School of Biological Sciences and
Department of Geography

College of Science

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Estuarine Research Report 42

*Seasonal effects of vehicles on juvenile tuatua (*Paphies donacina*) on an intertidal surf beach in Canterbury, New Zealand*

Gareth F. Taylor
Islay D. Marsden
Deirdre E. Hart

12

Estuarine Research Report 42

Seasonal effects of vehicles on juvenile tuatua (Paphies donacina) *on an intertidal surf beach in Canterbury, New Zealand*

Gareth F. Taylor
Islay D. Marsden
Deirdre E. Hart
School of Biological Sciences
and Department of Geography
University of Canterbury
Christchurch, New Zealand

Prepared for:
David Owen
Environment Canterbury

Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

Cover Photo : Gareth Taylor

Seasonal effects of vehicles on juvenile tuatua (*Paphies donacina*) on an intertidal surf beach in Canterbury, New Zealand.

Table of Contents

1 Executive Summary 2
2 Introduction 3
2.1 Shellfish in New Zealand's sand beaches 3
2.2 Pegasus Bay, Canterbury 4
2.3 Vehicle use in Pegasus Bay 6
2.4 Study aims 7
3 Methods 7
3.1 Site selection 7
3.2 Experimental procedures 8
4 Results 13
4.1 Tuatua densities and mortality 13
4.2 Effects of vehicle passes on shellfish mortality 13
4.3 Reburial 15
4.4 Tyre tracks 17
4.5 Pore water 18
5 Discussion 20
5.1 Mortality effects 20
5.2 Reburial 21
5.3 Sediment properties 21
5.4 Research implications 22
5.5 Management recommendations 23
6 Further research 24
7 Conclusions 25
Acknowledgements 25
References 26

1 Executive Summary

In June and December 2010 the effects of driving a four-wheel-drive vehicle (Mitsubishi Triton) over juvenile tuatua (*Paphies donacina*) beds on an exposed sandy surf beach at Pines Beach, Pegasus Bay, Canterbury was investigated. The study used an *in situ* population of bivalves in high abundance rather than transplanting individuals to avoid the stress associated with pre-treatment handling. The tuatua occurred at densities of 272 to1712 m^{-2} in winter and 240 to1392 m^{-2} in summer. Along the same vehicle tracks, up to 50 vehicle passes were made through the tuatua bed.

In all, 40 driving trials were undertaken, 20 in June and 20 in December. After each number of passes (1, 5, 10, 15, 20, 25, 30, 40 and 50), the sediment from a 625 cm^2 quadrat was dug up, tuatua sieved from the sediment and any shell damage recorded. Sediment was collected to measure pore water contents. Tyre tracks were measured to provide a measure of sediment compaction. The reburial success for 15 surviving individuals to bury was measured. Counts of those unburied were recorded every minute for 15 minutes.

Tuatua collected in the tracks ranged in length from 5-28 mm in June and 5-32 mm in December. The most common forms of damage were cracking of the shell or slipped shells. These injuries are fatal. The percent mortality increased with increased vehicle passes for both seasons and the mortality rate was the same. The rate of mortality increased at 0.27% per vehicle pass (line equation: $y=0.27x + 4.79$, $R= 0.58$, $p<0.001$). Reburial success was variable, but there was a negative correlation between reburial success and the number of vehicle passes in the summer.

Vehicles driven on Pegasus Bay sand beaches have detrimental effects on juvenile tuatua. Mitigation may be necessary to prevent shellfish damage. Completely banning vehicles could be an option but may not be acceptable to the general public. Other options would be to implement mitigation measures aimed at achieving positive ecological goals whilst still allowing activities in a controlled fashion. This could include: restricting vehicles from the intertidal zone, designating tracks for vehicle use, and directing vehicle use to areas where they are required (e.g. near river mouths for whitebaiting). If these measures were implemented shellfish populations are likely to be better protected for future generations.

2 Introduction

Vehicles are permitted to be driven on most sand beaches throughout New Zealand. How does this affect the biota in these ecosystems? Studies in Australia suggest that vehicles cause reductions in diversity (Schlacher, Richardson & McLean, 2008), alter bivalve behaviour (Schlacher and Lucrezi, 2010) and result in shellfish mortalities (Schlacher, Thompson & Walker, 2008). These studies have highlighted the need to control vehicles and have led some authorities to implement complete bans, as seen in South Africa (Full 4x4 Regulations, 2010), or stipulate where vehicles are permitted (Northern Pegasus Bay Bylaw, 2010). In New Zealand, vehicles are driven on sand beaches to access fishing areas, for organised events and tourism.

The intertidal zone is often the focal point for activities, such as vehicle driving and horse riding, and the species present in this area are most vulnerable. New Zealand's sand beaches contain a wide range of biota including shellfish, shore birds, polychaetes, amphipods, and other crustaceans. Shellfish have an important ecological role in nutrient cycling, increasing faunal diversity, and reducing water turbidity (Dame, 1993; Gosling, 2003; Marsden, 1999a; Vaughn & Hakenkamp, 2001). Shellfish are a food source for many predatory organisms in the ecosystem (Williams, 1969) as well as for humans. In New Zealand they are a valued source of *mahinga kai.*

2.1 Shellfish in New Zealand's sand beaches

New Zealand's geographical isolation has led to a high level of endemism. Bivalves that inhabit the surf zones of sand beaches are referred to as surfclams. Some of these species remain in the subtidal, whilst others may inhabit the intertidal zone throughout their life. However, there are some species that inhabit particular zones at certain stages of their lifecycle. Reproduction of surfclams is through broadcast spawning (Cranfield *et al.*, 2002). This process is often largely seasonal in the South Island, with the high production of gametes in the warmer summer months (Marsden, 2002).

Tuatua populations inhabit the intertidal zone of sandy beaches as juveniles and move to the surf zone as adults. These include two species of tuatua, *Paphies donacina*, found on the South Island and southern shores of the North Island, and *P. subtriangulata*, found mainly in the North Island (Marsden, 1999a). Tuatua (*P. donacina*) is the dominant species of shellfish on the beaches of Pegasus Bay (Marsden, 2010). Toheroa, *P.ventricosa*, another important species of surfclam, has recently had its fishery closed due to a large decline in its population

(Ministry of Fisheries, 2012). Toheroa are also present intertidally, but, unlike tuatua, adults are also present in this zone (Cranfield *et al.*, 2002; Kingett Mitchell Limited, 2003; Marsden, 2002). Other species of surfclams inhabiting New Zealand's sand beaches include *Spisula aequilatera, Mactra murchisoni, M. discors, Dosinia anus, D. subrosea* and *Bassina yatei* (Cranfield *et al.*, 1996).

Historically the two species of tuatua and toheroa have been important to Māori who have gathered them as a customary food source, or *mahinga kai* (Moller *et al.*, 2009). In some parts of New Zealand customary gathering has become reduced. For example, it has been reported that local iwi no longer collect tuatua (*P.donacina*) from certain areas of Pegasus Bay, Canterbury, due cultural sensitivity to sewage outfalls in the area (Cranfield *et al.*, 2002).

2.2 Pegasus Bay, Canterbury

Pegasus Bay is a large eastern facing bay situated in the province of Canterbury in the South Island of New Zealand (Figure 1). The Bay extends approximately 50 km from the mouth of the Waipara River in the north to Banks Peninsula in the south. The beaches within this bay include gravel, composite and sand types (Hart *et al.*, 2008). Sandy beaches start at the southern end of Pegasus Bay beside Banks Peninsula and extend northwards for approximately 40 km. Tuatua are abundant along most of this area, except adjacent to the mouth of the Waimakariri and Ashley Rivers discharging into the bay (Marsden, 2010).

