Estuarine Research Report 38

Impacts of Vehicles on Junvenile Tuatua, *Pahies donacina* on Pegasus Bay Surf Beaches

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Executive Summary

A field experiment was undertaken during January 2010 to investigate the effects of driving an off-road vehicle (ORV) a Holden Rodeo on intertidal shellfish *Paphies donacina* (tuatua) on the exposed surf beach adjacent to Bottle Lake Forest Park, Pegasus Bay. Ongoing beach sampling had found densities of juveniles greater than 100 per m^2 close to the most recent drift line. Markers were used to plot a 20m long x 5m wide area of beach parallel to the water line. Seaward of this, a wider zone was used for turning the vehicle. The beach locations were recorded using GPS co-ordinates. After preliminary trials in December, the main experiments were undertaken in January 2010 on 4 separate days. A control (no vehicle traffic) was done at the start of each day and between 3 and 7 passes were done daily using run over frequencies between 5 and 100.

In all 20 trials were undertaken. After each prescribed group of passes, 25cm x 25cm areas were sampled in the upper tyre track. The sand was dug to a depth of 20cm, sieved and all shellfish removed and counted. Tuatua shell length and shell damage were recorded for each individual. The depth and width of the tyre tracks were measured and a core sample collected to measure pore water. Individuals extracted from the sand on the upper wheel tracks were used for a field experiment to determine the ability of tuatua to rebury in 2L experimental chambers, half filled with sand and seawater to a depth of 2cm above the sand. Three replicate experiments, each using 5-8 individuals, placed on the sediment surface, were undertaken over a 15 minute period.

Tuatua between 2 and 27mm length were collected from the tyre tracks. The main damage was shell cracking, shell displacement and crushing of small individuals. Percent damage increased significantly with passover frequency but the results were very variable. No shell damage was recorded on one of the experimental days and shell damage did not correlate with pore-water content of the sediment.

Percent burial of tuatua over a period of 15 minutes decreased with the number of passes (regression analysis $P = <0.05$). The time for reburial ranged between 2 and 7 minutes with an average time of about 4 minutes. Tuatua dislodged onto the sediment surface were unable to rebury and would be exposed to air-drying conditions and potential prey for predators.

Driving on the sand produced wheel tracks which compressed the sand by a similar volume on the drivers and seaward side of the vehicle. Percent shell damage correlated with the pressure exerted by the vehicle on the sand (regression analysis $P<0.01$). Although the number of vehicle passes was a guide to potential tuatua damage, the extent of the damage depended upon the sand structure at the time of impact. Tuatua were more vulnerable to damage when the sediment was loosely rather than heavily compacted and most susceptible within the sediment in extreme wind and drying weather conditions.

It was concluded that the main factors affecting the susceptibility of juvenile tuatua to vehicle passes were body size, the frequency of passes and the sand conditions. Other features likely to be important include the ground pressure exerted by the vehicle and also the level within the intertidal zone where the vehicle is driven. Further research is needed to understand whether the findings reported here apply to other areas and at different times of the year.

1. Introduction

Exposed sand beaches are prominent along the Canterbury coastline and are important ecologically, they have high cultural values and are important for activities such as swimming, shellfish gathering, boating, walking and horse riding. The beaches provide access to vehicles, including off road vehicles, surf kites and motor bikes. Local by-laws permit motor vehicles to be driven along the beach of Pegasus Bay from just north of Spencerville from an access gate at the end of Heyders Road. It excludes a 7km stretch of beach extending from the Woodend Beach access way north up to the Ashley River mouth (RCEP). However this by-law permits vehicle access to fishing sites close to the mouth of the Ashley river within the no-vehicle zone.

The fauna of sand, surf beaches and sand dunes is thought to be impacted by human activities (Ander and Leatherman 1987, Braje et al. 2007, Defeo et al. 2009, Thompson and Schlacher 2009). Schlacher and Dugan (2007) suggest that beach fauna is particularly vulnerable to disturbances. Although there have recently been a number of studies on the potential effects of vehicles on the fauna of sand beaches (see studies by Schlacher and others) very little is known about the potential effects of vehicles on New Zealand's sand-beach fauna. Research from Australia has investigated the effects of vehicles on the damage of a surf clam *Donax deltoides* and reported direct crushing of clam shells (Schlacher et al. 2008). In New Zealand the intertidal sand beach organisms include bivalve shellfish, four species of *Paphies*, cockles, amphipods, isopods and insects.

Along the Pegasus Bay coastline the dominant shellfish species on the surf beach is the southern tuatua *Paphies donacina.* The population distribution and biology of this species in Pegasus bay has been studied over the past 50 years (Dawson 1954, Marsden 1999, 2000, 2002, Cranfield et al. 2002, Kingett Mitchell 2003). Southern tuatua has a smaller maximum shell length than the toheroa *Paphies ventricosa* which is found on Southland beaches. Recent research by Moller et al. (2009) examined the effects of racing bikes and spectator vehicles on toheroa survival and confirmed that significant fatalities occurred as a result of being driven on by a variety of different vehicles.

The study was a joint research project between the University of Canterbury and Environment Canterbury. The aims were, firstly to assess whether driving a vehicle over the tuatua bed damages or kills tuatua, secondly to assess whether the behaviour of the tuatua is affected by the intensity of the exposure and thirdly to identify any factors that influence the effects of vehicle on the tuatua survival.

2. Materials and Methods

Site and vehicle selection

The site selected for the study needed to be representative of the coastal area, with easy access and an area where there were sufficient tuatua to undertake the research. If possible it would be an area where there was likely to be relatively few people. A 3km section of beach seaward of Bottle Lake Forest Park, south of the Waimakariri River was selected. This area usually does not have vehicle access apart from Christchurch City Council workers and fisheries officers. Access was through a padlocked gate which was closed after entry or departure. For all trials the same vehicle was used, an Environment Canterbury 2001 Holden Rodeo double cab model which weighed empty at 2040kg and fitted with semi-off road tyres. The same driver whose weight was 85kg was used each time.

