must be worked out in advance so that when a die-back occurs a team can immediately count, measure and collect specimens in a way that allows the risk to toheroa populations to be quantified and potential causes identified. The proposed protocol has been transmitted to the stakeholders in a separate report[24].

Study Area

Oreti Beach is 29 Km long, running southeast to northwest. It has a main vehicle entrance situated 10Km from central Invercargill city (Fig. 1). Most research was based 1-3 Km southeast of the main vehicle entrance (Dunns Rd.), but collection of juvenile toheroa for translocation and penetrometer measurements extended from ca 3.4 Km northwest of the main vehicle entrance to the Oreti River mouth, 6.4 Km southeast of the main vehicle entrance. The Burt Munro Challenge beach race track began 1.15 Km southeast of the main entrance and extended a further 850 m southeast. The beach

[21] See Eggleston & Hickman (1972), Beentjes et al. (2006b), Futter & Moller (2009) and Moller et al. (in press) for written reports. Recent sporadic dieback events have also been noted by Dallas Bradley & Lloyd Esler (pers. comm.)
[22] Beentjes & Gilbert (2006b).
[23] Hamilton & Moller (1995).
[24] Moller & Futter (2009).

is a gently sloping fine-sand beach with no gravels, cobbles or rocks visible. The width of the beach (from high to low in spring tides) averages 210 m and the tidal fall is 1.2 – 1.3 m below mean sea level[25].

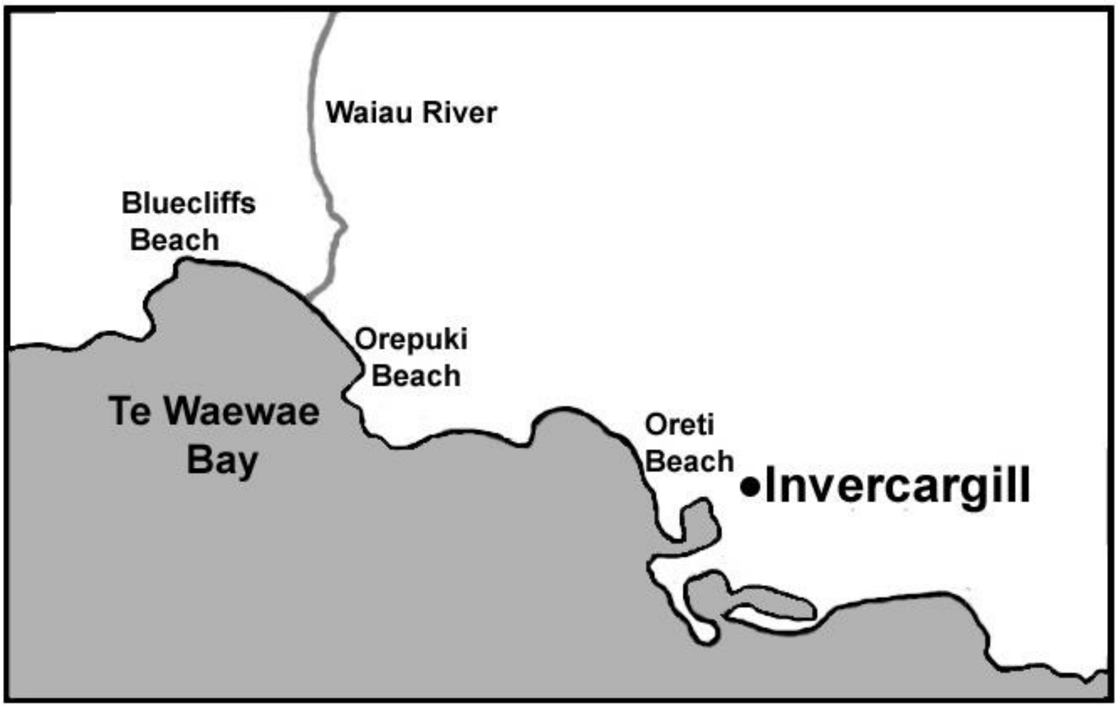

Figure 1. Locations of beaches which support toheroa populations in Murihiku (Southland), South Island, New Zealand. The main populations of toheroa occur at Oreti Beach, Orepuki Beach ('Monkey Island') and Bluecliffs Beach.

Methods

Burt Munro Challenge Beach race

The race track and study design

The races were a simple straight dash from a starting line along one side of a row of road-marker cones, around an end-drum and back to a drum at the other end (for a single lap) (Fig. 2 & 3). Several of the events had multiple laps, so clear 'turning circles' were designated at each end-drum where the bikes rounded for the next lap. Churning of the surface by the bikes meant that the race track was to be shifted downshore twice during the event, so three parallel strips with median strips

[25] Beentjes & Gilbert (2006b)

spaced 20 m apart were marked out before the race (Fig. 4a). Spectators were seated on the top of the sand dunes and the first races were held in the strip closest to the dunes, allowing maximum time for the sand to harden as the tide receded before it was raced on (Fig. 5). The midline of the first racing strip was placed approximately 5 m below the high tide mark. High tide was at 1.47 pm at Oreti Beach on the 28th November 2008, and low tide was 8 pm that night, giving just enough time for the organisers to establish the course on the falling tide and have the race completed and all spectators and vehicles clear of the area by nightfall. It was impossible for the researchers to sample until first light the next morning when one tidal cycle had wiped most surface evidence of the race away.

We used a 'Before' vs. 'After' study design in which the proposed course was marked out by David Morris[26] and Steve Winteringham[27] on Wednesday 26th November 2008 evening; the 'Before' survey was completed from dawn until dark on Thursday 27th and from dawn up to midday on Friday 28th; the race was held from ca. 5 – 8.30 pm that evening; and 'After' survey was conducted from dawn until 8 pm on Saturday 29th. Unfortunately the race organisers altered the course layout considerably and at the last minute from that prescribed beforehand, so there was no longer a close match in the 'Before' vs. 'After' areas i.e. (i) the race was shifted to start approximately 120 m further southeast of the main vehicle entrance to the beach; (ii) the track extended 800 m instead of the 500 m advised; and (iii) rather than re-setting the course twice in parallel, it was reset once and the southeastern end turning circle was broadened but retained in the same place[28] (Fig. 4).

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[26] David Morris is president of the Southland Motorcycle Club, one of the organisers behind the Burt Munro Challenge event. The event organising committee includes members of the Southland Motorcycle Club executive committee and Venture Southland.

[27] Supervisor of the beach race.

[28] This was because an electronic timing and lap counting equipment was buried just short of the end-drum on the dune side (Fig. 2). Each rider carried a transponder with their ID encoded so their lap count and time was recorded every time they passed over the sensor.

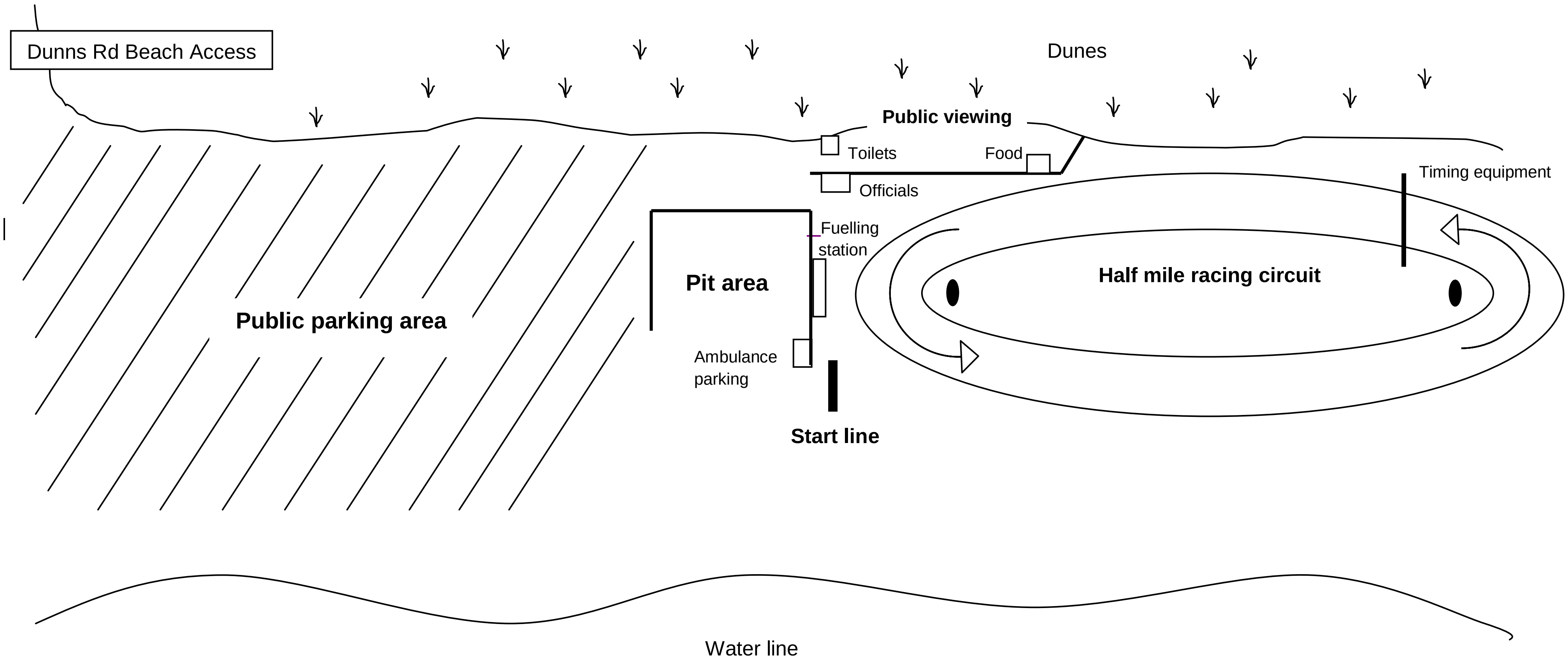

Figure 2. Lay out of the Burt Munro Challenge Beach Race event. The public viewing and pit areas were sectioned off with wire fences. The timing equipment was dug under the surface of the track.

a)

b)

c)

Figure 3. Burt Munro Challenge beach race, 28th November 2008, Oreti Beach Southland: (a) starting line-up; (b) return leg; and (c) turning circle at end-drum nearest start.

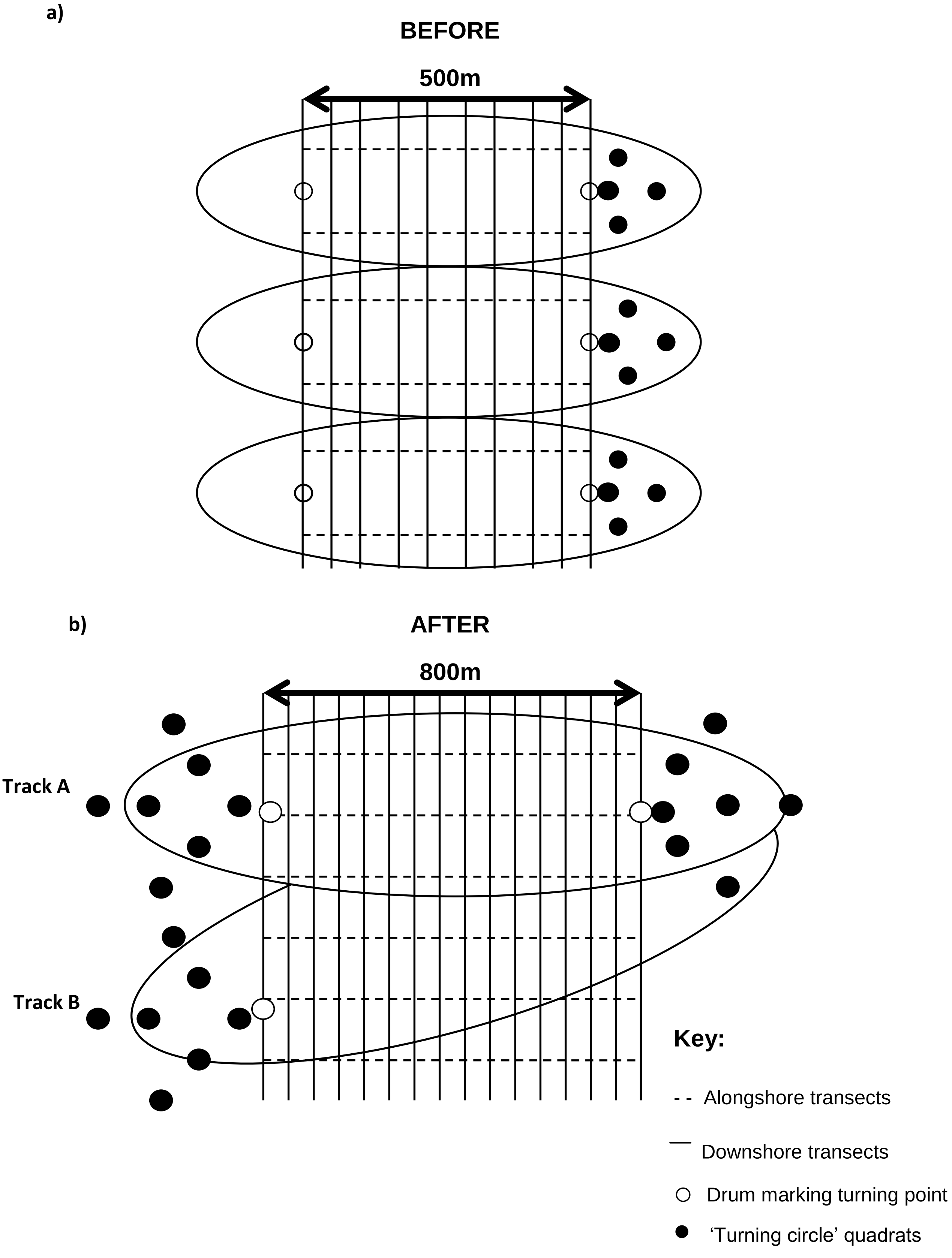

Figure 4. Design of the (a) 'Before' and (b) 'After' beach race surveys to measure abundance of toheroa, Oreti Beach, 26th – 29th November 2008. (b) illustrates Track A and Track B after the course was reset.