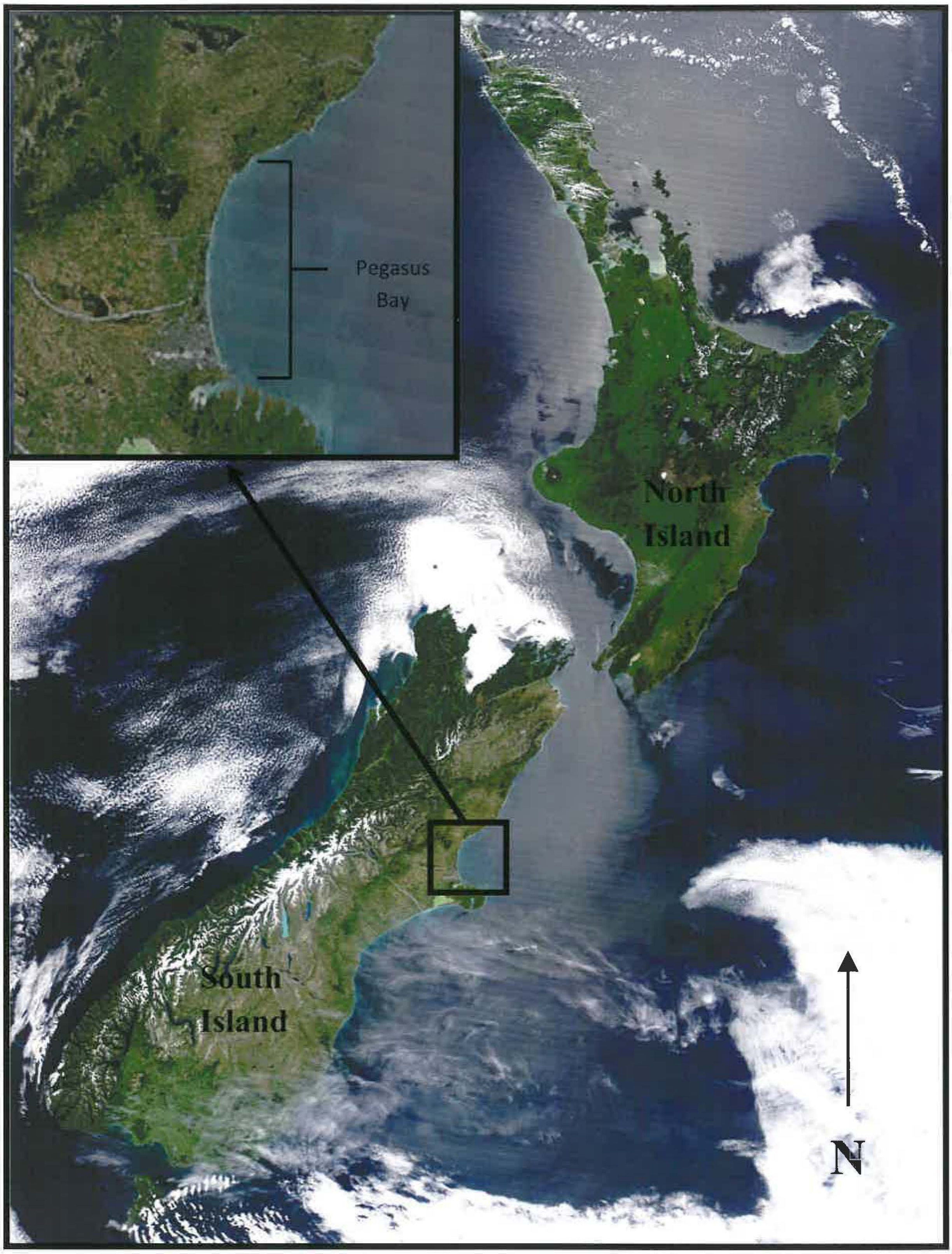


Figure 1: Satellite maps showing the North and South Islands of New Zealand. Insert satellite image is of Pegasus Bay, Canterbury. (Image courtesy of NASA, 2010)

2.3 Vehicle use in Pegasus Bay

Vehicles are commonly driven on the sand beaches along much of Pegasus Bay to carry fishing and whitebaiting gear, and to access fishing spots and other off road coastal areas. Current areas where driving is allowed include; North of the Heyders Road entrance but south of the Waimakariri River mouth, Kairaki, south side of the Ashley River mouth and Ashworths Beach. The current bylaws in Pegasus Bay stipulate that vehicles should enter and drive directly to the intertidal zone (Waimakariri and Hurunui Northern Pegasus Bay Bylaw, 2010). This bylaw results in traffic being concentrated in the intertidal zone where shellfish and other intertidal organisms are vulnerable to being runover. No restrictions exist for the number, type or weight of vehicles that can be used; however, the type of vehicle commonly used is 4-wheel-drive Suburban Utility Vehicles (SUV), as seen in Figure 2.

Figure 2: Four-wheel-drive vehicles used by whitebaiters parked on the intertidal zone at the Waimakariri River Mouth, Pegasus Bay, Canterbury

2.4 Study aims

The overall aim of this study was to quantify the relationship between vehicle traffic and shellfish mortality, and to evaluate the sub-lethal effects from these activities. This study extended the study undertaken by Marsden and Taylor (2010) by using experimental manipulation to quantify the relationship between intensity of vehicle traffic and shellfish mortality. Reburial success following runover was also investigated. Experiments were seasonally repeated to identify whether shellfish may be more vulnerable at certain times of the year. Seasonal vulnerability could be due to factors such as differences in shellfish burial depths or sediment texture.

We expected a positive relationship between the number of vehicle passes and shellfish mortality and predicted a seasonal difference in mortality. If increased vehicle passes resulted in more stress on surviving individuals, the burial success might be reduced. Reburial activity may be more successful in the summer due to individuals being more active and in better health and condition (Marsden, 1999b)

3 Methods

The method used was designed to minimise disturbance to the shellfish and sediment. Other studies have transplanted shellfish into an area of the beach to be runover (Moller *et al.*, 2009). Results from such experiments are unlikely to be indicative of undisturbed populations. Transplanted individuals may not rebury to their original depths and when burying the shellfish the sediment properties may be altered by loosening the sediment. Finally, the size of individuals used in experiments may not be representative of the natural assemblages for the area. To keep results indicative of natural population impacts, testing was undertaken where shellfish densities were high. Individuals and sediment were not disturbed prior to conducting the experiments.

3.1 Site selection

Pines Beach, Canterbury, was selected as the study site for both the winter (14th - 17th June 2010) and summer (6th - 9th December 2010) experiments. Pines Beach is located approximately 4.3 km east of Kaiapoi and is a popular area for vehicle use as it is in close proximity of the Waimakariri River mouth (Figure 3). The beach in this area is up to 140 m wide with a 90 m wide intertidal zone. The sediment properties at this beach are similar to the other sand beaches in Pegasus Bay. All experiments were conducted on the ebbing tide on days when the Lyttelton tidal predictions ranged from 0.3 to 0.4 m in the winter and 0.4 to 0.5 m in the summer. A population census confirmed there were more than 10 tuatua individuals per 25 x 25 cm quadrat at this location.