Photo plate 1. Environment Canterbury off-road vehicle used in field experiments

Vehicle experiments

Preliminary trials were undertaken on the 7th and 8th December 2009 to test the methodology, field equipment and devise the protocols for the field and laboratory experiments. A random section of beach was selected where there was tuatua of a sufficient density (>100m^2) to do the experiment. The zone where there was sufficient tuatua was found by surface sediment digging from the most recent high-tide mark towards the low tide. Normally this was about 20m below the most recent high-tide drift line. The exact location was recorded using a Garmin GPS. A 20m length x 5m depth area of beach, running parallel to the ocean and along the zone of the greatest abundance of tuatua was marked out using stakes. Seaward of this zone a further 20 m down the beach was used to return the vehicle to the start of the tyre tracks. In this way any potential damage of the sandflat due to the vehicle turning was minimised (Schlacher at al. 2008). The main experiment was run over four separate days between 9th and 18th January with a control (0 passes) at the start of each day and up to 100 run overs (Table 1) based on previous literature (Schlacher et al. 2008). The number of passes was allocated randomly and the same tyre tracks were used for each consecutive pass driven from north to south through the zone. The vehicle was driven at a at a speed of between 10 and 30 km per hour.

Shellfish Damage

Shellfish were removed from sediment from quadrats, area 25cm x 25cm dug to a depth of 20cm, placed within the upper tyre tracks of the vehicle. The sand was sieved through a 5mm mesh sieve, all the tuatua were removed and placed in a container of seawater. The length of each tuatua was measured using a plastic vernier callipers and extent of damage was noted. This process was repeated using additional quadrats until a minimum number of 15 tuatua had been found. After the sediment had been removed, the holes were filled in using sand from an adjacent area. The location of the removed quadrats was marked to prevent them being resampled following subsequent passes. Only the upper shore tracks of the vehicle were sampled and each quadrat sampled was separated from the others by at least 1m.

Disturbance and Compaction of Surface Sediment

This was assessed before driving over the area (control for that day) and also after each group of completed vehicle passes. During the preliminary sampling an attempt was made to record sand compaction using a cone penetrometer kindly loaned by the School of Engineering. Readings were compared from the undisturbed sandflat and from sand where the vehicle had repeatedly driven over. Although differences were visible by eye, the penetrometer readings were similar. This methodology was therefore abandoned. Compaction was therefore determined by direct measurement of the depth and the width of the vehicle tyre track and by measuring the water content of the sediment. After each completed group of passes, a core (diameter 50mm x 5cm depth) was removed from the wheel track and placed in a sealed 250ml labelled plastic vessel. This was done within 10 seconds of the last completed pass. On the four days of experiment, allotted vehicle passes ranged from 0 (every day) to a maximum of 100 passes (Table 1). The December trial was undertaken during spring tides and the main experiments were done in January during neap tides.

Table 1. Summary of the locations and number of vehicle passes achieved daily in summer (December to January 2010).

Expt	Date	GPS Location	Runovers	Time and (height) of tide and state
Trial	9 Dec 2009	S43°26.951 E172°42.957	0, 20, 100	High 11.10 (2.4). Low 17.28 (0.3) Outgoing
1	11 Jan 2010	S43°26.951 E172°42.957	0, 20, 40, 60, 80	Low 8.29 (0.6). High 14.33 (2.2) Incoming
2	12 Jan 2010	S43°27.026 E172°42.979	0, 10, 70	Low 9.23 (0.6). High 15.24 (2.1) Incoming
3	13 Jan 2010	S43°27.051 E172°42.982	0, 5, 30, 50, 65, 90, 100	Low 0.1 (0.6). High 16.13 (2.1) Incoming
4	18 Jan 2010	S43°26.864 E172°42.959	0, 50, 60, 70, 80	High 7.33 (2.2). Low 13.47 (0.6) Outgoing

The sediment samples were returned to the laboratory and immediately processed to determine the percent pore water. A sand sample, greater than 10gm wet weight was placed in a preweighed porcelain crucible and the wet weight measured to 0.001gms on a top-pan balance. The crucibles and sediment were put into an oven at 60^{o}C and reweighed after drying for 3 days. The weight loss was calculated as pore water (water as a percent of the wet weight of the sediment).

Field reburial experiment

The reburial rates of tuatua collected from the control sediment and after each set of passes were measured in the field using sediment collected from undisturbed sediment at the same tidal level as the experiments using fresh seawater at the same temperature as the seawater. Three replicate 2L containers were half filled with sand and seawater to a depth of 2cm overlaying the sand. Approximately 20 tuatua sieved from the tyre tracks were divided into three approximately even length groups of between 5 and 8 individuals and placed on the sand surface. Totally crushed individuals were not

Photo Plate 2. Research assistant measuring juvenile tuatua and bowl with seawater containing a representative length range of individuals

included. At 1min intervals for a 15-min period, the number of tuatua left on the sand surface of each container was recorded. The process was repeated for each different vehicle passes including the control (0 passes). After 15 min the tuatua were removed from the experimental vessels and placed in a 250ml plastic vessel with undisturbed sediment and brought back to the laboratory for further testing and to record their behaviour and longer term survival.

Data presentation and statistical analyses

Data were compiled in Excel and mean and standard errors calculated for replicate samples. Relationships between tuatua damage, pass frequency and sand characteristics were investigated using regression analyses using a critical value of $P<0.05$.