Figure 5. Vehicles, spectators, competitors in the Burt Munro Challenge beach race, 28th November 2008, Oreti Beach Southland.

Quadrat sampling

Our sampling methods broadly replicated those of regular NIWA sampling on Oreti Beach and Bluecliffs Beach[29], so that results would be comparable. We stratified the course into 50 m lengths between the end-drums, and randomly placed six quadrats 10 m apart along transects running down the beach perpendicular to the midline of the race tracks (Fig. 4). The first of these quadrats was placed 5 m inland from the midline of the course closest to the dunes, so the second fell 5 m on the seaward side of the same midline, and the third was 5 m inland of the middle of the second parallel course, and so on down the beach. The transects of six quadrats fell squarely in the most intensely covered part of the racetrack, but bikes became concentrated close to the end-drums in order to turn, and then some arced well down the beach (towards the water line) as they accelerated out of their turn to return down the beach. Some bikes therefore drove over sand another 30-50 m or so below the positions of our lowest ('60 m') quadrat, but all of our 'Before' and 'After' quadrats were run over several times by racing bikes. We expected that damage to toheroa would be higher in the 'turning circles' at each end of the racetrack because the bikes slide sideways (Fig. 3c), spray sand and accelerate strongly once rounded, leading to added churning of the sand in these zones. Therefore we also measure toheroa in 12 other quadrats in the three turning circles envisioned on the southeastern end of the 'Before' course (Fig. 4a). When the course layout was changed, we added 21 'turning circle' quadrats arranged equally around three end-drums for the 'After' survey (Fig. 4b).

Each sampling quadrat was demarked by 200 mm high vertical metal sides used to guide a spade to dig out the standard area of 0.5 m^2 (1.0 x 0.5 m) (Fig. 6a). All sand within a quadrat was excavated to a depth of 300 mm and the sand was transported and sieved in the surf within trolleys with sides and bottom made of 4 mm metal mesh. We closely inspected all the toheroa we excavated for cracks or visible damage and measured their maximum length to the nearest 1 mm[30]. Several intact halves of toheroa were also measured (these were entire valves and obviously remnants of toheroa that had died a considerable time beforehand, judging from their smooth surface and bleached colour). All toheroa shell fragments (>4 mm) were also counted but not measured. Intact toheroa were placed on saturated sand close to where they were excavated and watched for up to 20 minutes. Toheroa that dug themselves back into the sand were classed as 'Viable', whereas those that did not dig were classed as 'Dead' and, together with damaged ones, were retained and removed from the beach as required by our Customary Authorisation (Number SI 01528) to conduct

[29] Beentjes & Gilbert (2006a,b)

[30] Vernier callipers were used to measure length along the largest/longest shell dimension on anterior/posterior axis.

a)

b) c)

Figure 6. Sampling equipment used for assessing impacts of a bike race and vehicles on toheroa on Oreti Beach. (a) The metal sided quadrat used for marking out quadrats to assess changes in density of toheroa after the Burt Munro Challenge beach race is seen in the foreground. Excavated sand was transferred to the mesh cart which was then run into knee-high water and agitated to wash all the sand away so the shellfish could be identified and measured. (b) & (c) The force required to push a soil penetrometer to a depth of 8 cm into the sand was used as an index of sand compaction.

the study. In the 'After' survey some intact half shells were found with raw flesh still attached, these were tallied as a 'Dead' toheroa.

New sand was collected from the dunes to fill in the quadrat holes after excavation. A small motorised compactor was used to consolidate the new material to remove any risk to the riders[31].

Surface scans and bird counts

We were concerned that the tides covering the racetrack after the event would wash away damaged shells, or that bird predation the next day would remove damaged toheroa[32]. Accordingly, a scan and collection of exposed toheroa over the entire race course was conducted at first light on 29th November by six researchers walking in a cordon over the area covered by our quadrats. A similar surface scan and collection was done on 26th November once the proposed course was demarked.

A scan count of the number and species of birds and their activity on the entire sampling area was done on three occasions both before and after the race.

Vehicle counts and passes by racing bikes

Vehicles bringing competitors, their bikes and spectators were guided onto the beach at the main entrance and south towards the racetrack by race officials. They were parked side by side in 3-4 rows along the beach stretching 1 Km back to the entrance (Fig. 2 & 5). A count of these vehicles was completed in the first hour of the race itself once most of the visitors had arrived.

In order to measure the intensity of the vehicle traffic, we also counted the number of bikes and laps completed on the racetrack during the event, including the practice circuits held before the racing properly began.

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[31] Most of the quadrats were covered by at least two tides between excavation 'Before' the race and the race itself, so they naturally consolidated anyway. The race organisers dug a trench to embed the electronic tracking system near the southeastern end of the course in the two hours before the event began (Fig. 2). The sand was not consolidated there after the trench was filled in. Heavy metal bars were dragged behind a tractor driven down the inland margin of the racecourse and then back and forward over the trench to level the sand. Otherwise the substrate was compacted naturally by the tides and the results should be considered representative of risk to toheroa in undisturbed conditions.

[32] Brunton (1978) recorded intense predation of damaged and exposed intact toheroa by gulls on Northland beaches after vehicles had driven over them, and Street (1971) noted predation by pied oystercatchers (*Haematopus ostralegus*) at Bluecliffs Beach.

Statistical analysis

The last minute shift in the racetrack layout has weakened the analysis and interpretation and wasted considerable effort for the researchers. We have therefore analysed the 'Before' vs. 'After' comparisons in two complementary ways: we compared the density of :(a) alive and intact toheroa; (b) dead or damaged toheroa; and (c) toheroa shell fragments found 'Before' vs. 'After' the race on (i) the subsection of the two areas that overlapped[33]; and (ii) the entire 'Before' (ca. 550 m long) and entire 'After' (ca. 850 m long) sampling areas. Restriction of the area to the strict overlap zone reduces sample size for density estimation by around a half, so statistical uncertainty is wider using the first approach. Using the entire data set for 'Before' vs. 'After' comparisons (the second approach) retains maximum statistical power for estimating the impact of the race on the toheroa, but the comparison will only be an accurate indication of impact if the density of toheroa on the entire 'Before' area was the same as that in the entire 'After' area before the race occurred.

Sparse and patchy distribution, as is typical of toheroa beds, meant that most 0.5 m^2 quadrats had no toheroa in them while some had up to seven. The skewed distribution of counts is not readily amenable to parametric statistical analysis even after severe transformation of the data[34]. Therefore we compared the density 'Before' vs.' After' the race using 'bootstrapping' techniques[35] by computing 10,000 random draws from the observed distributions 'with replacement'[36].

Beach traffic impact study

Test vehicles and vehicle weight loadings

Most of our experimental tests were done with a 2002 Toyota Fielder station wagon (Vehicle A in Table 1 & Fig. 7). The heaviest vehicle was a 2009 Mazda light truck (Vehicle B), followed by an Isuzu Bighorn utility (Vehicle C). The area of tyres in contact with the ground was estimated and pressure calculated assuming that the weight of the vehicle and driver was distributed equally over four tyres (cars, utilities and quad bikes) and two tyres (motorbikes). The Honda 250 cc racing bike (Vehicle D)

[33] This excluded the first 100 m of the 'Before' area and the last 450 m (including southern most turning circles) of the 'After' area.
[34] Fletcher et al. (2005).
[35] See Manly (2007) and Chernick (2008).
[36] The 2.5th and 97.5th percentile bootstrap confidence limits around the means, differences between means and ratios (after/before) have been reported. They approximate the 95% confidence limits found by parametric methods.

exerted by far the lower pressure on the sand, but it had a very different tyre moulding in which the lugs were raised and widely spaced, a design to give maximum traction in soft substrates.

We compared the specifications and tyre dimensions of our four test vehicles with those of another 23 cars, 20 utilities or light trucks and nine motorbikes. We also recorded specifications of five quad bikes even though we did not use this category of vehicle in our experimental trials. These measurements were made by visiting car and bike dealerships in Invercargill and Dunedin to sample a wide range of makes and sizes of vehicles within each category, and by consulting manuals and online details posted by the vehicle manufacturers.

Table 1. Vehicle and tyre specifications of test vehicles used to measure risk to toheroa on Oreti Beach, April 2009.

ID	A	B	C	D
Category	Car	Utility	Utility	Motorbike
Make/Model/Year	Toyota Fielder 2002	Mazda BT50 Freestyle Cab 2009	Isuzu Bighorn (1st Generation) 1990	Honda CRF 250R 2008
Weight[µ] (Kg)	1130	1876	1678	111
Pressure[β] (Kg/cm^2)	1.30	1.34	1.31	0.28
Tyre Make/Model	Goodyear Radial 185/70R14	Sumitomo Serengeti SL80	A/T GT Radial	Pirelli Scorpion (medium soft)[¥]
Tread depth (mm)	8	15	8	11
Width between lugs[†] (mm)	4-5	12-22	5-12	12-20

[µ] Weights quoted are 'Kerb weights', calculated as unladened vehicle with oil and water coolants added and the fuel tank full. See http://www.mitsubishi-motors.co.nz/resources/acronyms/#KERBWEIGHT
[β] Weight was calculated as Kerb weight + 75Kg per driver + estimate of weight of gear being carried. The area in contact with the sand was calculated by pressing four (1 mm thick) rulers towards the tyre (until they were obstructed by the rubber) from either side, front and back of the tyres when the vehicle was parked on a hard surface. Front and rear tyres on motorbikes are slightly different, so we averaged the area of each and assumed the weight of the vehicle and rider were distributed equally over each.
[¥] This tyre is designed specifically to give the bike maximum traction in sand and mud.
[†] 'Lugs' are the raised segments of the tyre that are separated by treads.

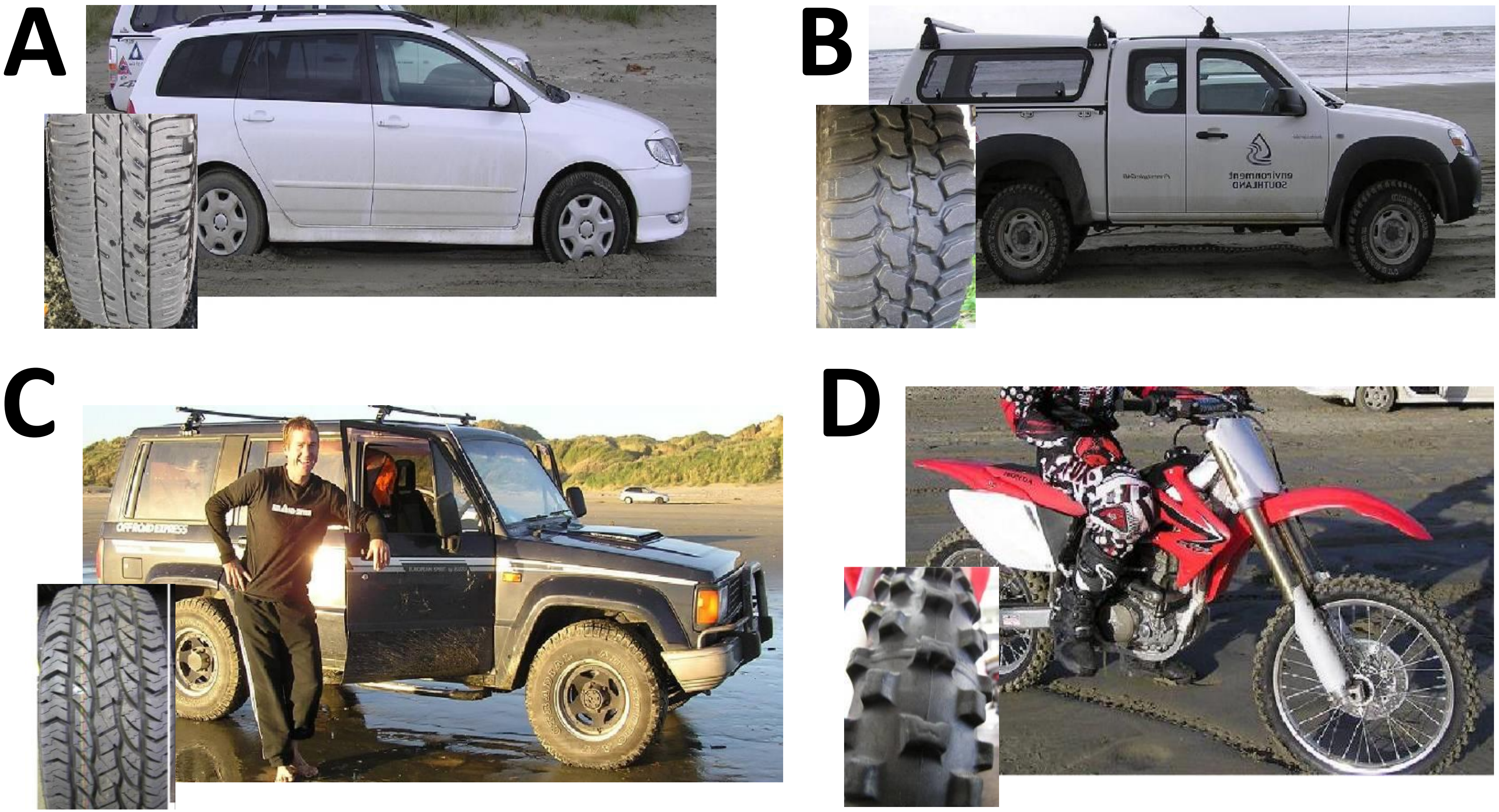

Figure 7. Test vehicles used to run over experimentally translocated juvenile toheroa and their tyre patterns. Specifications are given in Table 1.