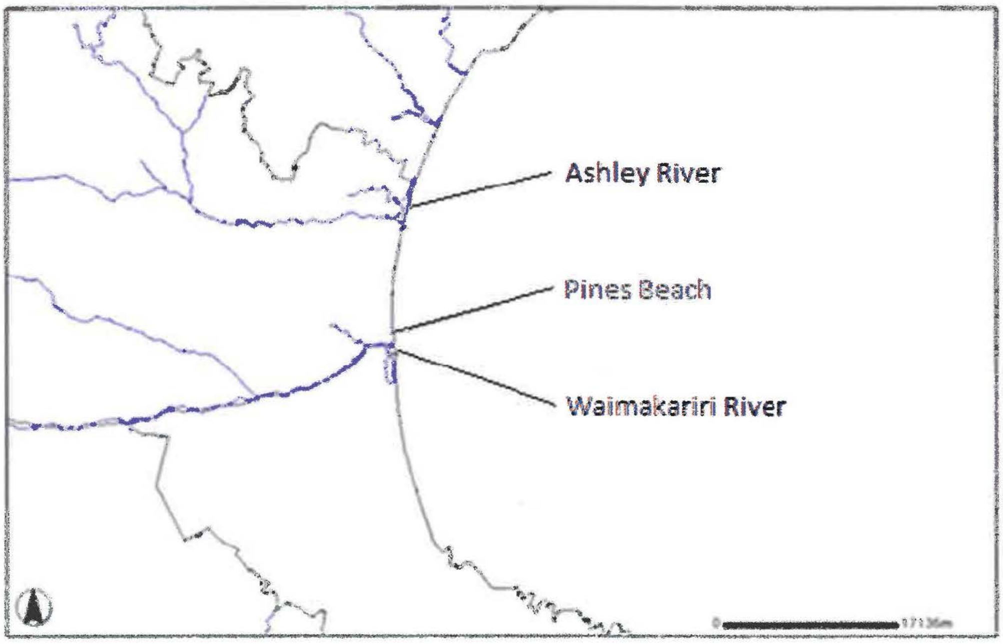


Figure 3: Outline map showing the location of Pines Beach where vehicle impact experiments took place

3.2 Experimental procedures

3.2.1 Vehicle disturbance

A 2008 Mitsubishi Triton fitted with semi-off-road tyres was used for the experiments (Figure 4). It weighed 1955 kg with a full fuel tank and was driven by a driver weighing 85 kg. The pressure exerted by the vehicle was 21,230 kgm^{-2} where

$$P=F/A$$

and F is force of vehicle (kg), A is area of tyre tread (m^2), P is pressure exerted by car tyre (kg/m^2). The exact location on the beach was determined by finding where densities of shellfish were highest. This was done by scraping the sediment surface seaward of the most recent high tide mark. The driving line was marked out where most shellfish were found. The vehicle track was marked by measuring out a 20 m line parallel to and approximately 20 m to 30 m below the last high tide mark. The driver's side tyre was aligned with this line, and was on the landward side in each experiment. The vehicle was driven at speeds between 10-30 kmph north to south until the desired level of passes was reached. Each pass took approximately 30 s to complete. To ensure accuracy, a person was used to guide the driver through the same tracks. The same number of designated passes was completed for each day in both seasons with a control each day of zero passes. This was taken in the undisturbed experimental area before vehicle driving was started.

Figure 4: Photo of the Mitsubishi Triton used for shellfish runover experiments

Table 1: Designated number of vehicle passes on each day of testing

Day	Number of vehicle passes
1	0, 1, 10, 25, 40, 50
2	0, 5, 10, 25, 30, 50
3	0, 1, 20, 30, 40, 50
4	0, 5, 15, 20, 35, 50

After the designated number of passes, tyre treads, shellfish population and sediment pore water levels were measured. Sediment cores were taken as quickly as possible so that water could not re-enter the sample.

3.2.2 Sampling of the disturbed population

A quadrat 625 cm^2 (25 cm x 25 cm) was laid down so that it was in the middle of the tyre track. Sediment within the quadrat was removed carefully to a depth of 15cm to minimise damage to the tuatua. The sediment was sieved through a 5 mm screen with the number of tuatua retained on the screen counted. Quadrats in the driver's side tyre track were sampled before those on the passenger's side track. The shell length of each individual was measured and any damage recorded until at least 15 non-fatally damaged individuals were found.

3.2.3 Sediment samples

Sediment samples were collected from the middle of the driver's (landward) side tyre tracks using a 50 mm diameter corer. This was taken within 10 seconds of the vehicle finishing its passes to ensure that water displaced would not refill the sediment. The sediment sample was bagged, sealed and returned to the lab where it was refrigerated at 4°C before processing. Pore water sample processing entailed breaking the core into three pieces to get an average, measuring the wet weight of the sample, then drying it in a 60°C oven for three days. After three days, samples were removed from the oven and reweighed (dry weight). The difference between the dry and wet weight of the sediment gives the weight of pore water. The overall pore water content was calculated as a percentage of the wet weight and recorded.

3.2.4 Tyre tracks

Tyre tracks were measured for each level of vehicle passes to give an indirect measurement sediment compaction. The width and depth of tyre treads on each side of the vehicle were measured in the same area of the tracks at each time. Tyre track width was measured from the widest part of the tread. Tyre track depth was measured by placing a ruler over the tyre tracks which was assumed to be the original ground level then a ruler was used to measure from the middle of the base of the tyre track up to the flat object. These measurements were then recorded for each tyre track (landward and seaward) (Figure 5).

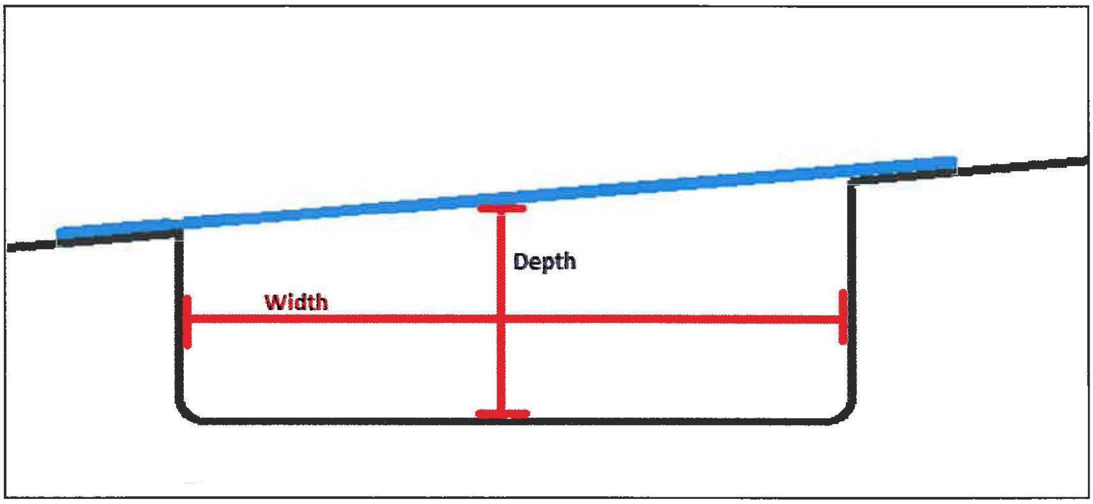


Figure 5: Measuring tyre track depth (in mm) and width (in mm)

3.2.5 Reburial testing

The 15 individuals picked for the reburial test were those that appeared undamaged, i.e. there were no cracked or slipped shells. They were placed in a plastic container that contained 5cm depth sediment from the area that individuals were collected and seawater to a depth of 5 cm. Individuals were placed on the sediment surface so that they were lying on their side (horizontal axis). Timing for reburial success started when all individuals were on top of the sediment surface. At the end of each minute for 15 minutes, the numbers of individuals remaining on the surface were counted and recorded. An individual was considered to be buried when it was completely in the sediment, or only the siphons could be seen protruding.

The bivalves were then kept in a laboratory refrigerator in containers of sediment and fresh seawater at 15°C and were retested for burial 24 hours after they were run over. The method described above was used for this testing.

Figure 6: Field assistant timing and counting individuals that had reburied into the sediment

3.2.6 Data and Statistical Analyses

All data were recorded in Microsoft Excel spreadsheets. Mean and standard error were calculated for each of the replicate samples. Regression analyses were used to investigate relationships between vehicle passes and shellfish mortality, reburial success and tyre track characteristics. Statistical testing was carried out using 'Statistica 7'. Analysis of Covariance (ANCOVA) and tests for homogeneity were used to determine if there were seasonal differences in relationships. The slope of the lines were tested first, if these were the same elevation was tested. If slopes of the lines were different, no further testing was needed because the relationships were different. T-tests were used to determine if there were differences in reburial success after 24 hours.