3. Results

Tuatua damage

The tuatua retained in a 5mm mesh sieve ranged in length between 2mm and 27mm with the average being similar in each of the experimental areas tested. The densities of tuatua in the 25 x 25cm quadrats ranged between 2 and 21 (equivalent to between 32-336 per m^2). For tuatua that were damaged, the most common damage was cracking, however some of the smaller individuals were crushed completely. In some instances the shell of larger juveniles had been distinctly displaced to one side. Tuatua damage was variable between days irrespective of the number of passes.

Effects of pass frequency on tuatua damage

The results from the January trials were grouped together combining the effects of weather, drying and tidal conditions. The percent tuatua damage was variable between 0 and 56% (60 passes) with significantly greater damage with increasing passes (The % damage = 0.206 x N passes +2.83; r = 0.43, P = <0.05, Figure 1.). On day 2, 12th January for the control (0) and after 10 and 70 vehicle passes there was no tuatua damage. These results also illustrate that juvenile tuatua were damaged by as few as 20 vehicle passes.

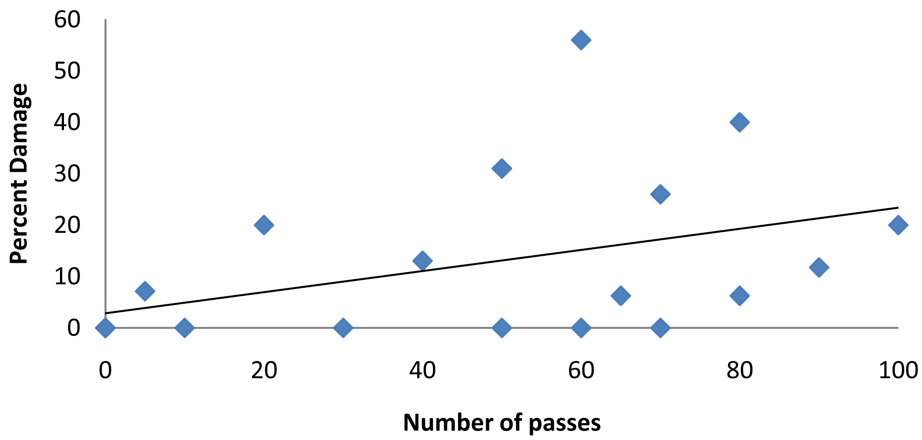


Figure 1. The effects of number of vehicle passes on tuatua damage, January 2010.

Effects of vehicle pass frequency on tuatua reburial

Following removal from the sediment and placing in fresh seawater on the natural sediment surface, the ability of tuatua to burrow depended on damage. Individuals that had been crushed or obviously damaged were unable to burrow and remained on the surface sediment until the end of the 15min exposure time. Although the results were more variable with increasing vehicle passes there was a significant decrease in the burrowing ability with increasing vehicle passes (regression analysis r = 0.49, P <0.05 Figure 2). The response was greatest for experiments done in the 4th trial. For all days the percent burial was similar for up to 40 passes.

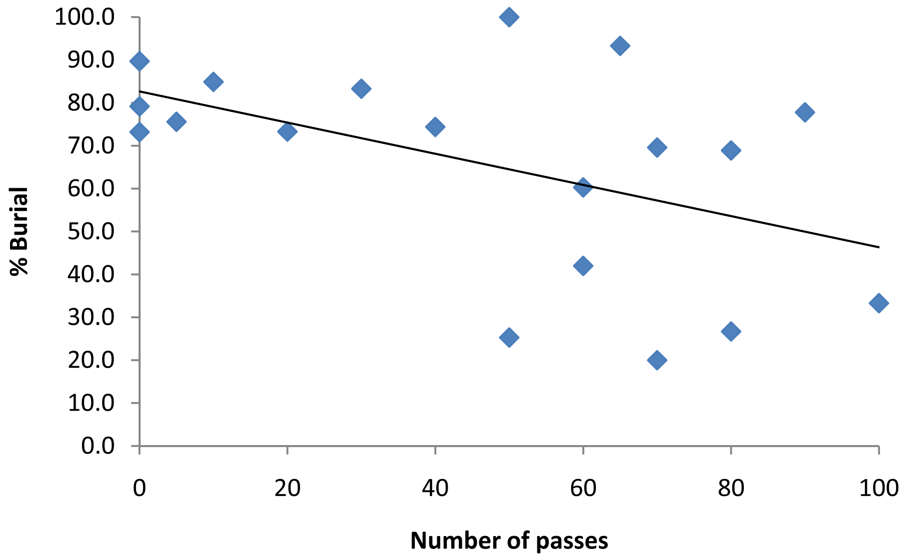


Figure 2. Average percent burial of juvenile tuatua exposed to sets of vehicle passes and then allowed 15 minutes to bury in control sediment from the habitat. Average values from 3 replicates of up to 8 individuals.

Effects of shell length tuatua damage

Tuatua damage was recorded in the preliminary trial, and in three of the four January trials (Figure 3). However, there was greater damage in the 4th trial. The results suggests that the smallest tuatua (5mm shell length or less) were always susceptible to vehicle damage but that individuals of all shell lengths were susceptible to shell damage.