Experimental placements of juvenile toheroa

We at first tried to locate and mark spots on the beach where a toheroa was found feeding during the ebbing tide so that we could then run over the spot, dig up the focal animal and inspect it for damage to the shell. Despite having six searchers, it proved impossible on the first day (9th April 2009) to locate any juvenile sized toheroa by this method[37]. Accordingly, for the following three days we changed to gathering "drifting" juvenile toheroa in the last 2-3 hours of the incoming tide and then placing them in 32 transects (lines) of 2-10 animals[38] as the next tide receded. Toheroa were spaced 20 cm apart within transects, and transects were 8-20 m apart and placed at different levels of the beach as the tide was ebbing. The juveniles gathered from the 'drift'[39] were either floating in the shallow wash of the waves (sometimes with siphons or foot protruding[40]) or cast onto wet sand once the wave had retreated. Many of them quickly tried to dig into the sand before we could intercept them.

The collected animals were first arranged in transects on their side on the top of the sand and then gently washed with water to simulate a wave and stimulate them to dig. We discovered that stirring the pottle holding the trial animals just before placing them on the sand accelerated their digging into the beach, but still some took 20 minutes to dig into the sand. Others were rejected when they did not dig after 20–30 minutes, or showed effort to dig by protruding their foot but did not have the strength to gain traction in the sand, tilt their body into the vertical position and dig into the substrate. It is clear that several of the juvenile toheroa that we gathered from the top of the tide were moribund and presumably would soon die. The translocated animals dug into the sand much more rapidly when placed on saturated sand near the tidal fringe than in drying sand that had been

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[37] We did find and run over ten adults (≥100 mm), none of which were damaged by the vehicle. Thereafter we entirely targeted the juvenile size classes (<40mm) because these are considered to be by far the most vulnerable to vehicle traffic.

[38] Most transects had ten toheroa once the technique was perfected, but initially we trialled groups of five and accidents disrupted some of the placements ie. We misjudged the waves and the experimentally place toheroa were sometimes swept away before they had fully submerged themselves into the sand.

[39] 'Drift' is a term used by stream ecologists to denote the invertebrates that are washed of the substrate or deliberately release themselves into the water column in order to disperse. Our study took advantage of a similar phenomenon in the top 10 m of the incoming tide which clearly redistributes the juvenile toheroa along and up and down the beach. Drift is apparently not a term recognised thus far in marine systems.

[40] Previous observers have referred to the juveniles being washed out of the sand by wave action (Brunton 1978), but there is also increasing evidence that immature stages of marine invertebrates actively influence dispersal in several ways (Keough & Swearer 2007). It may be that the toheroa that we found protruding appendages were maximising dispersal, rather like spiders "balloon" on the wind by extruding threads. Alternatively these may be spent animals in last stages before death.

exposed up to an hour earlier[41], so our main challenge was to place the trial animals in rows at the very edge of the receding tide while the sand was saturated and only very small waves flushed the transect without washing the trial animals out of place.

The position of each toheroa that dug itself into the beach was marked with a numbered wire stake offset by 20 cm down the beach, and a shallow ring was marked in the sand over the spot where each had dug in (Fig. 8b). This gave space and guidance to the driver of the test vehicle to run over each transect and we were able to check from the tyre marks that the vehicle passed directly over the spots where the animals had buried themselves[42]. Vehicles were driven at approximately 30 Km per hour, the speed limit on Oreti Beach. Northland studies[43] highlighted that repeated traffic over the same spot may pose additional risk to the toheroa because vibration and/or the semi-liquidification of the sand profile appears to stimulate the toheroa to move closer to the surface. It is also possible that pooling of water following the pass of the vehicle causes toheroa to become oriented side-on rather than their natural vertical position. Any following vehicle is therefore more likely to run over it (the side on profile is bigger), the animal is closer to the surface, and the animal is not firmly supported by surrounding sand. Accordingly we did trials on five additional transects (50 juvenile toheroa) using the heaviest vehicle (B) and driving over the toheroa five times in the space of 30 minutes.

Within 30 minutes of each driving trial, each transect was carefully dug up and the sand sieved in a bucket of seawater to retrieve each test animal. Each was carefully inspected for cracks to the shell and retained in a pottle with seawater to test their motility over the subsequent days.

[41] We stimulated digging in the latter areas by flooding the transect area with water from buckets.
[42] Occasionally the vehicle did not pass exactly over the line of animals and had to be driven over the group again.
[43] Redfern (1974); Brunton (1978).

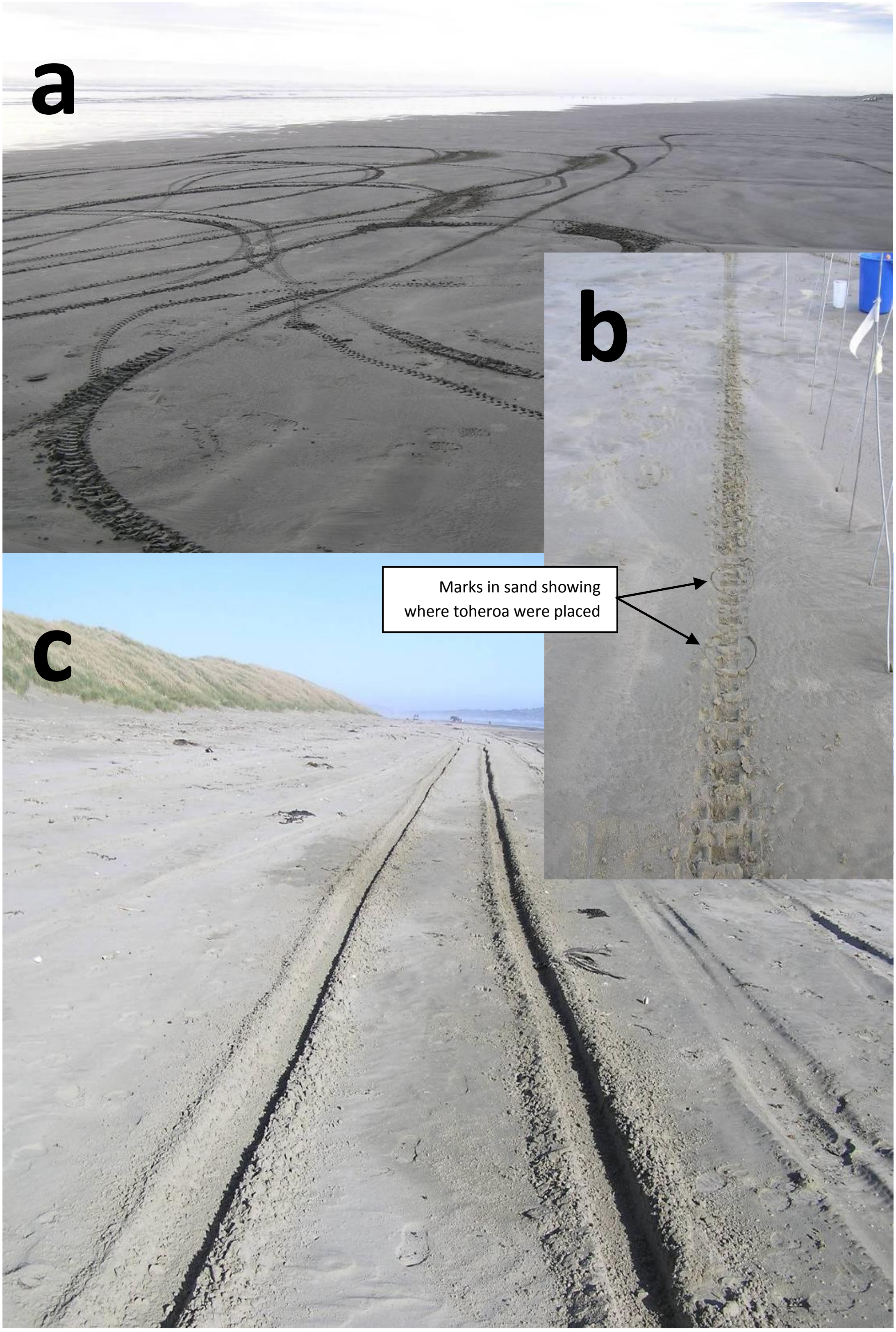

Figure 8. Damage to Oreti Beach and experimental set-up for measuring risk to translocated juvenile toheroa, April 2009. (a) Distributed sand and tyre marks made by the motorcycle (Vehicle D, Fig. 2d); (b) marks made as the motorcycle ran over the spots where toheroa juveniles had buried themselves (note location marks on surface) and pegs offset to guide the vehicle over the experimental animals); (c) deep wheel ruts made by Test Vehicle A in part of the 'High' beach zone (the 10 m below high tide mark). The sand was particularly soft in this area.

Allocation of strata down the beach

As the experimental trials progressed we noticed that much deeper wheel ruts were being formed by vehicles driving in the top 10 m of the beach soon after high tide in some patches along the beach[44] (Fig. 8c). Accordingly we (*a posteri*) allocated the previous trials into transects run over in this 'High' beach zone compared to 'Mid/Lower' beach zone and in the last day of field work targeted more transects in the 'High' zone to build more balance into the stratification. Overall we ran over 8 and 32 transects in the High and 'Mid/Low' beach zones respectively, collectively testing damage to 303 experimentally placed juvenile toheroa (Table 2).

Table 2. Number of transects run over by test vehicles in the 'High' and 'Mid/Low' zones of Oreti Beach, and the number of damaged and undamaged juvenile toheroa recovered in April 2009.[β]

	'High' beach			'Mid/low' Beach		
Vehicle	Transects	Damaged [β]	Undamaged	Transects	Damaged [β]	Undamaged
A-Fielder	5	4	30	10[μ]	3	41
B – Utility	2	2	17	5	1	37
B - Utility - 5[†]	1	3	6	5	2	37
C-Isuzu				6	0	61
D-Motorbike				6	11	48
Total	8	9	53	32	17	224

[β] The data in the table exclude five toheroa that were damaged by our trowel while we excavated the transect after the vehicle pass.
[μ] An additional 13 single toheroa (i.e. not arranged in transects) were run over by Vehicle A in initial trials on 9th April 2009.
[†] In these trials the utility (Vehicle B) was driven over each transect five times within 30 minutes.

[44] Other stretches of the beach had relatively firm sand even in this strip along the high tide.

Viability tests and control group measurements

We designed a viability test to check whether toheroa with cracked shells were likely to die or could recover, and to check whether some apparently intact toheroa were nevertheless internally injured by having been run over by the vehicle. Initially we tested the viability of toheroa that had been run over by scoring the proportion of test animals with foot or siphons extended once the toheroa were held in plastic pottles in seawater overnight. However, we soon discovered that this motility test was too easy to truly measure the impact of having been run over on toheroa viability. Even some badly crushed juveniles were still capable of extending their siphons and foot, and rapidly withdrawing them when prodded with forceps after 2-3 days in seawater. Therefore, after holding the animals in pottles for three days, we placed the experimental and a control group of juvenile toheroa on a laboratory tray filled with 5 cm depth of sand covered with 5 mm of seawater at room temperature. We then scored the proportion of them that successfully dug into the sand after 20 minutes. Those that extended their foot and/or siphons, but lacked strength to dig into the sand and others that were completely inactive were classed as 'Non-viable'. Those that dug themselves completely into the sand were classed as 'Viable'.

A 'control' group was established by: (a) placing 170 toheroa gathered from the drift on 13th April 2009 on a 1 m^2 plot of recently immersed beach; and (b) digging up the 133 that successfully dug themselves into the sand within 20 minutes. These toheroa therefore passed the same test and were subsequently treated and stored for three days in the same conditions as those used in experimental placements. We then measured the proportions viable amongst: (i) those that did not dig into the beach within 20 minutes when first collected (these were excluded from the 'control' group, but retained in pottles to check the consistency of our viability test); (ii) the control group (ones that dug within 20 minutes but never run over by a vehicle); (iii) those run over but apparently intact juveniles; and (iv) those run over and visibly damaged toheroa.

If lack of digging within 20 minutes indicates poor condition and imminent death of the toheroa, we expect a low proportion of group (i) to dig in the laboratory set up three days later. If visible damage to the shell triggers mortality, we expect a lower proportion viable amongst group (iii) than (ii). Additionally, if internal damage raises mortality even when the shell is not visibly damaged, we would expect a lower proportion of group (iv) to remain viable after three days than group (ii).

Penetrometer measurements

A soil penetrometer was used to measure compaction of the sand because this potentially affected the risk of damage to the toheroa (Fig. 6b&c). We also noted that the sand near the high tide mark rapidly hardened after wetting and the tide receded. Accordingly we measured the force required to drive the penetrometer 8 cm into the sand:

(a) at 20 points around each of our test transects five minutes before they were run over by the vehicle;

(b) ten times in each of six periods spaced at 20-35 minute intervals ranged along a 20 m stretch of the beach at the 'High' beach zone (0-5 m band from high tide mark) on 11thApril 2009; and

(c) along 25 transects (spaced ca 300 m apart throughout the whole study area) running the full length down the beach on the morning of 14thApril 2009. Measurements within each transect were made: (i) at the base of the sand dunes; (ii) in any vehicle track present between the dunes and high tide mark; and then (iii) at ten pace intervals down the beach from the high tide mark to low tide mark. Once between the high and low tide mark we also scored whether the spot where the penetrometer reading was made appeared 'dry' (i.e. had a gray/mat surface) or 'wet' (i.e. had a dark wet sheen showing saturation of the sand at the surface or was covered in shallow standing water).