4 Results

4.1 Tuatua densities and mortality

The tuatua collected on the 5 mm mesh in winter ranged in length from 5- 28 mm with a mean of 15 mm (June, 2010), and in summer ranged in length from 5- 32 mm with a mean of 21 mm (December, 2010). Densities of 17 and 107 individuals per quadrat (272-1712 m^{-2}) occurred in the summer, and 15-87 per quadrat (240-1392 m^{-2}) occurred in the winter.

The most common damage caused by vehicles was a slipped shell for the larger individuals, and the smaller individuals had broken shells (Figure 7).

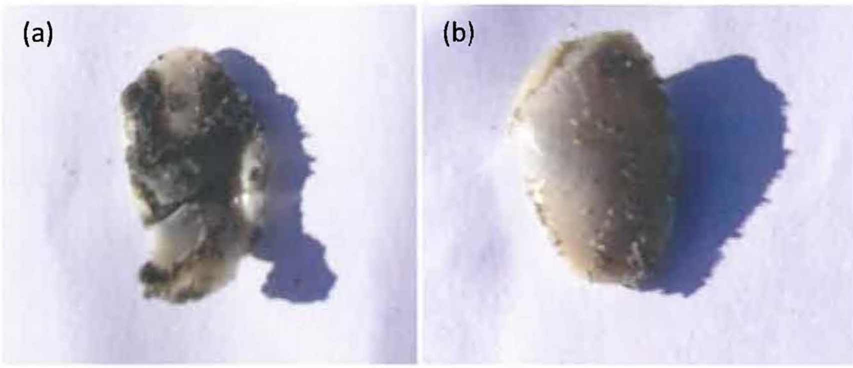


Figure 7: Photos of the two common fatal damages caused by vehicles, (a) broken shell (b) slipped shell

4.2 Effects of vehicle passes on shellfish mortality

The percent mortality after 50 passes ranged from 2.3% to 20% in the summer and 13.5% to 29.8% in the winter (Figure 8). Tuatua mortalities were variable in both seasons, but individuals of all lengths were affected except from those of shell length 5 to 7 mm. Mortality rates were the same in both summer and winter ANCOVA, F- slope $(1,45) = 0.313$, $p<0.579$; F-level $(1, 45) = 3.008$, $p<0.09$). The overall rate of increase in shellfish mortality was 0.27% per vehicle pass (line equation: $y=0.27x + 4.79$, $R= 0.58$, $p<0.001$).

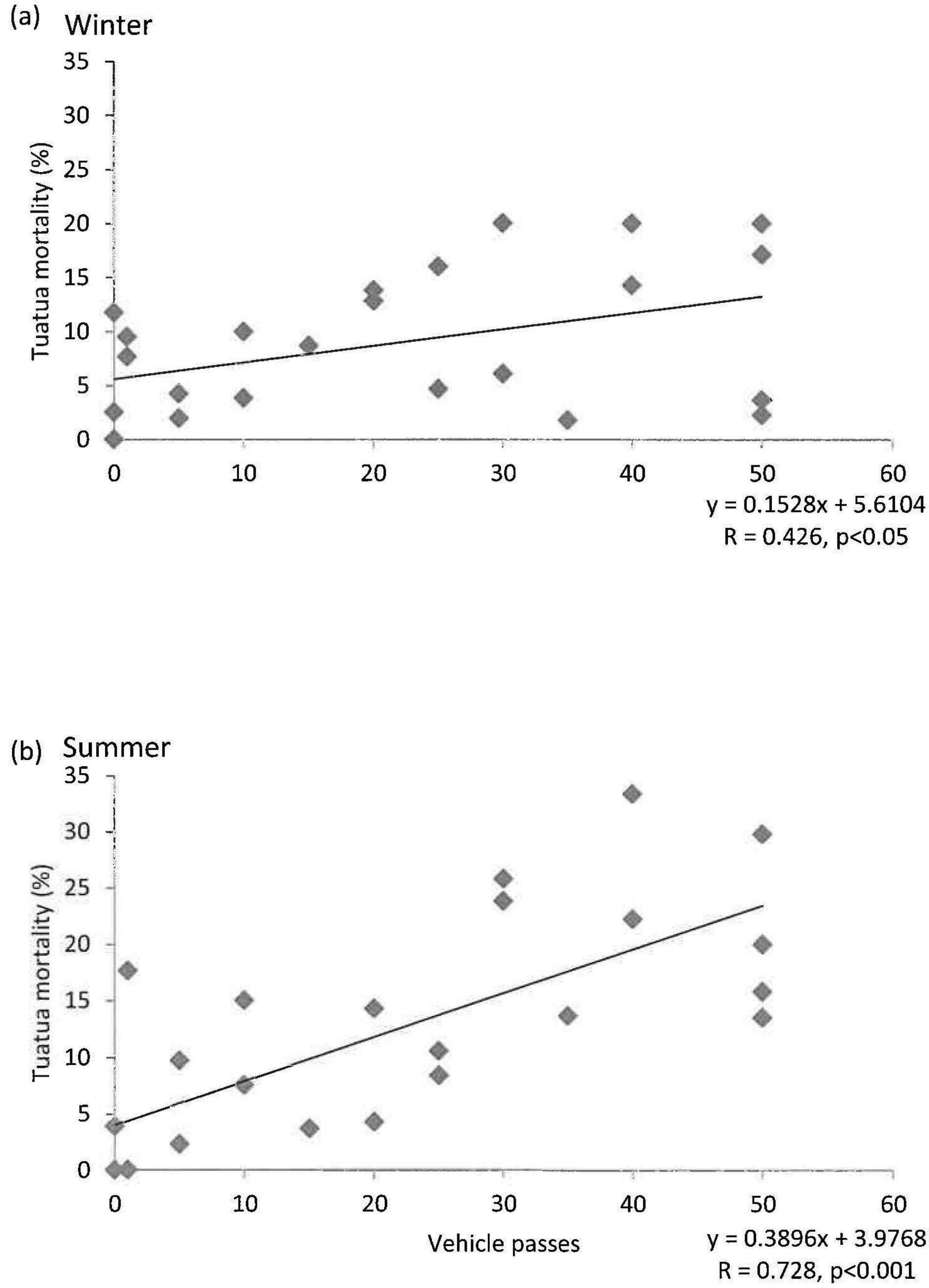


Figure 8: The relationship between vehicle passes and individual tuatua mortalities in (a) winter (June, 2010), and (b) summer (December, 2010). Also included are the regression equation, correlation coefficient R and probability p

4.3 Reburial

The results from this study were variable with 26.7% to 93.3% of individuals re-burying successfully after exposure to 50 vehicle passes. In summer there was a statistically significant negative relationship between number of vehicle passes and percentage reburial immediately after the vehicles passes ($p<0.001$). This could be due to individuals being more active and so exhibit faster reactions (e.g. reburying faster). There was no relationship in winter (Figure 9). There was a seasonal difference in reburial (ANCOVA, F-Rate $(1, 45) = 2.987$, $p<0.001$).

Reburial success after 24 hours had a negative relationship with increased vehicle passes for the summer ($p<0.05$), but not in the winter (Figure 9). This relationship was significantly different between the winter and summer (F-Rate $(1, 45) = 6.5176$, $p<0.014$). There was no significant difference between winter and summer average reburial success after 24 hours (Figure 10). Reburial success after 24hours higher than immediately tested individuals in the winter (t test: $t(23) =-3.823$, $p<0.001$), but not significantly different in the summer (t test: $t(23) =1.531$, $p<0.139$).