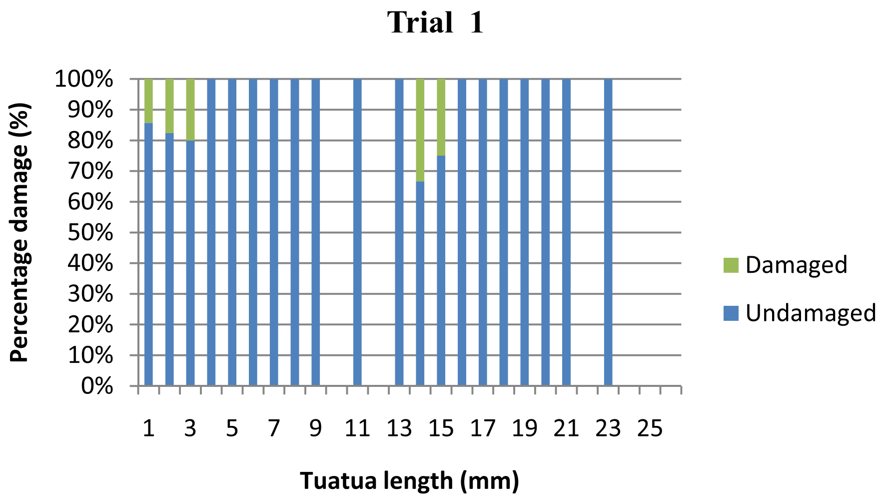


Figure 3. Effects of shell length (mm) on shell damage in tuatua

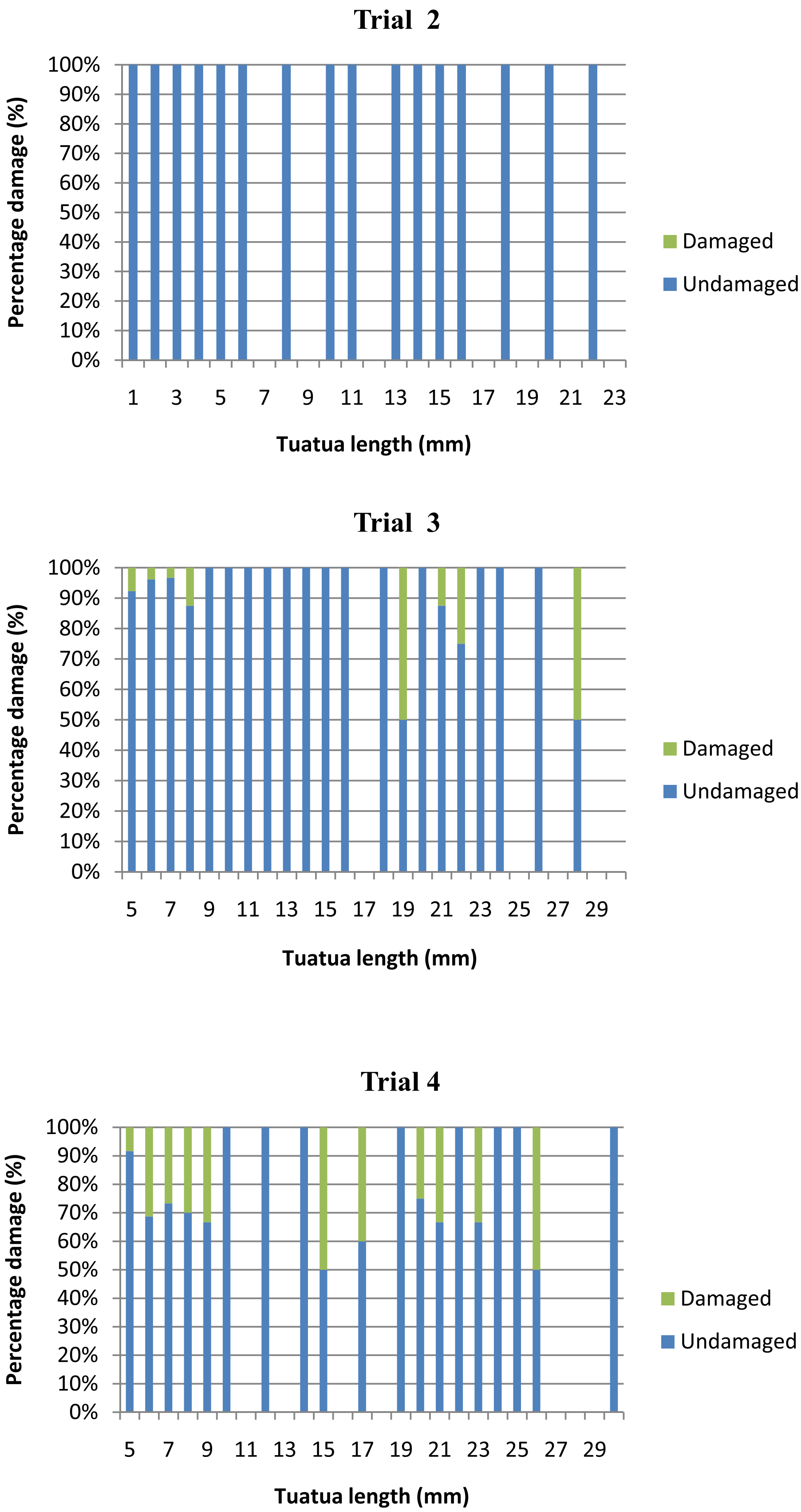
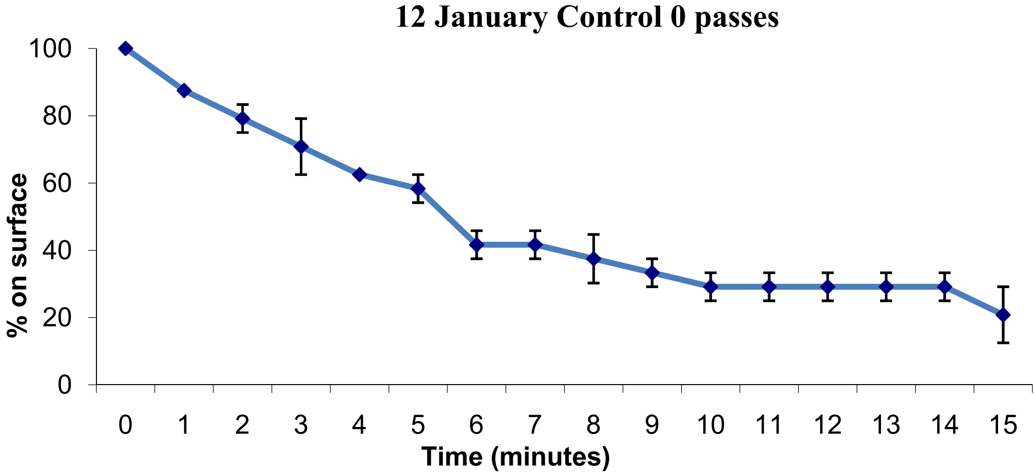


Figure 3. Effects of shell length (mm) on shell damage in tuatua. Note there was no tuatua damage of tuatua in Trial 2 in January.