Statistical analysis

Binomial 95% confidence intervals were fitted to the proportion of test animals found damaged or alive were calculated from Mainland et al. (1956). The overall proportions of damaged toheroa were low in many groups, so testing for differences in risk from different vehicles and strata generated several low expected frequencies. Therefore we used Fishers Exact Tests calculated within GenStat™ (Edition 9) to test null hypotheses of equal risk. Distributions of the length frequency of toheroa were markedly skewed, so we used non-parametric tests to compare median sizes of experimental/control and damaged/undamaged groups.

Results

Burt Munro Beach race

Bird activity before & after the race

There were only trace numbers of birds on the racetrack area both before[45] and the day after[46] the race. Most/all of those present were roosting rather than feeding[47]. Accordingly we can be sure that bird predation has not altered the results of our impact assessment.

Vehicle and racing bike levels

We estimated that there were 1734 trips along the beach other than the race traffic on the race course itself (Table 3). The median distance driven along the beach for these vehicles was approximately 500 m, so the return trip would have involved around 1 Km of driving, and the total additional traffic outside the racecourse was therefore of the order of 1700 Km. Two large passenger buses came and went continually delivering spectators[48]. Ticket sales suggest that around 6,000 spectators, along with 150 competitors and approximately 20 organisers[49].

Counting practise sessions and occasional restarts of the races, there was a total of 88 laps by racing quad bikes and 3040 laps by two-wheeled bikes (Table 4). Each lap is 2x800 m + ca. 50 m pathway in the two turning circles and start-line lead-in combined, the total racing traffic travelled a minimum of 5161 Km (Table 4). Overall 67% of the traffic was on Track B, after the course was re-set. Once the distance is multiplied by the average tyre width (determined from our general traffic impact study), the racing bikes' tyres covered 108 hectares of sand. If the passage was equally distributed over the course, which we have conservatively estimated as 6.37 hectares[50], this is equivalent to each spot on the course being run over around 11 times. Some areas, especially close to the

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[45] There were two black-backed gulls (*Larus dominicanus*) and two red-billed gulls (*Larus novaehollandiae*) in total from three scan counts before the race.

[46] There were four black-backed gulls, seven red-billed gulls and two pied oystercatchers counted in three scans on the day after the race.

[47] There was abundant feeding sign of black-backed and red-billed gulls feeding on 'sou'westers' (*Mactra discors*, *Macra muchisoni* or *Spisula aequilatera*) 500 m north of the racetrack, but none on the sampled area.

[48] Probably about ten round trips but surveillance of the parking area was not continuous so this count is approximate.

[49] David Morris, pers. comm.

[50] Calculated as 850 x 75 m.

Table 3. Number of vehicles parked on Oreti Beach for the

Burt Munro Challenge beach race, 28th November 2008.

Type	Number
Cars	755
SUVs	392
Vans & People carriers	104
Campervan	7
Small truck	10
Non racing bike	19
Racing bikes	400µ
Buses (2 running continuously)	10†
Trailers	37
Total	**1734**

µ Many racing bikes arrived on the back of trailers, so this is an approximate estimate of the maximum number driven in part along the beach

† This is an estimate of the number of round trips made by the buses

end-drums and along the centre line of traffic cones, would have been run over more often than that, while areas half way along the track and well away from the midline will have been run over many fewer times. Some traffic by race organisers prior and during the race is not included in the data presented in Table 4.

The lines taken by individual riders clearly varied, but most preferred to swing out onto harder sand lower on the beach – some even entered the shallow pools of standing water 75-100 m down the beach. Occasionally a bike travelled above the high tide mark while returning to the start line in Track A, but most stayed within the corridor between the cones and high tide mark. The sand in the turning circles became very loose and bikes sometimes sank into the sand and tipped[51]. The average speed reached by the two-wheeled motorbikes was around 180Km/h, with some reaching speeds of 200Km/h, whereas the average quad bike speed was around 150Km/h with a maximum speed of 180Km/h[52]. The quads also appeared to cause more dramatic 'rooster tails' of sand flung into the air behind the bike.

[51] Only one broken leg resulted!

[52] David Morris, pers. comm.

Table 4. Traffic by racing vehicles on the Burt Munro Challenge beach race course, 28th November 2008.

Area	Vehicle type	Participants[µ]	Laps per race	Total passes[¥]	Distance[€] (Km)	Area covered[ø] (ha)
Track A[†]	Quad Bikes	11	3-5	88	145	10
	Two-wheeled bikes	213	2-8	883	1457	29
Track B[β]	Quad Bikes	0	NA	0	0	0
	Two-wheeled bikes	236	3-37	2157	3559	70
Combined	Quad Bikes	11	3-5	88	145	10
	Two-wheeled bikes	449	2-37	3040	5016	98
	All vehicles	460	2-37	3128	5161	108

[¥] Total passes is the total laps made by all participants combined.
[€] This is the cumulative run of a vehicle (number of passes x 1650 m per pass)
[ø] This is the total are run over by a tyre, calculated as the distance covered multiplied by the number of wheels per vehicle x average width of each tyre (98 mm for motorbikes, 175mm for quad bikes).
[†] This is the first strip parallel to and closest to the dunes and high tide mark – see Fig. 4b.
[µ] A participant is defined as a bike raced in a given event of the programme. Some individuals entered in multiple events and so would have been counted several times.
[β] This is the track after it was reset part way through the event – see Fig. 4b.

Surface scan counts for damaged toheroa

The scan of the surface of the sampling area revealed no exposed or damaged toheroa before the race. In contrast we found 48 damaged or dead toheroa lying on the surface on the morning after the race (Fig. 9), some of which were sufficiently intact for the animal's length to be measured (Fig. 10). An additional 22 badly damaged or fragments of toheroa shell were found exposed on the surface. Some of the smaller pieces of shell still had pieces of flesh adhering. While carting sand into the surf to sieve the samples from quadrats on 29th November we also encountered several apparently intact specimens floating in the surf adjacent to the racing area. These did not have their foot or siphons extended and did not dig when placed on wet sand, so we assume they had been killed and washed out of the racing area during the overnight tide and perished in the meantime.

Figure 9. Examples of damaged toheroa found lying on the beach surface or extracted from the sand on the Burt Munro beach race course, 29th November 2008.

Sizes of toheroa

There is no evidence for a statistically significant difference in the median length of toheroa that were found dead or damaged on top or within the sand after the race compared to the length of those that were alive and able to dig back into the sand after extraction from the quadrats[53]. Overall six (5.4%) of the measurable toheroa were ≥40mm (Fig. 10), the size threshold used to distinguish juveniles from subadults[54]. This suggests that very few subadults and no breeding adults were damaged by the bike race, although we cannot formally discount the possibility that some were damaged further down the beach than where our quadrats were placed and therefore not detected.

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[53] A Mann-Whitney U-test comparing median length of alive cf. dead or damaged toheroa gave a *p*-value of 0.53.

[54] Beentjes & Gilbert (2006a).

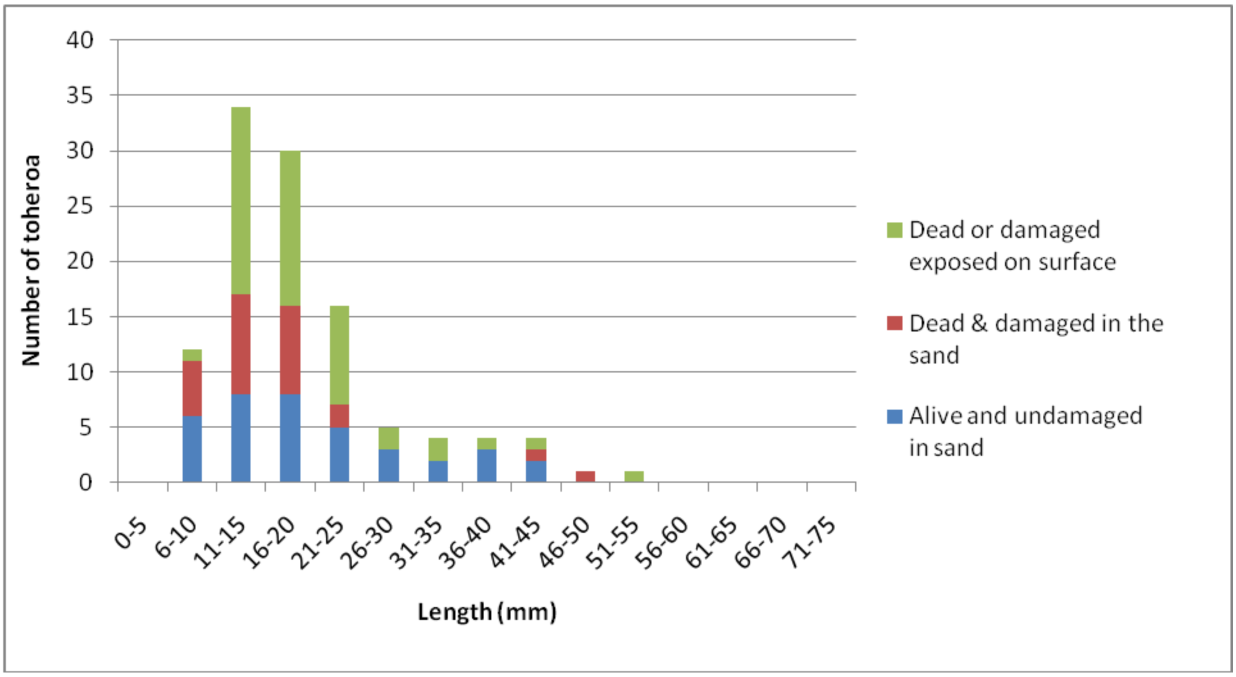

Figure 10. Size frequency distribution of toheroa found alive, dead or damaged on the surface of the racetrack or within the sand after the Burt Munro Challenge beach race, 28th November 2008.

Toheroa abundance in quadrats 'Before' vs. 'After' the race

We found two dead and three damaged toheroa (0.13 m^{-2}) in the quadrats in the 'Before' survey (Table 5). It is likely that the latter three were damaged by a spade during excavation of considerable quantities of sand, but it is also possible that some had been damaged earlier by normal vehicle traffic on the area[55]. There were also 47 intact and apparently old halves of toheroa that had died long before our survey (these are not considered further in our report). Similarly there were about 1.1 m^{-2} fragments of shells embedded in the sand that were recognisably from toheroa (Table 5), and many other finer shards for which we could not confirm the species. There were 1.17 and 1.50 m^{-2} intact and active toheroa in the restricted (ca 400 m) overlap zone between the 'Before' and 'After' survey areas, but the bootstrap confidence intervals show considerable uncertainty in these average estimates (Table 5).

The mean ratios of the number of toheroa surviving the race compared to present before the race suggested that around 56% and 71% of the toheroa were killed, depending on whether the

[55] We assumed all three were damaged by the spade in calculations of impacts based on reduction in abundance of live animals after the race; and the reverse (all three were damaged 'naturally' before the race) when calculating increases in the number of dead or damaged toheroa after the race. This gives the extremes of the possible interpretations.

comparison is made only on the 400 m subsection that overlapped or the wider areas surveyed (Table 6). The density of dead or damaged toheroa increased by 5.3 - 6.0 times after the race, and the overall density of toheroa shell fragments by 2.6 – 2.9 times.

The total number of toheroa killed on the racetrack was estimated from the decrease in density of alive and undamaged toheroa multiplied by the initial ('Before') density and the overall dimensions of the racetrack. This method estimates that around 50,000 juvenile toheroa were killed on the race track, but the percentile-bootstrap confidence interval is from 20,000 to 70,000 (Table 7). The number killed can be cross-checked by the abundance of dead or damaged toheroa found on the full 'After' race area. The raw estimate is 46,859 dead or damaged toheroa[56], but this will be somewhat inflated by damage inflicted by the spade while excavating the quadrats after the race. We estimate that 3/27 (11.1%) of the whole toheroa found before the race had been damaged by the spade. If this same artificial damage rate applied after the survey, we estimate the number killed by bikes to have been 0.89*89,250 = 41,622 toheroa[57]. However, it is also possible that some toheroa were broken in to two or more large pieces by the bikes and therefore were counted multiple times in the after survey. If so, the estimate of 79,333 deaths will still be inflated. Therefore we think the most reliable estimate of number of deaths is from the reduction in abundance of live toheroa (Table 7).

[56] The margin of error (confidence interval) is 30,512 to 67,564.

[57] The margin of error (confidence interval) is 27,122 to 60,057.

Table 5. Estimated density (number per m^2) of alive, dead or damaged and fragments of juvenile toheroa on Oreti Beach before and after the Burt Munro Challenge beach race, 28th November 2008.

	Alive		**Dead or damaged**		**Fragments**	
Areas compared	Before[ø]	After	Before[¥]	After	Before	After
400 m overlap zone only[†]	1.17 (0.70–1.67)[β]	0.32 (0.13-0.55)	0.13 (0.03-0.27)	0.81 (0.42-1.35)	1.13 (0.67-1.67)	3.32 (2.39-4.32)
Full course 'Before' and 'After'[µ]	1.50 (1.03-2.00)	0.65 (0.39-0.92)	0.14 (0.03-0.28)	0.74 (0.48-1.06)	1.08 (0.67-1.53)	2.72 (2.03-3.47)

[ø] The three damaged toheroa in the 'Before' sample have been assumed to have been damaged by the spade, and therefore categorised as alive in this calculation

[¥] The three damaged toheroa in the 'Before' sample have been assumed to have not been caused by spades in this calculation.