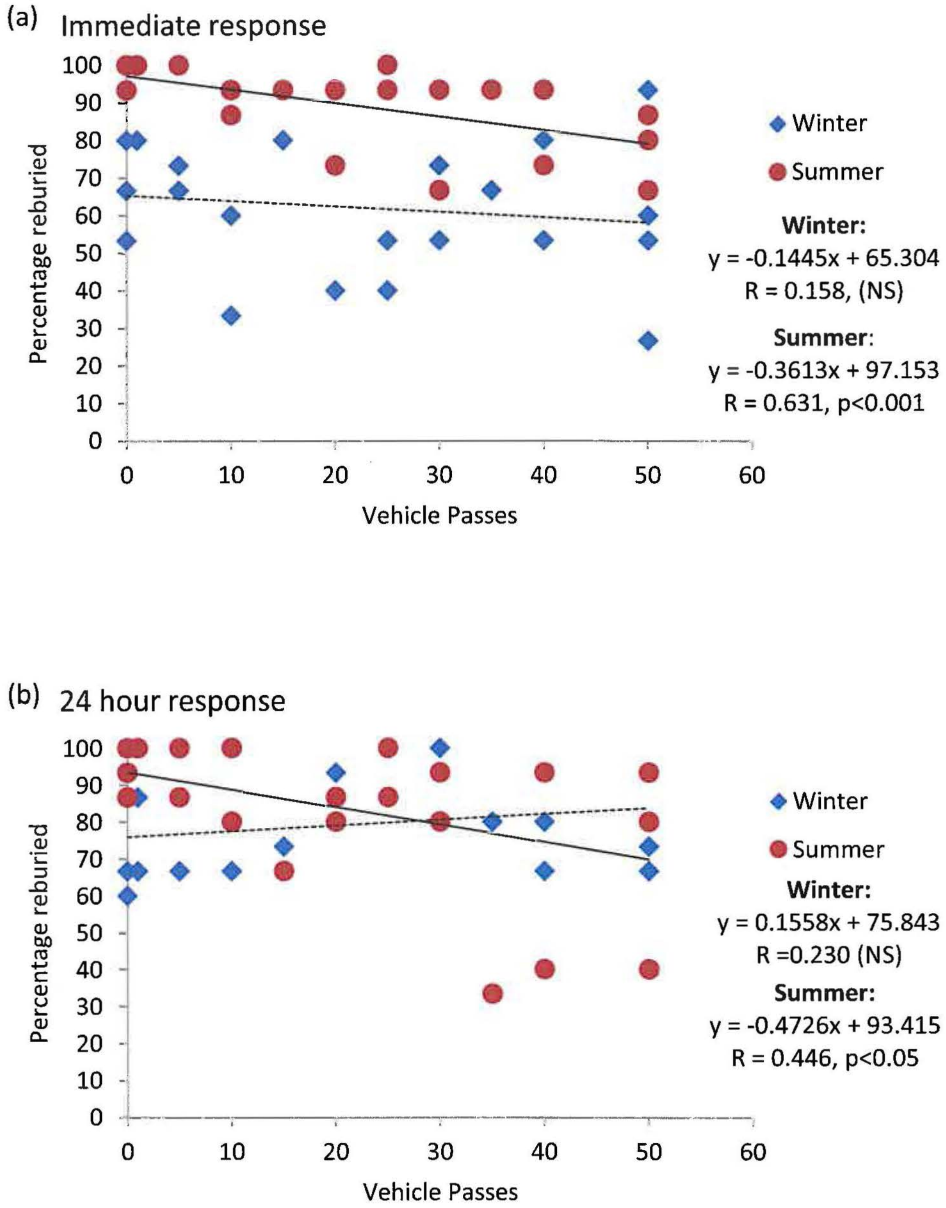


Figure 9: The relationship between percentage of tuatua reburied (a) immediately and (b) 24 hours after each number of vehicle passes in the winter (June) and summer (December) of 2010. Also included are the regression equation, correlation coefficient R and probability p. NS= null relationship

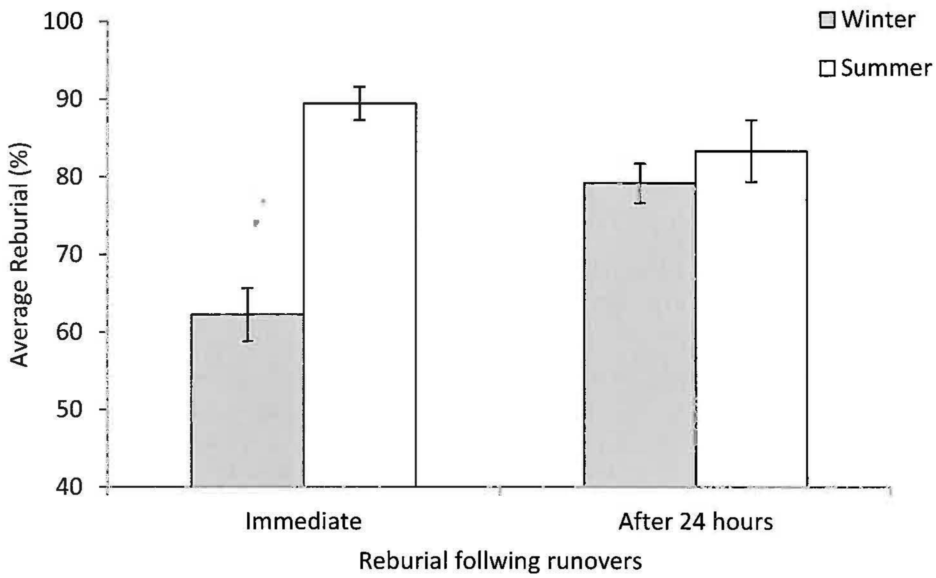


Figure 10: The average reburial percentage immediately and 24 hours after being runover in winter and summer of 2010

4.4 Tyre tracks

Sediment displacement caused by vehicle tyres followed a log pattern (Figure 11). This showed that as passes increased, sediment became more compacted. This was up to 30 passes then the rate decreased. There was no significant difference to the pattern between seasons (ANCOVA, F-slope $(1, 45) = 0.860$, $p=0.360$; F-elevation$(1,45)= 3.008$, $p<0.090$).

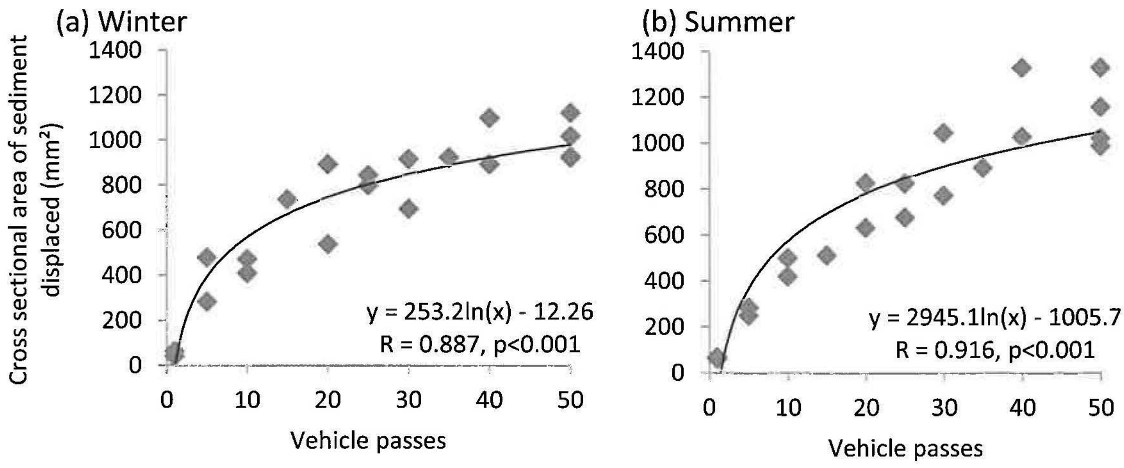


Figure 11: The relationship between the number of vehicle passes and cross sectional area of sediment displaced in (a) winter and (b) summer. Also included are the regression equation, the correlation coefficient R and probability p

A positive correlation was found between sediment displacement and tuatua mortality ($p<0.001$) (Figure 12). There was no significant difference in sediment displacement between winter and summer experiments (ANCOVA, F-slope $(1,36) = 0.033$, $p<0.857$; F-elevation$(1,36)= 0.020$, $p<0.887$).