Effects of time on burrowing activity

Most of the tuatua from controls (without vehicle passes) buried within a few minutes (Figure 4 for a selection of examples). In the vehicle experiments the majority of individuals buried within 7 minutes. In experiments where there was significant damage many individuals failed to burrow (see 100 passes).



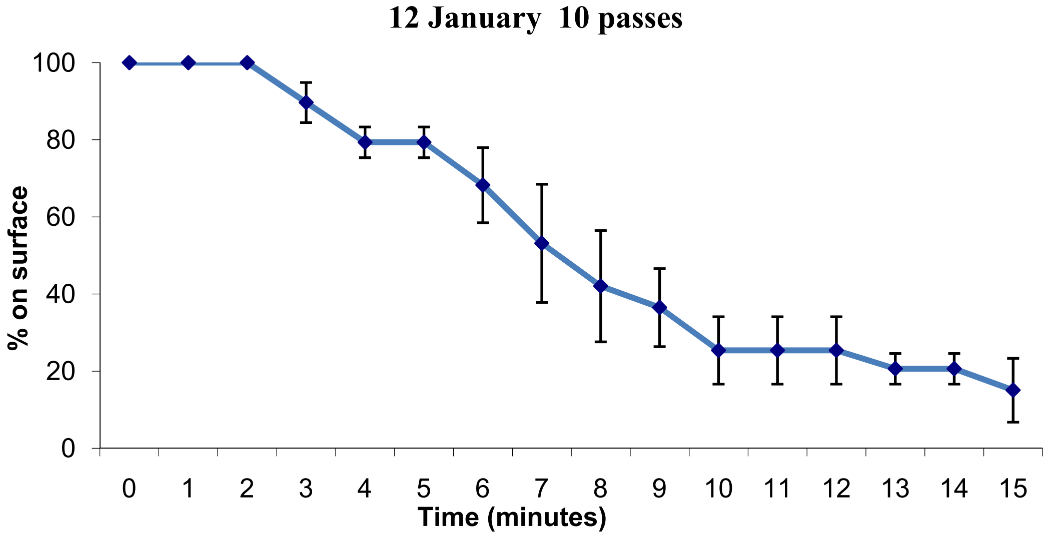


Figure 4. The impacts of the number of vehicle passes on burrowing activity in tuatua over a 15min exposure period.