[†] The course was altered at the last minute so our 'Before' samples were no longer exactly the same as those 'After' the race. Accordingly this comparison is limited to just those sections that overlapped in the two areas.

[β] The 2.5th and 97.5th percentiles are given in brackets. These are the results of bootstrapping (with replacement) by 10,000 computer simulations in each case. The interval is equivalent to a 95% confidence interval.

[µ] Here we used the full set of samples 'Before' cf. 'After' the race. The comparison will only accurately reflect the impact of the race if the overall density before the race was about equivalent between the two different areas.

Table 6. Estimated ratio of the number of alive, dead or damaged, and shell fragments per m^2 'Before' vs. 'After' the Burt Munro Challenge race on Oreti Beach on 28th November 2008.

Areas 'Before' vs. 'After'	Alive and undamaged ø	Dead or damaged¥	Fragments
400 m overlap zone only†	0.29 (0.10 – 0.59) β	6.05 (2.26 – 26.13)	2.93 (1.77 – 5.37)
Full 500 m course 'Before' vs. 800 m 'After' µ	0.44 (0.25 - 0.72)	5.29 (2.34 – 22.15)	2.62 (1.59 – 4.22)

ø The three damaged toheroa in the 'Before' sample have been assumed to have been damaged by the spade, and therefore categorised as alive in this calculation

¥ The three damaged toheroa in the 'Before' sample have been assumed to have not been caused by spades in this calculation.

† The course was altered at the last minute so our 'Before' samples were no longer exactly the same as those 'After' the race. Accordingly this comparison is limited to just those sections that overlapped in the two areas.

β The 2.5th and 97.5th percentiles are given in brackets. These are the results of bootstrapping (with replacement) by 10,000 computer simulations in each case. The interval is equivalent to a 95% confidence interval.

µ Here we used the full set of samples 'Before' cf. 'After' the race. The comparison will only accurately reflect the impact of the race if the overall density before the race was about equivalent between the two different areas.

Table 7. Estimated number of juvenile toheroa killed and the number of new toheroa shell fragments added to Oreti Beach by the Burt Munro Challenge race on 28th November 2008.

Areas 'Before' vs. 'After'	Number killed [ø] (from reduction in abundance of alive)	Number killed [¥] (from abundance of dead or damaged after)	New Fragments created
400 m overlap zone only[†]	53,531 (20,085 – 89,661) [β]	51,411 (26,734 – 86,371)	139,020 (71,014 – 210,237)
Full 500 m course 'Before' vs. 800 m 'After' [µ]	54,417 (19,615 – 89,904)	46,859 (30,512 – 67,564)	104,071 (51,899 – 157,195)

[ø] The three damaged toheroa in the 'Before' sample have been assumed to have been damaged by the spade, and therefore categorised as alive in this calculation

[¥] These estimate was calculated by multiplying the observed mean and percentile-bootstrap confidence intervals for the density of dead and damaged toheroa after the race by the dimensions of the final race track

[†] The course was altered at the last minute so our 'Before' samples were no longer exactly the same as those 'After' the race. Accordingly this comparison is limited to just those sections that overlapped in the two areas.

[β] The 2.5th and 97.5th percentiles are given in brackets. These are the results of bootstrapping (with replacement) by 10,000 computer simulations in each case. The interval is equivalent to a 95% confidence interval.

[µ] Here we used the full set of samples 'Before' cf. 'After' the race. The comparison will only accurately reflect the impact of the race if the overall density before the race was about equivalent between the two different areas.

Test vehicles and vehicle weight loadings

Utilities and light trucks were considerably heavier than cars, but they also had bigger tyres, so the overall pressure on the sand surface from a pass of a utility or light truck was about the same as for a car (Fig. 11 & 12). Motorbikes exerted about a third of the pressure of cars and utilities, but the high and well-spaced lugs of the tyres clearly displaced large amounts of sand (Fig. 7d). Quad bikes exerted the least pressure on the sand and have relatively smooth tyres.

Our test car and utilities exerted around middle of the pressure range for each of their vehicle categories, but our test motorbike was at the lower pressure end of its range (Fig. 12).

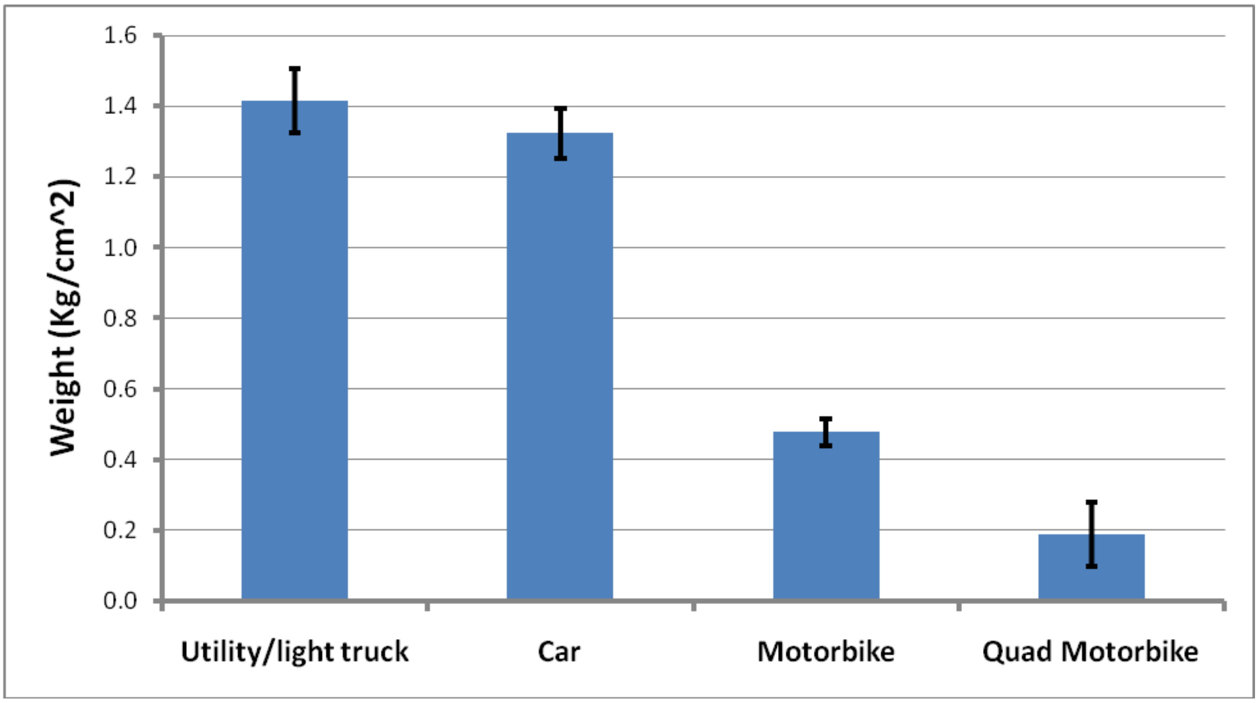

Figure 11. Average pressure (kg per square cm of tyre touching the sand) exerted by four categories of vehicle. The error bars show 95% confidence intervals for the mean.

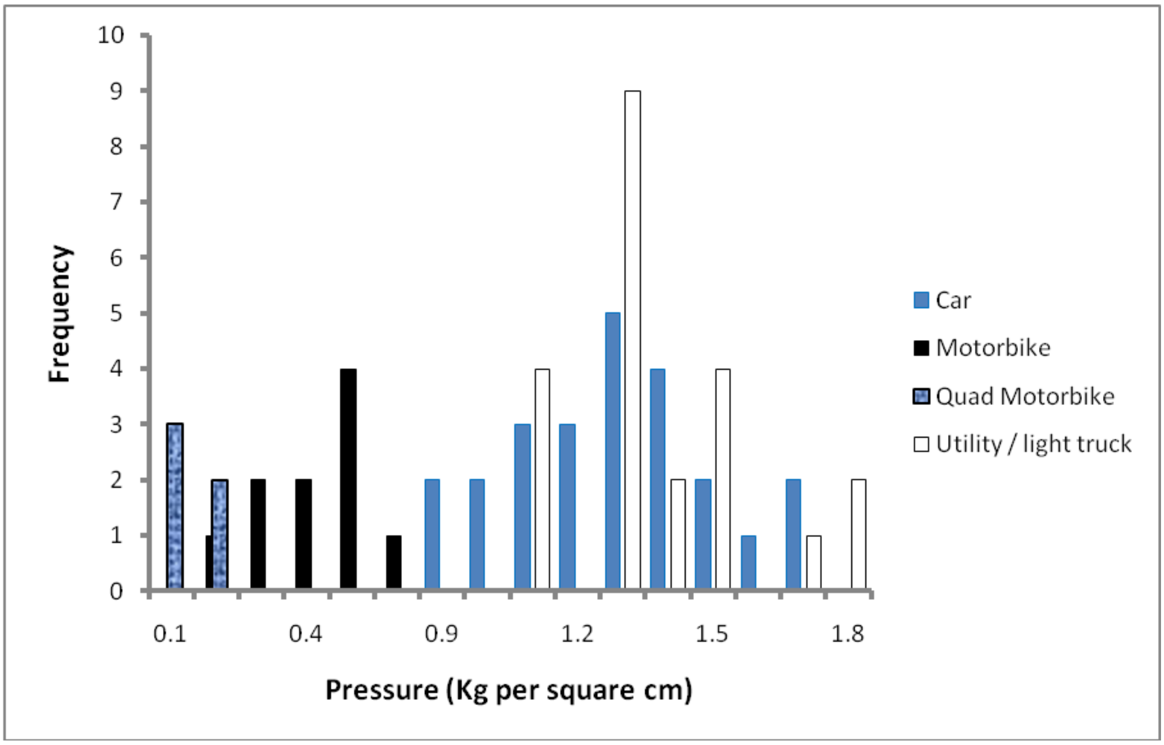

Figure 12. Frequency distribution of pressure exerted by different models and categories of vehicles. Our test car (Vehicle A) exerted 1.3 Kg per cm^2; Test utilities B and C exerted 1.34 and 1.31 Kg per cm^2 respectively; and the test motorbike (Vehicle D) exerted 0.28 Kg per cm^2.

Damage to toheroa

Damage to toheroa was obvious in chipped leading edges of the shells and fractures across one of the two valves (Fig. 13). Some very small chips occurred near where the two valves are hinged.

The motorbike stood out as posing much greater risk to toheroa than our test car and utilities (Fig. 14 & Table 2). Restricting the comparison to just the 'Mid/Low' beach zone[58] shows that the motorbike damaged 18% of the test animals compared to the other vehicles damaging only 3%[59].

[58] We restrict the comparison to data from the 'Mid/Low' beach because the motorbike was not tested in the 'High' beach zone.

[59] This difference is highly statistically significant (Fisher's Exact test, *p*=0.0003). The 'margin of error' around these estimates is given by '95% confidence interval'. This is the band within which the percent damaged would fall 95 times out a 100 when a sample of the same size was tested (chance alone would make it vary from the 18% and 3% that we measured in our trials. The 95% confidence interval for the motorbike was 10-31%, and for all other vehicles, 1-7% (Fig 14).

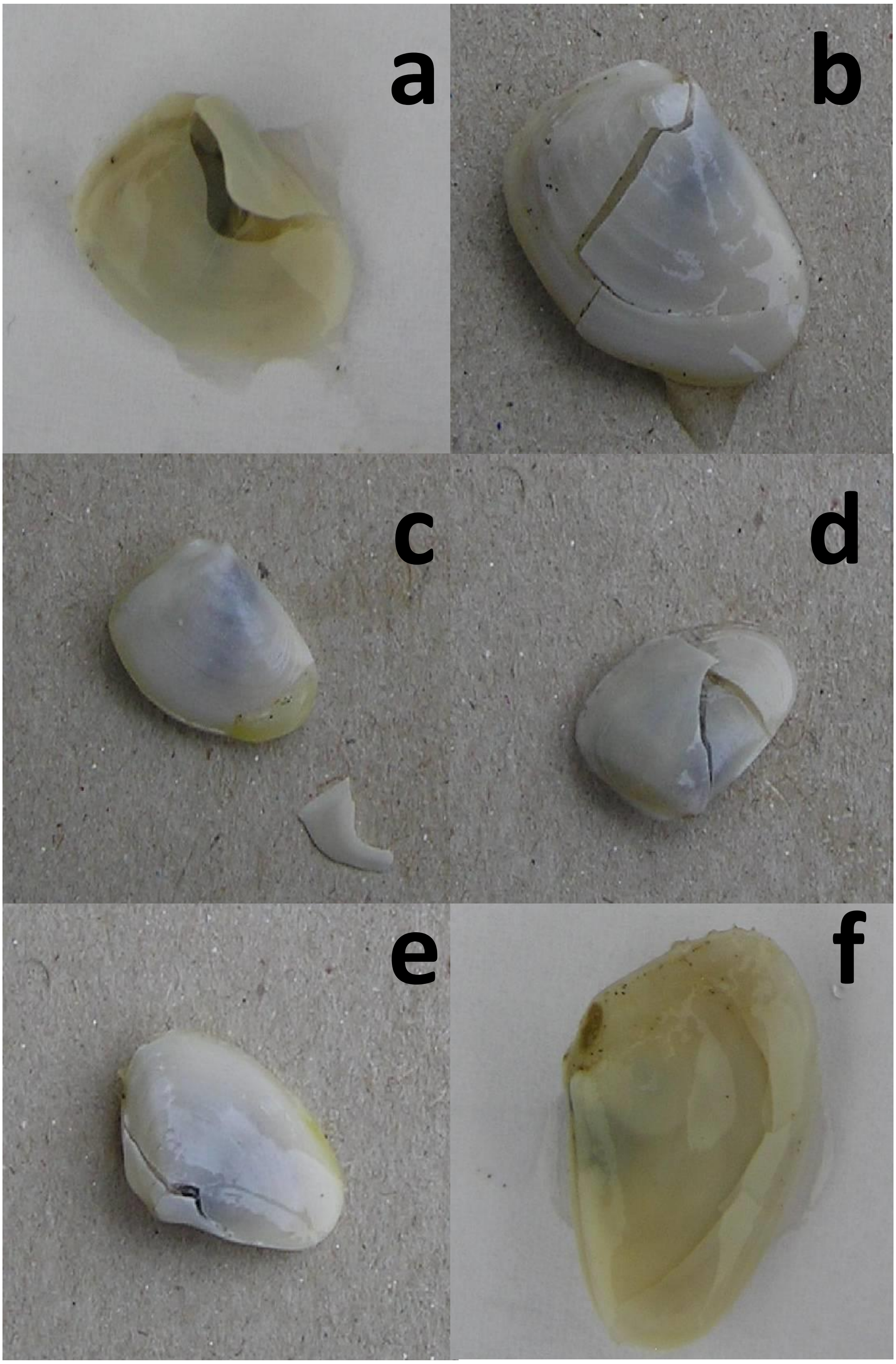

Figure 13. Examples of damage to experimentally placed toheroa after they had been run over by test vehicles, Oreti Beach, April 2009.