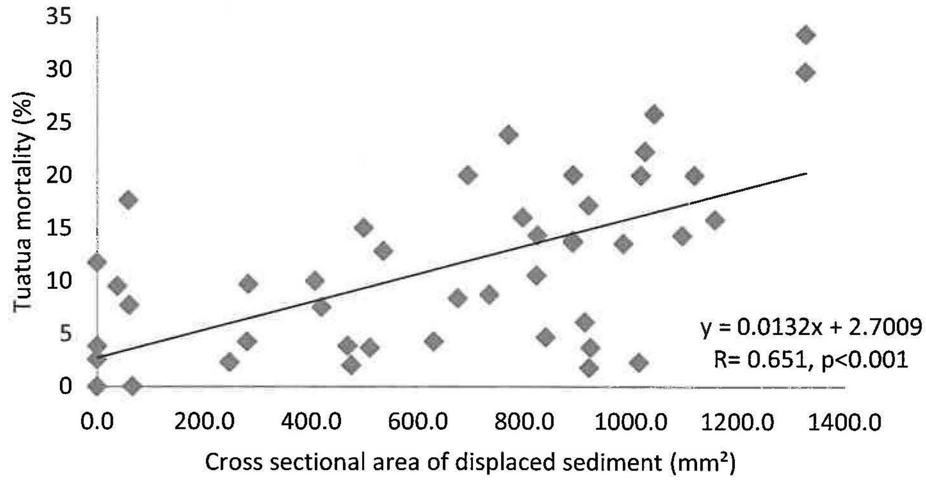
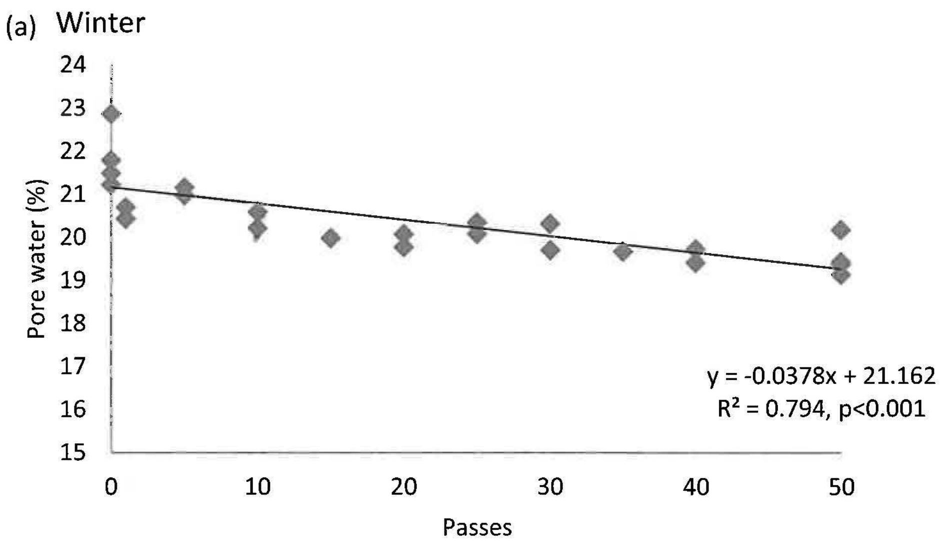


Figure 12: The relationship between sediment displacement and tuatua mortality. Also included are the regression equation, correlation coefficient R and probability p

4.5 Pore water

As the number of vehicle passes increased, pore water percentage decreased in both the summer and winter. The percentage pore water between winter and summer experiments were significantly different, with more pore water in the summer than the winter (ANCOVA, F-slope $(1,44)= 1.44$, $p<0.237$; F-elevation $(1,44)=36.39$, $p<0.001$).



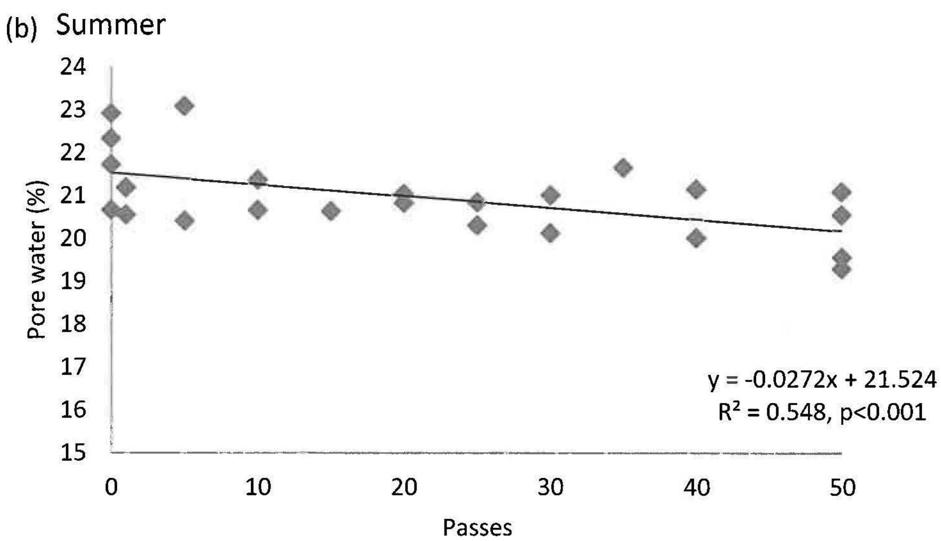


Figure 14: The relationship between pore water percentage and vehicle passes during (a) winter, and (b) summer of 2010. Also included are the regression equation, correlation coefficient R and probability p.

5 Discussion

Juvenile tuatua (*Paphies donacina*) in the intertidal of a Pegasus bay surf beach where vehicles are driven were detrimentally affected. Schlacher *et al.* (2008a) also had similar findings in North Stradbroke Island, Australia, using *Donax deltoides*. The percent mortalities of *P. donacina* in the present study were similar to Schlacher *et al.* (2008a), although the damage rate for *P. donacina* was slightly higher (0.27) than the reported 0.16 for *D. Deltoides* as found by Schlacher *et al.* (2008a). The levels of mortality reported in the present study were variable. This variation is likely to be due to factors including sediment properties, burial depth and the size and condition of shellfish. Burial depth could vary on a day-to-day basis because shellfish migrate up and down the beach with the tide.

5.1 Mortality effects

In the present study damage rates were similar to those reported by Marsden and Taylor (2010), and the same relationship was found between sediment displacement and tuatua mortality. Other studies on different species of shellfish have also found a similar relationship. Moller *et al.* (2009) conducted a study on Oreti Beach in Southland on toheroa (*P. ventricosa*) which evaluated the effects of different types of vehicles. That study only used 5 passes, but found that even with this low rate SUV vehicles resulted in 3% damage to toheroa individuals of similar length to the tuatua in the present study. With an average rate of 4.56% damage for 5 passes (SE=1.78), the damage in the present study is comparable to that of other New Zealand-based studies.

Moller *et al.* (2009) methods involved moving individuals to areas they where they were usually not found and this may have influenced the results. For example, the shellfish used in their study may have been in poor condition, may not be the size naturally found, and may have not buried to their normal depths below the sediment surface. If the individual was not buried as deep it would normally it might not be protected from vehicle exposure.