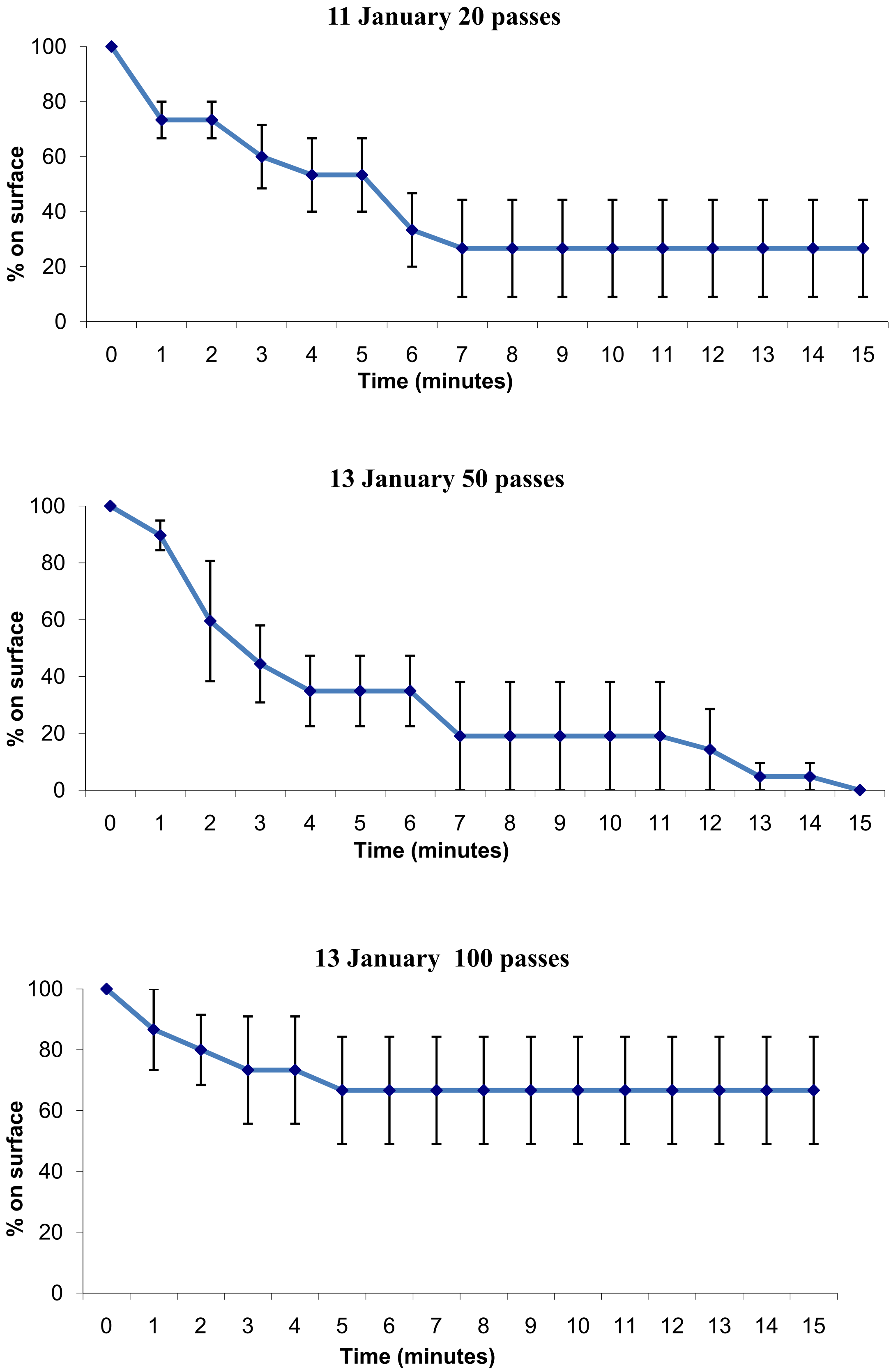


Figure 4. The impacts of the number of vehicle passes on burrowing activity in tuatua over a 15min exposure period.

The average burial time for bivalves in control sediment ranged between 2 and 5 minutes. Burial times for bivalves exposed to the vehicle passes were more variable with average burial times ranging between 2 and seven minutes. In approximately 25% of the reburial trials, less than 50% of tuatua were able to bury within the 15 minutes exposure time (Figure 5) and no LT_{50} could be calculated. For those experiments where little or no damage was recorded the average burial times were similar to control bivalves and close to 4 minutes.

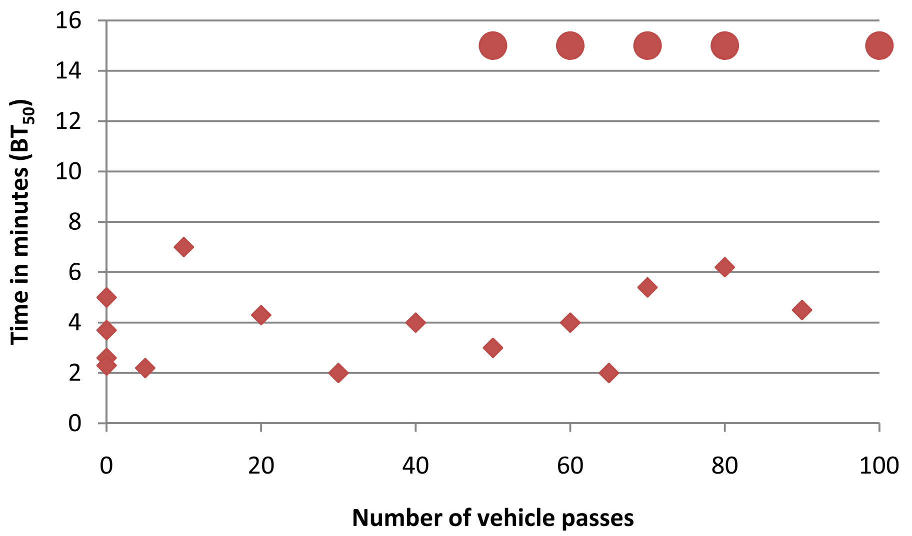


Figure 5. Effects of vehicle passes on tuatua BT_{50} , the burrowing time for 50% burial within 15min. Points at the top of the graph are vehicle passes where greater than 50% of bivalves failed to burrow during the exposure time.

Effects of vehicle pass frequency on sediment properties.

The same vehicle and driver were used in each trial and the sediment percent pore water at the start of the field experiements was similar for the four January trials (20.8, 19.3, 20.1 and 22.0). Generally porewater decreased with increasing runovers (Figure 5) but this was not a significant result for the combined data set (regression analysis r = 0.38, P = .>0.05). The lowest average value for pore water was 14.4%, recording a 4% change after 70 passes on the 12 January.