Overall, a higher percent of toheroa were damaged when placed in the 'High' beach zone (compare 'a' and 'b' in Fig 14). Again, the most useful comparison between zones can be made if the data for the motorbike are excluded (motorbikes were only trialled in the mid/low beach zone). In that case, around 3% of the toheroa were damaged in the 'Mid/Low' zone, compared to 14% in the 'High' zone[60].

Driving the test utility (Vehicle B) five times over transects in the high beach zone damaged 33% of nine translocated toheroa, whereas 10% of 19 toheroa were damaged by the same vehicle driving over them once. The difference between trials could easily have occurred by chance because sample sizes were so small[61], so we have no evidence to conclude or disprove that multiple passes in quick succession adds risk to toheroa.

In all cases the 95% binomial confidence intervals around percent of damaged toheroa are relatively large (Fig. 14). This arises because of low sample sizes and also the low overall risk posed by most categories[62]. A future research priority for follow up work is to build sample sizes to around 400 in each category to achieve margins of error of around ±2.5% (about three times current available sample size). The most prominent part of the beach is what we called the 'Mid/Low' beach. The overall percent damaged by all vehicles combined in this zone is 7%, with a margin of error of 4-11%.

Our experimental group of juvenile toheroa were a slightly biased subsample of the animals we found drifting in the rising tide (Fig. 15). We sought to test the vehicle risk to as wide a size range of toheroa as we could, so we experimentally placed a higher proportion of the infrequently encountered relatively large ones (> 20 mm long). However there was no evidence that a higher proportion of the comparatively longer animals amongst the drift sample were capable of digging themselves into the sand when we established the control trial (Fig. 15)[63]. Importantly, amongst the experimentally translocated group, there is no evidence that the risk of damage by the vehicle was affected by the length of the juvenile[64].

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[60] This difference is highly statistically significant (Fisher's Exact test, p=0.003)

[61] The difference in damage rate between single and five passes is not statistically significant (Fisher's Exact test, p=0.29)

[62] Margin of error increases markedly when the estimated percentage approaches zero or 100 percent for binomial measures.

[63] The mean size of those digging was 11.7 mm (95% confidence interval 11.1 – 12.3) compared to 12.0 mm (95% confidence interval 11.1 – 13.0) for those not digging.

[64] A Mann-Whitney U Test was used for the comparison because of the skewed distribution in lengths of toheroa in the drift sample (Fig. 15). This accepted the null hypothesis for there to be no difference in the length of damaged and undamaged toheroa within the experimental group (p = 0.28).

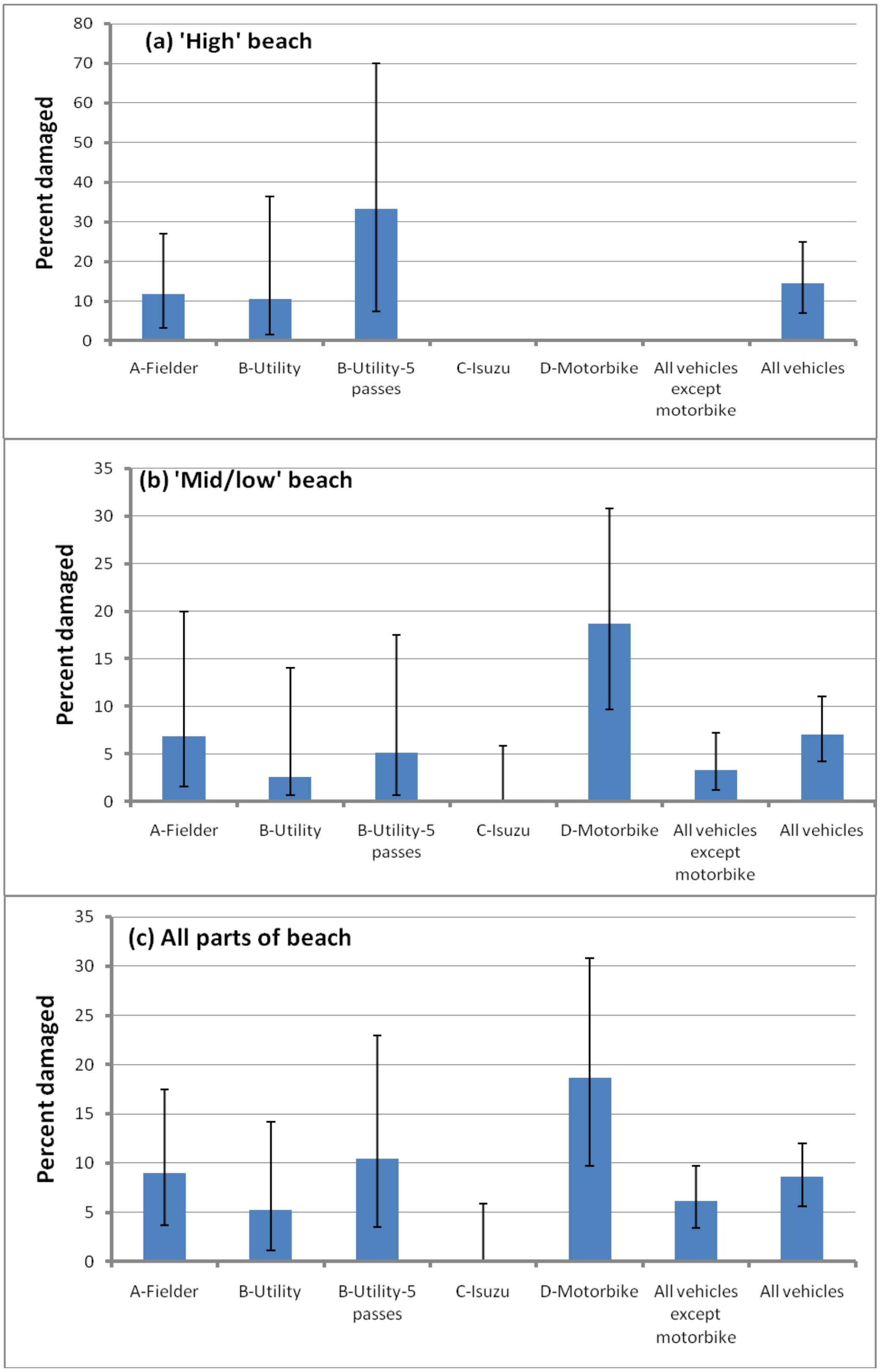

Figure 14. Percent of experimentally placed toheroa that were visibly damaged by vehicles in the (a) 'High' beach zone; (b) 'Mid/Low' beach zone; and (c) all parts of the beach combined. The error bar shows the 95% binomial confidence interval. Note the different scale on the y axis of 'b'.

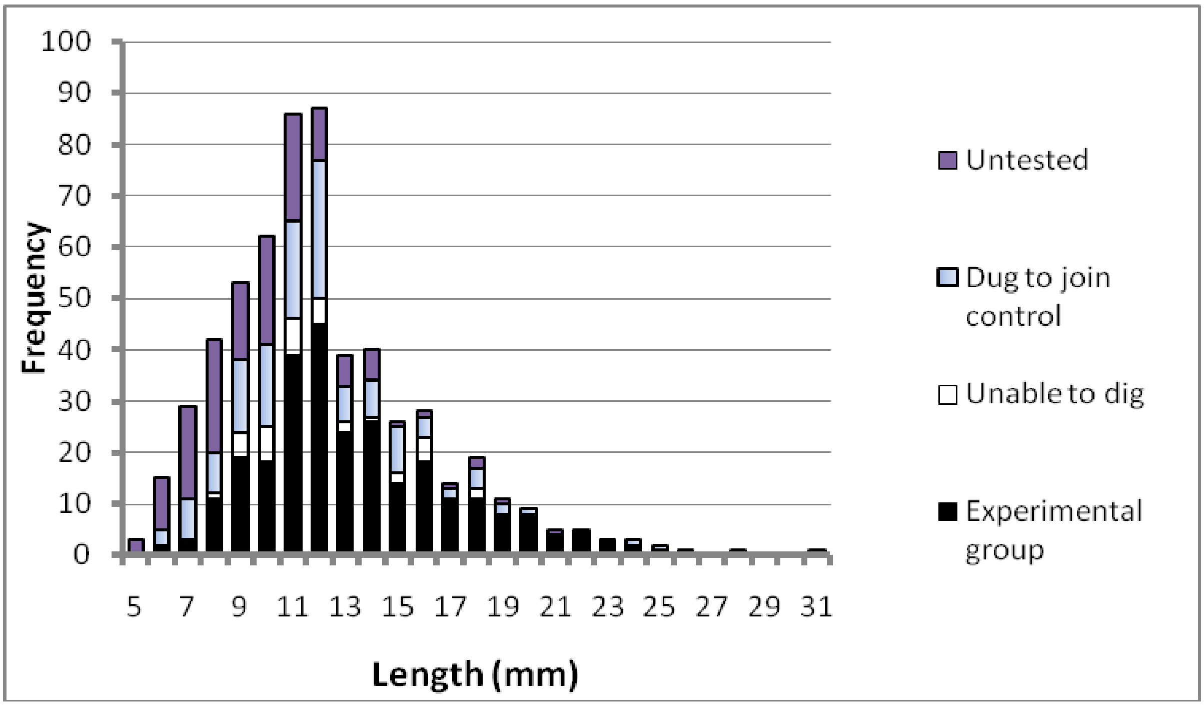

Figure 15. Length frequencies of juvenile toheroa gathered from the drift sample.

Control sample comparisons

Of the 33 juveniles that were initially unable or reluctant to dig into the beach to join the control sample, only one (3%) dug into the laboratory sand tray three days later (Fig. 16). It seems clear that these toheroa were already moribund or spent when we first found them in the drift sample. In contrast, 29% of those that dug initially were also able to dig in the laboratory three days later. Slightly more (35%) of the apparently intact sample that had been run over by our vehicles dug into the laboratory sand tray three days later, but the difference between this ability amongst the undamaged experimental group and the control group was not statistically significant[65]. However only 12% of those showing visible damage to their shells from having been run over were capable of digging in the laboratory three days later – they were obviously dying at a faster rate than undamaged ones in laboratory conditions[66].

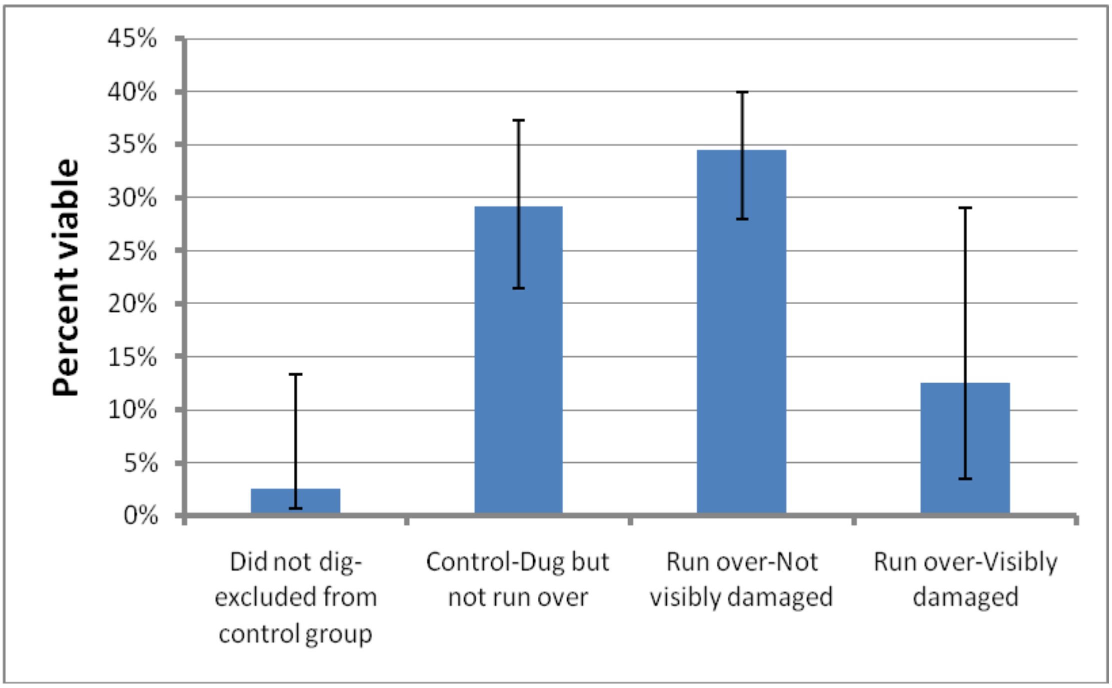

Figure 16. Percent of different groups of toheroa that dug into sand in a laboratory tray 3 days after their collection and experimental treatment. The toheroa were kept in plastic pottles with unaerated seawater and at room temperature for the intervening three days. Error bars are 95% binomial confidence intervals.