In the present study, tuatua mortality increased linearly as the number of vehicle passes increased, indicating that increased growth in vehicle numbers driving along the beach will exacerbate these effects. Thus, if vehicle numbers stay high over an extended time period, shellfish populations would sustain long-term damage. This could include altering species assemblages and reductions in population size (Schlacher *et al.*, 2008b; Schlacher *et al.*, 2007).

5.2 Reburial

Being able to bury in the sediment is an important adaptation for bivalves that inhabit sand beaches, it protects them from stressors such as desiccation and predation. Being able to rebury when disturbed is just as important for avoiding these stressors. Using reburial success as a measurement of stress is not likely to be a clear indicator especially during times of low activity, such as in the winter months. This is because individuals are not as active so the rate of response would differ. These sublethal effects were not as easily identified using the methods chosen, but vehicle passes negatively affected reburial success in the summer- the period when tuatua are likely to be more active (Marsden, 1999b).

Sheppard *et al.* (2009) found that after 5 vehicle passes the burial time of *Donax deltoides* doubled. The present study did not find this with burial time averaging 6.64 minutes at zero passes and 6.08 minutes at 50 passes. However, Sheppard *et al.* (2009) used transplanted shellfish which may have affected their results. Nonetheless, this difference may represent species specific differences or an environmental effect such as warmer temperatures. Reburying faster in warm climates is particularly important because the individual will desiccate more quickly if it remains exposed. During winter, desiccation will not be so important as temperatures are lower. Shellfish remain on the sediment surface are prone to predation by shore birds, this will influence the bivalve population size.

Reburial after 24 hours was more successful with on average 79.2% of individuals reburying during the winter testing compared to 62.2% immediately after vehicle passes. Summer results showed no significant difference. The summer sample showed a slight decrease in reburial after 24 hours (immediate= 89.4%, after 24 hours= 85.3%) which could have been caused by the laboratory temperatures being lower than the outside temperature. This could cause shellfish activity to decrease slightly. This response may be as a consequence of individuals being kept in a laboratory 15 °C fridge for 24 hours. The temperature would have been higher than the natural night time temperature in June, and may have allowed the bivalves to become more active.

5.3 Sediment properties

Sediment pore water was similar in the winter and summer, with average pore water being 21.84% (SE=0.36) and 21.89% (SE=0.48) respectively. In the present experiments, changes in pore water are unlikely to influence shellfish survival because the reduction observed was a fraction of a percent and water refills the sediment within minutes of being disturbed. As the sediment became more compacted, the displacement in the tyre tracks changed less, but pore water percentage reduced linearly.

There was a positive relationship between sediment displacement and tuatua mortality, i.e. the amount of sediment volume a tyre displaces influences mortality rates; therefore, harder sediment would be likely to provide more protection. This was shown by Schlacher *et al.* (2008a), who showed that there were increased mortalities due to vehicle runovers in softer sediment when compared with medium compacted sediment.

In the present study, tyre tread depth increased less after compaction had reached 30 mm in depth, so tuatua buried below this would be less likely to suffer lethal damage. However, if a vehicle had off-road tyres tyres which dug into the sediment, it would be expected that more damage would occur as more sediment would be displaced. Schlacher *et al's.* findings (2008a) also support this idea because there were higher levels of mortality for shellfish in the vehicles turning circles, where the tyres had loosened the sediment.

5.4 Research implications

This study has shown that vehicles driven on sand beaches have immediate detrimental effects on intertidal tuatua in Pegasus Bay, Canterbury. The results may also be applied to other New Zealand sand beaches and species of shellfish, depending on the environmental characteristics of the beach. The other species of shellfish would need to be similar in size, morphology and burial depth to the individuals tested. The North Island tuatua (*Paphies subtriangulata*) has an almost identical morphology and distribution in the intertidal zone of sand beaches as *P. donacina* (Figure 13) and hence the results from this study could apply to both species. The toheroa (*P. ventricosa*) should also be considered,; however, adults (>80mm) are also found in the intertidal zone (Morton & Miller, 1973) and so experiments would need to be undertaken to quantify the effects of vehicles on larger individuals.

The damage rate could also be used to determine the amount of mortality that would occur over a defined time period. Other factors would need to be taken into account for this assessment such as the distribution of the shellfish and frequency of vehicle disturbance. Overall, this could give predictions of the impacts of these users.

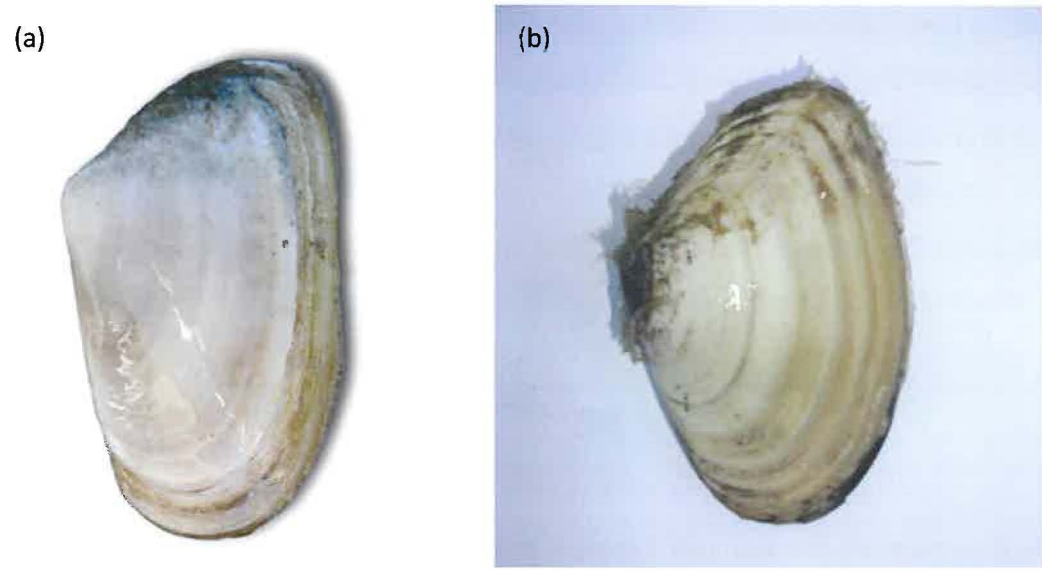


Figure 15: Photos of (a) North Island tuatua (*Paphies subtriangulata*), and (b) Southern tuatua (*P. donacina*). (Image a courtesy of NIWA)

5.5 Management recommendations

There is no current method of controlling vehicles on beaches in Pegasus Bay except for limiting where they can go. This also involves confinement to the intertidal zone where juvenile shellfish and other intertidal animals are vulnerable. In areas where vehicles are permitted, there is no control except near the Ashley River mouth. If protection of these bivalves is to be ensured, changes to this management method are required. Excluding vehicles from the intertidal zone, and the rest of the beach face, would be the most desirable option. This would allow all communities in the ecosystem to inhabit areas without vehicle disturbance. South Africa is one country where a complete ban of vehicles on beaches has occurred; however, there are exemptions that can be granted where necessary (Full 4x4 Regulations, 2004). Enforcement would be required and many regions of New Zealand may be unable to afford the costs of enforcement over large expanses of coast. However, this could be recouped by reducing the costs associated with construction and maintenance of infrastructure which allow activities to occur.

If driving vehicles is to continue on New Zealand's beaches, mitigation is needed to reduce the detrimental effects on ecosystems. Management authorities have successfully prevented dune erosion and damage to bird nests by confining vehicles to the intertidal zone; however, there are several improvements than can be made. Reducing the impact of disturbance is required if ecological protection is to improve in the presence of vehicles. If management authorities have sufficient funding, the most desirable option would be to confine vehicles to set paths above the Mean High Water Spring level (MHWS). This would reduce the area of impact whilst still allowing access along the beach. Birds would be mostly protected apart from in the paths; however, the high vehicle traffic in this area would deter birds from nesting. This method of management is used in Cape Cod, USA, and only allows vehicles on the intertidal zone if the track is cut off (National Park Service, 2011).