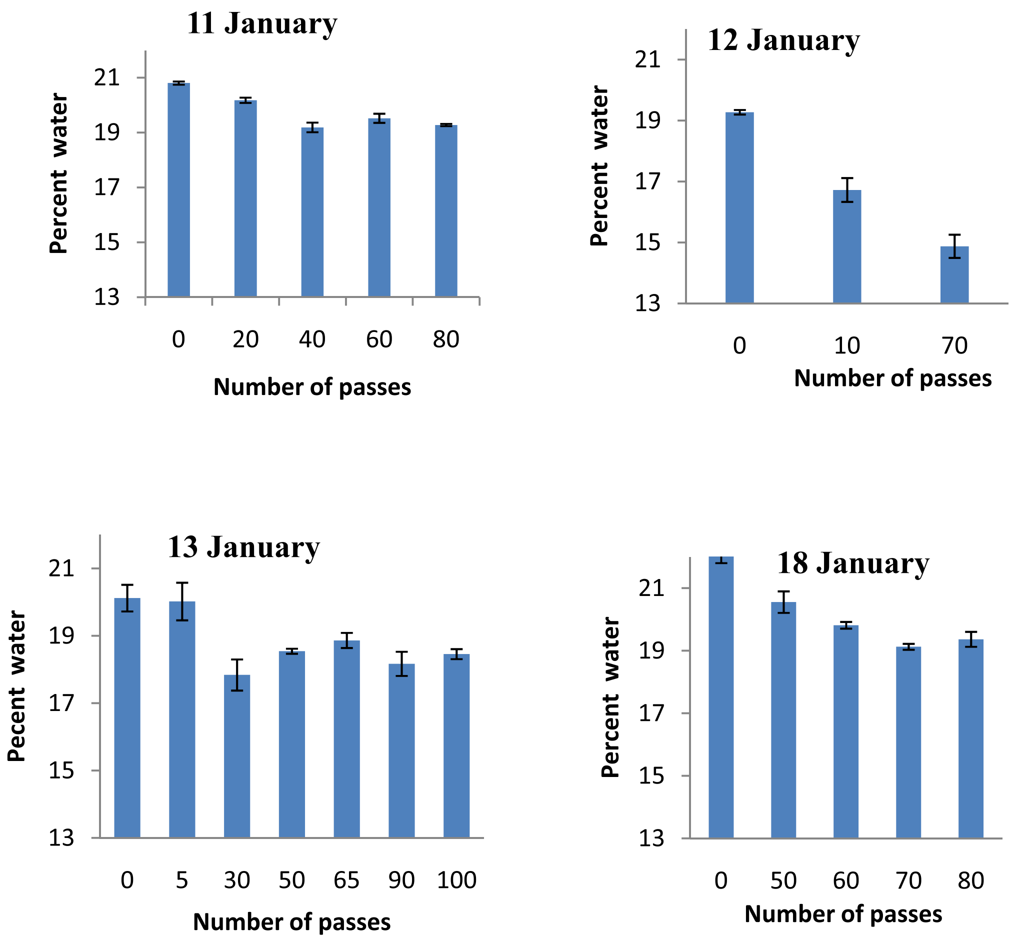


Figure 6. Percent pore water in sediments following different number of vehicle passes.

Photo 3. Researchers following the recovery of the sand surface during tidal inundation.

It was expected that the depth and width of the vehicle track would deepen and widen with an increase in the number of passes and this was the case (Figure 7).

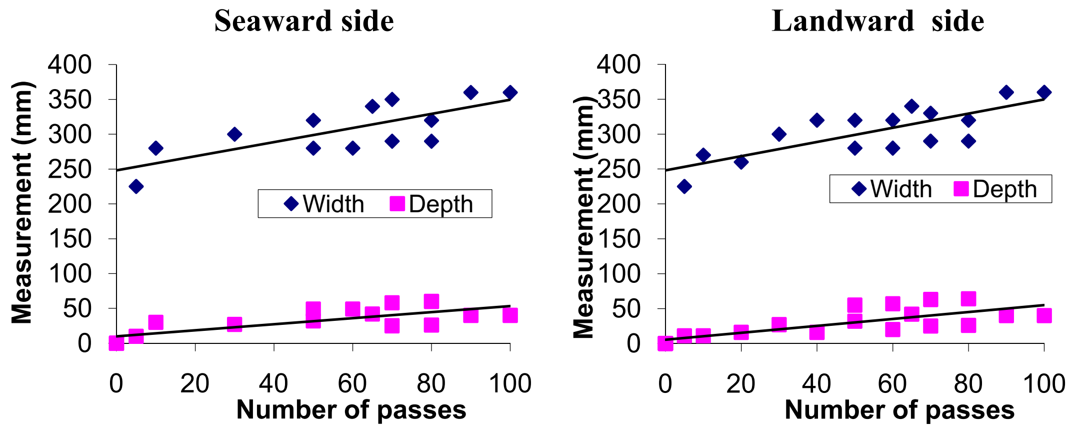


Figure 7. The effects of increasing passes on the depth and width of vehicle tracks. On the seaward side correlation coeficients for width (r) = 0.75 and depth r = 0.76. On the landward side r values for width and depth were 0.78.

With increased number of vehicle passes the volume of sand compressed by the vehicle increased significantly. This occured for the wheel tracks on both the landward side and the seaward side of the vehicle (Figure 8).

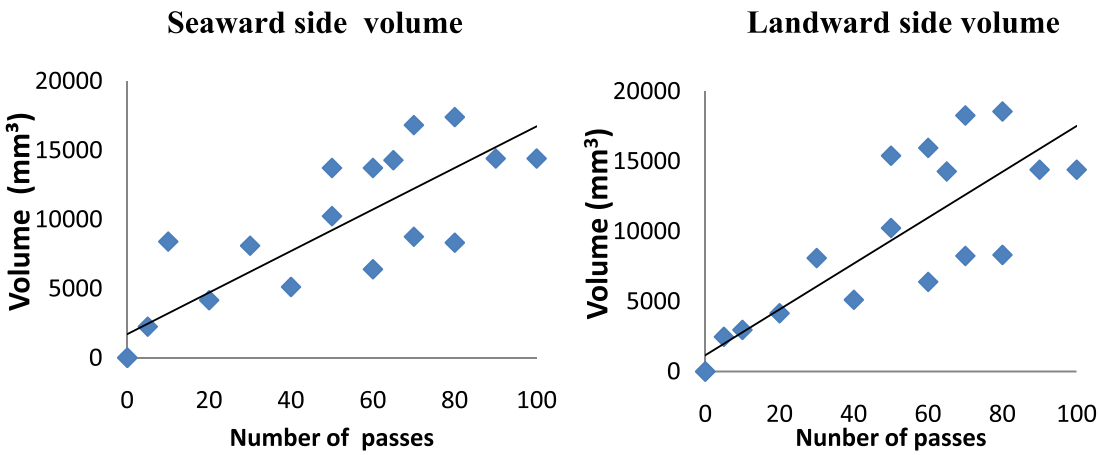


Figure 8. The effect of increasing number of vehicle passes on the volume of sand displaced in seaward and landward wheel tracks, r = 0.85 in both cases.

Relationships between sediment properties and tuatua damage

In the present study it was not possible to get an accurate measurement of sand compaction. However the width and depth of the vehicle tracks and pore water content were used as indirect measures. Damage of juvenile tuatua was not directly related to pore water content (regression analysis P >0.05). However, the percent tuatua damage increased as the volume of sediment displaced by the vehicle increased (Figure 9, r = 0.0.694, P = <0.01). A critical displacement value appeared above 15,000mm^3 beyond which tuatua damage increased markedly. This sediment parameter was the best measure to predict bivalve damage.