[65] Fisher's Exact Test, $p = 0.31$.

[66] Fisher's Exact Test, $p = 0.015$.

Sand compaction as indexed by penetrometer readings

The sand was relatively penetrable close to the dunes and once the lower half of the beach is reached where it is visibly wet or covered in shallow standing water even at low tide (Fig. 17). Our measurements were made close to low tide time on the morning of 14th April.

Sand just below the high tide mark hardened noticeably in the first hour after the tide had fallen (Fig. 18), but the penetrometer reading two hours later was still only half that recorded at the high tide mark in our wider survey along the beach at low tide the next day (Fig. 17). This may partly be due to longer exposure to air by the time it was low tide, but we think it more likely that our monitoring zone (used for the trial reported in Fig 18) was an unusually soft area. It is very noticeable when driving near the high tide mark that the softness of the sand varies a lot in different parts of the beach. The levelling off in the pentrometer readings after one hour since high tide shown in Fig. 18 is probably indicative of how the sand in that spot will have remained for the remaining period of exposure until flooded by the next tide.

The penetrometer readings taken in the vicinity of the experimental transects did not predict damage rates to the toheroa[67]. It may be that the instrument is not sensitive enough to detect a real affect, but more likely, the support of the embedded toheroa in very wet sand is probably related more to the incompressibility of water and consequent even support of the shell. We predict that degree of consolidation of the sand, and hence its penetrability, is likely to affect risk to toheroa only in relatively dry sand.

[67] We tested for this effect by building a multiple logistic regression model on the data excluding the motorbike trials. The average penetrometer reading taken in the vicinity of each transect five minutes before the trial took place was not a significant predictor of the proportion of toheroa damaged (p=0.18) once the zone on the beach ('High' vs. 'Mid/Low') was taken into account (p=0.047).

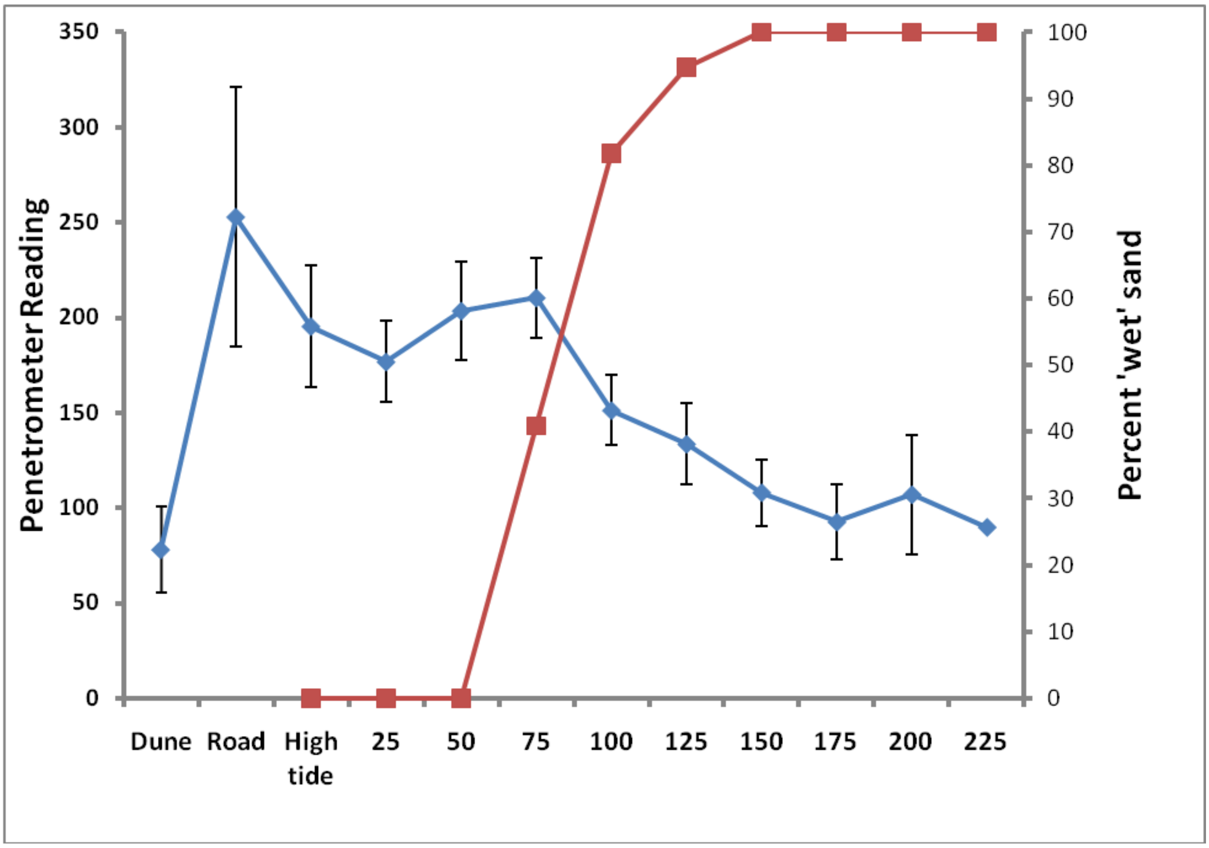

Figure 17. Sand compaction and wetting at different distances down Oreti Beach at low tide on 14th April 2009. The average penetrometer reading (triangles) is shown for the base of the sand dune, a vehicle track ('road') where present above the high tide mark, at the high tide line and then at successive 25 pace intervals down the beach. The error bars are 95% confidence intervals. 'Wet' sand (squares) refers to when the sand had a dark surface sheen or is covered by shallow pools of standing water.

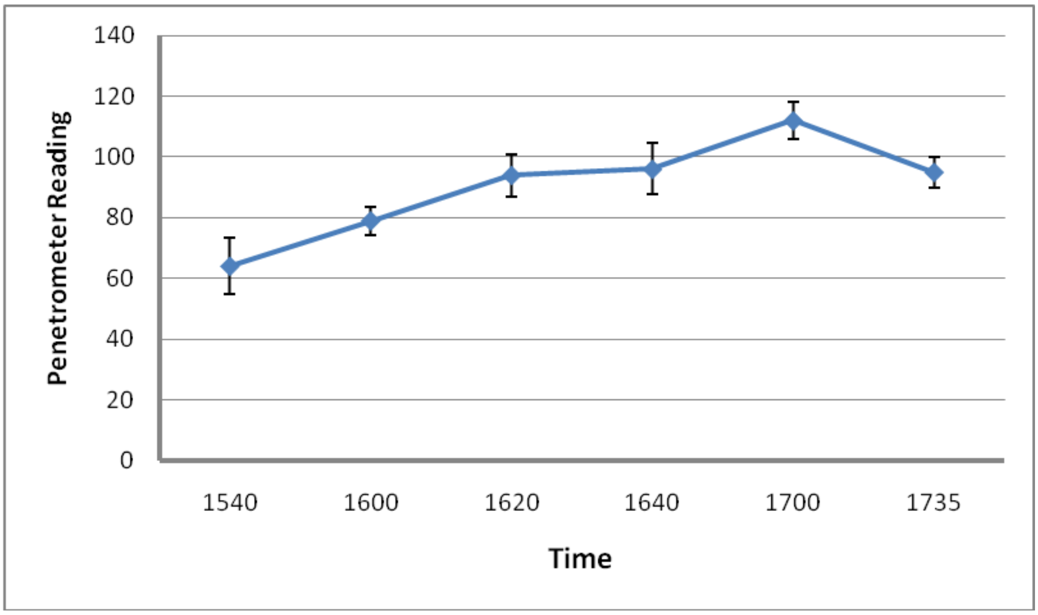

Figure 18. Average penetrometer readings in a 5 m zone just below high tide mark in successive intervals after high tide was reached (at ca. 1530 hours), Oreti Beach, 14th April 2009[68].

[68] The error bars show 95% confidence intervals.

Discusssion

Burt Munro Challenge Beach race impacts

Injury on the race track

Estimates of the number and proportion of toheroa killed by the Burt Munro beach race were broadly similar irrespective of whether we compared the full 'Before' and 'After' areas, or restricted the comparison to just the 400 m stretch that directly overlapped. Restricting the comparison to the latter overlapping zone is probably the most rigorous approach becuase it avoids assumption of there having been equivalent density of live toheroa on the two larger areas before the race[69]. Using just this restricted overlapping zone, the most likely estimate for the number killed by the race is around 53,000. The percentile-bootstrap confidence intervals show that this may have been as low as 30,000 and as high as 70,000. This caused a 72% (CI 40-90%) mortality of juvenile toheroa on the race track area. This interpretation is consistent with: (a) the finding of dead and damaged toheroa on the sand surface the day after the race but not before; (b) a leap in the number of dead and damaged specimens remaining in the sand (our best estimate was for 51,000 casualties (Table 7); and (c) a doubling of the number of shell fragments buried in the sand. Our second part of this research showed that motorbikes damaged around 18% of the toheroa on a single pass (two wheels in succession) over the top of them and that motorbikes pose higher risk to toheroa than other types of vehicle. This evidence, when coupled with the estimate of each part of the race track being run over about 11 times on average by a motorbike and the obvious large area of disturbed sand after the race, make the 72% mortality estimate and 53,000 deaths entirely plausible.

Nevertheless we suspect that the estimates of damage are minimal because:

- The race track was washed by a tide before even the first 'After' measurements could be taken, and then by a second tide before the 'After' survey was completed by the evening of 29th November 2008. This may have washed several dead and damaged toheroa out of the area (indeed, some were found floating in the tide adjacent to the race track throughout the day after the race).

[69] Toheroa abundance is quite patchy along the beach (Beentjes & Gilbert 2006a, b), so the assumption of equal abundance across the two areas prior to racing may not be fully met.

- The incoming tide just after the race may have deposited some new juveniles from the 'drifting' population that originated from surrounding areas, thereby inflating the aparent number of toheroa that survived the race.
- Some aparently intact toheroa may have been damaged internally – we found several intact ones on the sand surface and floating in the sea that did not dig when placed on wet sand above the tide. Whole animals lying exposed on the sand were not seen before the race, nor in the April trials of general vehicle damage, so we believe these had been destroyed as a consequence of being washed out of the sand after the bikes had disturbed the substrate .
- Some animals may have been pulverised to the extent where a whole animal was not counted or fragments did not remain.
- We have used a very conservative estimate of the dimensions of the race track so as to be careful not to exaggerate the size of the injury to the population.
- Our estimate does not include the damage caused by the large number of vehicles that drove on to the beach, parked and drove off again after the event.

Population impacts from the beach race

Although the local impact of the Burt Munro Challenge beach race is obviously severe, several broader considerations ameliorate its potential affect on the overall toheroa population on Oreti Beach, including:

1. The race track and associated disturbances from temporary buildings, fencing and vehicles coming, parking and going was restricted to a 1-2 Km stretch of the beach, whereas toheroa are spread along 17 Km[70]. The race track itself covered about 5% of the 17Km long colony.
2. The race impact is focussed on the upper 100 m of the beach, about half of the exposed reach of the beach at low tide. Averaged over the entire Oreti Beach, 55% of juveniles occur in the top 100 m of the beach, 14% of subadults and 2% of the adults[71]. Thus the race track is sufficiently high up the beach to not put the adults and crucial subadult recruits at risk even in the area immediately adjacent to the race track.
3. Nearly all the killed toheroa are juveniles. Many of these would have died of natural causes[72] had they not been destroyed by the bikes.

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[70] J Futter (unpubl. data).

[71] These estimates were calculated by reading the heights of the bars (by eye) in Fig. 6 of Beentjes & Gilbert 2006b.

[72] Ecologists measure the 'reproductive value' of the different life stages – this is a measure of the effect of removing each life stage on the number in the future population. Although formal estimates are not available, we expect the reproductive value of a juvenile toheroa to be 100 times less than that of an adult which breeds

4. The race occured in November, early in the spatfall season. Subsequent cohorts of juveniles are likely to be produced in December – April and so will partly replace those killed by the race.
5. The large drifting population of juveniles redistributes juvenile toheroa down the beach, so some rapid infilling of the depleted area can be expected.
6. The mātauranga (Traditional Ecological Knowledge) of the kaitiaki[73] suggests that density dependence is operating in the population[74] ie. thinning out local density triggers improved recruitment. If so, there will be some compensatory response to the impact of the race by triggering improved growth and survival of the surviving individuals, and the new ones from the drift or subsequent cohorts that replenish the area.

The racetrack was situated at the end of an atypical part of the beach where the distance from the high tide mark to the toe of the dunes is widest and where the dunes themselves are highest. We do not know whether the density of juveniles would have been naturally higher or lower in this zone, or whether concentration of year-round traffic in this zone might have lowered density there, or would subsequently have killed many of the juveniles killed by racing bikes.