The hard sand of the intertidal zone makes it a highly desirable part of the beach for vehicle drivers, so if this is to continue, mitigation is needed. Options include; driving in the same tracks as other vehicles and/or reducing vehicle numbers. Driving in the same tracks would reduce the area of disturbance and impact a smaller percentage of the population. The present study found a shellfish mortality rate of 0.27% per vehicle pass. If vehicles follow the same track they would be continuing to apply pressure on the surviving individuals, but the overall impact would be less than in a previously undisturbed area. Thus, fewer individual tuatua would be affected than if vehicles were to make new tracks. The linear increase in mortality shows that there is no maximum damage reached within 50 passes. Marsden and Taylor (2010) found this at up to 100 passes, so it would be recommended that the number of vehicles would be limited to reduce the daily impact. This would require a permit, which would incur a cost to the council to carry out administration of these. These costs could be covered by payment systems for permits. For example, Cape Cod, USA, charges $150 for an annual permit or $50 for 7 day permits, which would help to recover costs and deter unnecessary driving.

6 Further research

Further research is needed to test vehicles and other heavy impact activities to prevent further damage to intertidal organisms of New Zealand's sand beaches. Other species of shellfish need to be tested due to their differing dispersal patterns on the beaches. This would include toheroa which is of most concern because of its small population remaining. Organisms such as polychaetes and sand hoppers could also be evaluated because they are important organisms in the ecosystem where they form a significant food source for carnivorous animals such as fish. The level (e.g. individual, population, community) at which the impacts would occur also need to be evaluated to determine the level of protection that is needed. Management methods need to be devised which aim to prevent further ecological damage occurring, and this would be evaluated by ongoing monitoring after implementation.

7 Conclusions

This study clearly showed that vehicles cause detrimental damage to tuatua (*P. donacina*). The mortality levels recorded here were similar to those found in other studies using similar methods and species (e.g. Sheppard *et al.*, 2009; Moller *et al.*, 2010). There was no significant difference in the seasonal rates of mortality. Sediment properties influenced the results of the study with higher mortalities found when more sediment was displaced. Results of this study can be applied to other shellfish species, especially the North Island tuatua (*P. subtriangulata*) whose morphology and distribution is similar to that of *P. donacina*. Management options to mitigate damage include reducing vehicle numbers and driving in the same tracks; although, removing vehicles from the intertidal zone all together would be the most ecologically preferable option. Complete banning of vehicles would be the most ecologically beneficial option.

Acknowledgements

We thank Lesley Bolton-Ritchie, Rob Gerard, and David Owen of Environment Canterbury for their consultation, funding and provision of resources.

Thank you to our enthusiastic field assistants, Michael Steenson and Emma Thomas, for their help during the study, and Jan MacKenzie for assistance locating equipment.

References

Cranfield, H.J., Michael, K.P., Dunn, A. (2002). The distribution, abundance, and size of tuatua (*Paphies donacina*) on New Brighton Beach, Christchurch, in 2001. New Zealand Fisheries Assessment Report 2002/5, 24pp.

Dame, R.F. (1993). *Bivalve filter feeders in estuarine and coastal ecosystem processes.* NATO ASI series, *33*. Springer-Verlag. Berlin Heidelberg, Germany.

Gosling, E. (2003). *Bivalve molluscs: biology, ecology and culture.* Fishing New Books, Blackwell Publishing, Oxford, England.

Hart D.E., Marsden I.D., & Francis M. (2008). Coastal Systems. In: Winterbourne, M., Knox, G.A., Marsden, I.D., Burrows, C. (eds.) *Natural History of Canterbury (3rd ed.)* (pp 653–684). Canterbury University Press.

Kingett Mitchell Limited. (2003). Fisheries resources of Pegasus Bay 28pp.

Marsden, I.D. (1999a). Reproductive cycles of the surf beach clam *Paphies donacina* (Spengler, 1793) from New Zealand. *Journal of Shellfish Research, 18 (2)*: 539-546.

Marsden, I.D. (1999b). Respiration and feeding of the surf clam *Paphies donacina* from New Zealand. *Hydrobiologia, 405*: 199-188.

Marsden, I.D. (2002). Recruitment in the swash zone - Temporal variations in juvenile recruitment of an exposed sand beach surf clam. *Hydrobiologia, 477*: 47-57.

Marsden, I.D. (2010). Assessment of intertidal tuatua on Pegasus Bay surf beaches. *University of Canterbury: Estuarine research report 39*. 36pp.

Marsden, I.D., & Taylor, G.F. (2010). Impacts of vehicles on juvenile tuatua, *Paphies donacina*, on Pegasus Bay surf beaches. *University of Canterbury: Estuarine Research Report 38*. 28pp

Ministry of Fisheries (2012). Retrieved March 27, 2012, from http://www.fish.govt.nz/en-nz/Recreational/Most+Popular+Species/Fish+Identification/S+-+Z/Toheroa.htm?wbc_purpose=Basic&WBCMODE=PresentationUnpublished+++++++&MSHiC=65001&L=10&W=toheroa%20&Pre=%3Cspan%20class%3d'SearchHighlight'%3E&Post=%3C/span%3E

Moller J.S., Moller S.I., Futter J.M., Moller J.A., Harvey J.P., White H.A., Stirling F.F., Moller H. (2009). Potential impacts of vehicle traffic on recruitment of Toheroa (*Paphies ventricosa*) on Oreti Beach, Southland, New Zealand. *He Kōhinga Rangahau* No. 5. 61pp.

Morton, J.E., & Miller, M.C. (1973). *The New Zealand Seashore (2nd Ed.)*. Glasgow, Great Britain: William Collins Sons and Co. Ltd. 652pp.

National Park Service (2011) Viewed 5/07/2011- http://www.nps.gov/caco/cape-cod-national-seashore-oversand-beach-driving.htm

Schlacher, T.A., & Lucrezi, S. (2010). Compression of home ranges in ghost crabs on sandy beaches impacted by vehicle traffic. *Marine Biology, 157:* 2467-2474.

Schlacher, T.A., Richardson, D., & McLean, I. (2008b). Impacts of off-road vehicles (ORVs) on macrobenthic assemblages on sandy Beaches. *Environmental Management, 41:* 878-892.

Schlacher, T.A., Thompson, L., Price, S. (2007). Vehicle versus conservation of invertebrates on sandy beaches: mortalities inflicted by off-road vehicles on ghost crabs. *Marine Ecology, 28*: 354-367.

Schlacher, T.A., Thompson, L.M.C., & Walker, S.J. (2008a). Mortalities caused by off-road vehicles (ORVs) to a key member of sandy beach assemblages, the surf clam *Donax deltoids. Hydrobiologia, 610*: 345-350.

Sheppard, N., Pitt, K.A., & Schlacher, T.A. (2009). Sub-lethal effects of off-road vehicles (ORVs) on surf clams on sandy beaches. *Journal of Experimental Marine Biology and Ecology, 380*: 113-118.

Vaughn, C.C., and Hakenkamp, C.C. (2001). The functional role of burrowing bivalves in freshwater ecosystems. *Freshwater Biology, 46*: 1431-1446.

Williams, B.G. (1969) The rhythmic activity of *Hemigrapsus edwardsi* (Hilgendorf). *Journal of Experimental Marine Biology and Ecology, 3*: 215-223.

University of Canterbury
Te Whare Wānanga o Waitaha
Private Bag 4800, Christchurch 8020, New Zealand
Tel: 3667001, Fax: 364 2999
www.canterbury.ac.nz