Recommendations for minimising future impacts of the beach race

The race organisers are best placed to advise on practical methods for mitigation of risks to toheroa. We urge The Burt Munro Challenge Event organisers, Environment Southland, the Tangata Tiaki of Waihopai Rūnaka, and researchers to pool knowledge and workshop together to identify adjustments to future race management that will reduce the number of toheroa being killed. Aside from avoiding the use of a grader or similar machine to level the race track, there seems little that can be done to minimise the impact on the toheroa living in the race track itself. Mitigation therefore mainly comes down to optimal placement of the race track, timing of the race, reducing the number of vehicles going onto the beach by managing traffic bringing spectators and competitors to the event, and directing where the remaining vehicles drive once on the beach.

A preliminary list of actions for consideration include:

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continuously and may live for 20 years (Rapson 1952, Redfearn 1974). Accordingly the removal of more than 100 juveniles (probably several hundred) would have less of an impact on the future toheroa population than removing a single adult.

[73] See Futter & Moller (2009) and Moller & Lyver (in press) for details.

[74] See Metzger (2007); Futter & Moller (2009).

1. Avoid use of a grader or leveller if at all possible[75].
2. Keep the race track as high on the beach and as close to the dunes as practicable.
3. Keep the race track as narrow as practicable.
4. Minimise the distance of the race track from the main vehicle entrance to the beach.
5. Manage vehicles so they only drive and park above the high tide mark, or are parked off the beach. Parking spectators' vehicles in a thin strip above the high tide mark to the northwest of the main entrance would help eliminate all driving on the intertidal zone.
6. Consult previous NIWA research results to compile an index of recruitment sucess in 900 m stretches of beach at successive distances southeast and northwest of the main vehicle entrance to place the track where recruitment is least affected and Step 4 above is met.
7. If practicable, provide parking for spectators behind the dunes near the main entrance; if possible form a stable walking track from the parking area direct to the beach near the start of the race.
8. If practicable, only allow competitors and organisers to drive on to the beach.
9. Form a vehicle track above the high tide mark from the entrance to the race track and have the competitors and organisers use it and not the intertidal section of the beach. The intertidal area should be roped off to guide the traffic.
10. Do not allow heavy buses and trucks or heavily ladened trailers onto the beach at all and never onto the intertidal area[76].
11. Park the vehicles of the competitors and organisers as near to the top of the beach as possible, always above the high tide mark.
12. Hold the race as early in the spring as practical after consideration of other organisational constraints. This would minimise the proportion of the annual cohorts of juvenile toheroa that are exposed to the injury from the race.
13. Use the demonstration of the above best professional practices of the event organisers as an educational opportunity to encourage other Oreti Beach users to minimise impacts on toheroa for the remainder of the year. Include a pamphlet or section of the programme that outlines ways that beach users can help. Remind race spectators of the issues in the public comentary between the races[77].

[75] Use of graders, harrows, bars or blades should be discouraged and if possible eliminated altogether unless absolutely necessary to ensure operational safety of the riders.
[76] A 3.5 tonne weight limit is already prescribed by the Coastal Plan, but clearly some of the visitors to the race exceeded this requirement.
[77] There were repeated reminders during the 2008 event for patrons to pick up litter "for conservation" reasons, together with satirical mentions of the risk to toheroa. Really littering is more of an aesthetic

Beach traffic impacts

Evidence of potential risk

Our preliminary study has confirmed that a single pass over a juvenile toheroa, even when not feeding, can sometimes damage it. Our laboratory assay of longer term impact of shell damage on mortality was crude, but the comparisons with control samples suggest that cracks to the shell do indeed compromise survival. Our study will potentially have missed other invisible internal damage, or the effects from being dislodged from the substrate by displacement of the sand by the wheels[78]. Also, our brief test of the effects of repeated passing over the same spot found no statistically reliable evidence that risk was elevated by multiple exposure. Northland studies firmly conclude that multiple passes trigger increased damage by vehicles and make the juveniles vulnerable to predators, so further trials using our experimental placement approach would be valuable. The only practical soultion to measuring the risk to small toheroa was to use the translocation technique. This could have introduced bias if toheroa naturally ocurr in microhabitats in the beach that are less or more susceptable to damage by vehicles[79], or if the experimentally placed animals do not dig as far into the substrate as ones washed up that then bury themselves. Some experiments had too few samples for precise estimation of risk, so we recommend renewed sampling effort to triple sample sizes from those currently available. Now that we have streamlined the techniques, this should be possible in around four days extra field work by 4-5 people.

Neither the Burt Munro Challenge beach race study nor the general vehicle impact studies detected evidence that the smaller individuals within the juvenile section of the population were less or more at risk from traffic. Although we directly tested damage to very few adult toheroa, we are very

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imperative. The toheroa issue is truly a matter of conservation and important to some stakeholders that share the use of the beach so a professional commentary at the race about the way the risk is being mitigated would assist everyone and the toheroa.

[78] This potential effect was evidenced by the presence of a large number of moribund but intact toheroa on the Burt Munro Challenge beach racetrack. Displaced animals may be at risk even when the shell is not broken.

[79] Observations during several hours of gathering drifting specimens for our translocation experiments emphasised the patchy nature of juvenile toheroa settlement. Specimens became concentrated where riverlets of back wash concentrated them and gave them a brief opportunity to dig into the substrate. We hypothesise that at least part of the patchy distribution of toheroa on the beach is caused by the physical variation in flushing and retreat of waves that is itself caused by uneven substrate and corrugations in the beach surface.

confident that they are far too deep and too well supported by the saturated substrate that they are not at risk from standard vehicles or motorbikes. If drivers travel in the shallow puddles and where waves are lapping at low tide, feeding adults and larger subadults may also be damaged[80]. In the nine days that six researchers spent on the beach for the field work in this study, only a very few instances of vehicles driving in the lapping zone were noted. Public education material should firmly discourage this behaviour.

Larger and heavier vehicles appeared to pose very similar levels of risks to toheroa as did an ordinary car in our preliminary study. This probably partly reflected the SUVs having bigger tyres to spread the load of the vehicle. But we predict that future research will register higher risk of these larger vehicles, primarily because they have wider spaces between the lugs on the tyres. The likelihood of damaging a toheroa is probably related to how much the sand is disturbed, displaced sideways or flung into the air, so larger gaps between the lugs will add risk. If wider and deeper treads are combined with high torque, as in racing motorbikes, risk will be extreme. Swerving and tight cornering, especially boyracers doing "doughnuts", all add risk to toheroa. Public education programmes should discourage this behaviour.

Our penetrometer measurements did not predict risk to the toheroa and even very soft and saturated sand apears to support the toheroa very well when it is run over. We presume that the hydrostatic pressure evenly supports the shell so the fracture is less likely. Rather, risk of fracture is most likely related to lateral sheer forces in the sand as the substrate is forced sideways. If just the top half of the shell is subjected to lateral forces and the bottom half remains in firm sand, fracture is more likely.

The strong protection of even the small toheroa near the surface of the wet sand that prevails over most of the beach is the main reason for generally low risk per vehicle pass. We recommend use of our 3% mortality (1-7% confidence interval) as currently the best estimate of risk of a single pass over a toheroa by a four wheeled vehicle, and 18% (10-31% confidence interval) for each pass by a motorcycle.

Toheroa living in a narrow zone of 10-15 m at the high tide mark are generally more susceptable to damage by vehicles, primarily because the vehicles sink deeper into the softer sand and lateral

[80] Adults are concentrated in the bottom half of the beach (Beentjes & Gilbert 2006b; Futter & Moller 2009) so this is the area where feeding larger toheroa could be vulnerable.

movement of the toheroa is more likely. However, this zone represents only around 5% of the beach area, and only 7% of the juvenile toheroa live in this zone[81]. We also found that the sand rapidly hardened in that zone once the tide receded, so the high risk period is around one of the six hours in each tidal cycle (Fig. 18). We recommend a public education campagn to discourage driving in the soft sand at the high tide mark. However, generally it is the level of vehicle traffic use of the mid and lower sections of the beach and risk posed there that will have the greatest effect on overall toheroa recruitment.

Although our research indicates potential impact of vehicles on toheroa recruitment, it has not proven that any such impact is sufficient to be depressing the toheroa population. If other natural ecological factors are blocking recruitment to the crucial subadult and adult stages, then reducing vehicle impact will just prolong the lifespan of the juveniles a little but not trigger population growth. The 'Environmental Precautionary Principle'[82] and best professional practice suggest that all reasonable steps should be taken to build the toheroa population's resilience, so practical ways to minimise the risk posed by vehicles should be sought even though they may not be sufficient alone to guarantee population restoration.

Many of the multiple threats to toheroa, other aspects of beach ecology and the public will be mitigated only if the number of vehicles on the beach can be reduced. If funding were available, the obvious longer term solution is provision of either a road between the dunes and the high tide line[83] or, best of all, and network of formed roads, parking areas and increased predestrian beach access ways behind the dunes. This long term solution will be very expensive and probably still involves compromised recreational opportunities for some beach users (and enhanced opportunities for others). It would be prudent to do more research before the nature and extent of any such investment can be advised.

[81] Calculated from Fig. 6 of Beentjes and Gilbert (2006b).

[82] Raffensperger & Tickner (1999).

[83] One has formed by repeated vehicle use in sections northwest of the Dunns Rd entrance, but not everyone uses it. Also, maintaining a clear road will be difficult because of windblown sand and the narrow stretch between the high tide and primary dunes in some sections of the beach.

Research priorities to measure overall impact of vehicles on toheroa recruitment

Although our research demonstrates unequivocally that vehicles damage juvenile toheroa, this is not tantamount to having demonstrated that vehicles significantly disrupt recruitment to the Oreti Beach population. Making recommendations about managing the year-round vehicle threat will be entirely premature until the overall risk is better quantified.

The main future research priorities to allow quantification of risk to toheroa recruitment from vehicles are:

(a) determine year-round volumes of traffic on the beach (number and type of vehicle, how far they travel on the beach on each visit);

(b) measure the distribution of vehicle passage across the intertidal zone and especially along the beach and compare it with the distribution of toheroa and measures of recruitment failure;

(c) formulate more precise estimates of risk posed by single passes of four-wheeled vehicles and motorbikes on individual juvenile and especially subadult[84] toheroa;

(d) test the cumulative effect of multiple pases by vehicles;

(e) integrate measures a–d in a GIS model of the beach that predicts risk to recruitment in 10 x 10 m pixels and calculates the overall proportion of toheroa killed in each cohort; and

(f) conduct fundamental research on juvenile toheroa behaviour and ecology in general, and in particular to discover what triggers regular recruitment failure despite heavy and widespread spatfall. For example, we do not know if the juveniles at the very top of the beach can withstand desiccation for long or whether those deposited near the top of spring tides perish because they are not immersed sufficiently soon after or for long enough to feed and grow. Certainly we expect the ones placed highest on the beach are most at risk from natural causes, hence our recommendation to keep the bike race as high on the beach as practicable. Also it may be that the very early season cohorts are the main ones to recruit to the subadult stage, or those in the mid summer or even autumn. Knowing this would enable protective measures to be seasonally targeted and reduce threats in more cost-effective ways.

[84] A small number of small subadults were found damaged by the Burt Munro Challenge beach race. It is the recruitment of the subadult class that has the greatest potential impact on future populations (this stage represents a short-lived 'gateway' for rapidly growing toheroa to reach the security of adulthood where natural mortality rates plummet), so any damage of these intermediate- sized animals by vehicles would be particularly significant.

Interviews of users of different parts of the beach in different seasons would help to design potential mitigation strategies. Their primary focus would be to explore whether each recreational group has alternative options to meet their needs that would simultaneously reduce potential impact on toheroa and beach ecology. Year round use of a traffic counter on the main entranceway to the beach could be complemented by systematic interception surveys of users in weekdays, weekends and public holidays. Visitor numbers and their activities on a given day can be linked to standard weather records for that day in statistical models that can then more accurately predict vehicle traffic for the days not monitored. Comparison with the 1998/99 survey[85] in December to February could identify trends in vehicle use (Dallas Bradley has observed[86] that use of SUVs has increased greatly in the last decade).

Increasing vehicle traffic on beaches is recognised as a conservation threat overseas, and public education is difficult, expensive and slow[87]. Surveyers could distribute pamphlets on best professional practice to minimise impact on toheroa to begin a long-term education campaign to mitigate threats.

Vehicle traffic on Oreti Beach has became crowded, moves fast and is hazardous (even during the short period of observations by our research team made outside expected peak holiday periods). Frequent presence of marks showing spinning vehicles ("doughnuts") that dislodge considerable quantities of sand are extreme examples of risk posed to individual drivers and pedestrians and local ecology of the beach. Use of the beach is likely to increase in future and firm baseline measures of vehicle use could be matched with ongoing regular surveys of the toheroa themselves to test putative impacts of people and their vehicles on this taonga species.

There will be much to gain from drawing key beach user groups (such as the Burt Munro Challenge organisers), Tangata Tiaki, Ministry of Fisheries, Invercargill City Council, Environment Southland, Department of Conservation and researchers (egs. NIWA, University of Otago, local experts[88]) into a working party from the outset to apply detailed local knowledge in a search for practical solutions to moderating risk to the public, damage to the beach ecology and toheroa. This community management group could also take a public lead to lobby and support more colaborative research to

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[85] Wilson (1999).

[86] Email 27th April 2009 to H Moller.

[87] Schlacher & Thompson (2007); Schlacher et al. (2008)

[88] Lloyd Esler has an immense knowledge of the beach, and there are local research consultants that may be able to assist.

find out why toheroa recruitment failure happens in many years on Oreti Beach. Implementing strategies for population restoration are required to build the resilience of the toheroa population to withstand enjoyable and important events like the Burt Munro Challenge beach race, year-round community recreation and sustained customary use of a taonga species for our garndchildren and the generations after them.

Acknowledgements

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