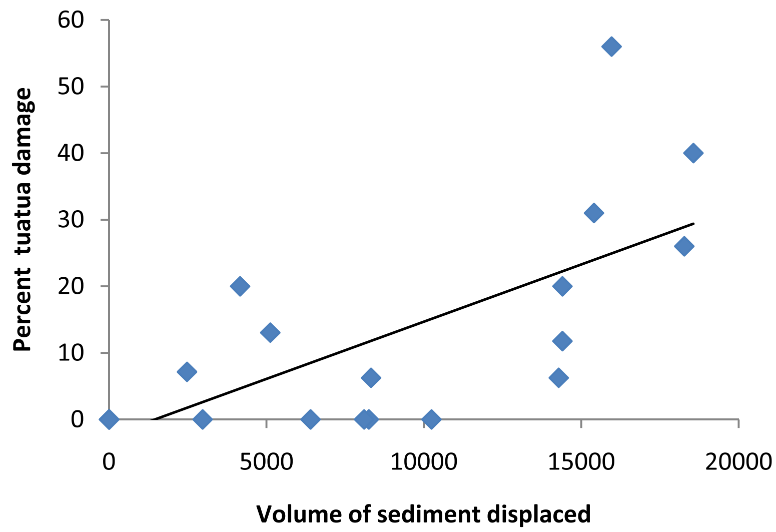


Figure 9. Relationship between percent tuatua damage and the volume of sand displaced by the vehicle.

While undertaking the research we followed the recovery of the sand beach profile during tidal inundation. The tyre tracks were usually undetectable within a few minutes of covering by the intertidal swash, and on the following day there was no evidence of either the tyre tracks or the turning zones used in the experiments.

4. Discussion

Four wheel drive vehicles driven over the exposed sand beach can damage juvenile New Zealand tuatua *Paphies donacina* which are present in densities up to about 300 individuals per m^2. Our research was based on methodologies used by Schlacher et al. (2008) who investigated a similar surf clam, *Donax deltoides,* in Eastern Australia. They found that the percentage of crushed clams increased with the number of vehicle passes and as few as 25 vehicle passes resulted in damage to 18% of the population. In the same study the highest percent of crushed clams was 28% found following 100 vehicle passes. For NZ tuatua from Pegasus Bay there was also a positive relationship with increased vehicle intensity, higher bivalve damage (up to 55%) recorded in experiments with 60 passes and significant (30% or more) damage occurred in approximately a third of the trials with 40 or more vehicle passes. These results confirm the high susceptibility of juvenile tuatua to vehicle traffic.

In a recent study Moller *et al.* (2009) undertook a field experiment on Oreti Beach Southland, on the toheroa *Paphies ventricosa,* using a test car, two utility vehicles and a motorbike. In that study the toheroa had been transplanted into the experimental areas. It was found that driving one of the vehicles just once over a transect in the high tide resulted in 10% mortality whereas driving it five times resulted in 33% of the transplanted toheroa. These data however were not based on a very large sample size. Also, because the toheroa had been collected from the drift and allowed to bury they may not have been in very good physiological condition.

The type of damage caused by the vehicles in Moller *et al.*'s (2009) study was the same as we observed for the southern tuatua, cracking of the shell and crushing. As bivalves grow and increase in shell length their ability to burrow deeper into the sediment increases, together with their burrowing time (McLachlan et al. 1995). Also, it would be expected that larger shells have greater resistance to the pressure exerted by vehicles. Our field experiment confirms that the smallest tuatua were susceptible to direct crushing but that larger tuatua were damaged by cracking. In our experiments the tuatua results may have been influenced by the size of the individual, however this relationship was not able to be tested from the present results. Further laboratory and field experiments are planned to investigate this.

Morphology, temperature and particle size all affect the burrowing ability of clams (Ansell 1983, McLachlan *et al*. 1995, Hull 1998). When displaced from the sediment and covered by seawater surf clams generally rebury quickly. Measurements by McLachlan et al. (1995) suggest that it would take less than 30 seconds for tuatua of the length range found in the present study to rebury. Reburial times in our field experiments were about 4 minutes, approximately eight times slower than previous records. However, because burial times for tuatua from the controls were similar to some of those exposed to vehicle passes, this difference cannot be attributed to vehicle pressure. It most likely represents the impaired ability of this species to burrow following aerial exposure within the sediment. Vehicle pressure significantly decreased the proportion of tuatua that were able to rebury within 15 minutes when covered by seawater. It is not known if this impairment of burrowing activity was permanent or if tuatua would be able to burrow if given time. Laboratory testing (not included in this report) will provide additional information on repeated burial activity and survival after 24h of submergence. Sheppard et al. (2009) measured the burrowing ability of transplanted *Donax deltoides* on eastern Australia sandy shores. They found that burrowing time for clams that had been driven over 30 times by a Toyota Hilux was more than twice as long (23 minutes) as control treatments (8-10 minutes) and also found that the time to start burrowing increased with the number of passes. Such differences were not obvious in tuatua in our experiments.

We noted that bivalves sieved from the sediment and then placed on the sand surface without seawater did not re bury. In order to burrow bivalves need to open their shell valves, take in water and inflate their foot. When buried within the sediment they most likely are closed tightly to minimise water loss when the tide goes out. If suddenly they were displaced from the sediment in air they would be exposed to increased temperatures, drying conditions and bird predators. Once covered by the tide the slow reburial time would make them easily available food for predators such as paddle crabs and fish.

The susceptibility of bivalves to vehicles on sand beaches may depend on sediment characteristics including compactness. In their study Schlacher et al.(2008) found that there was higher clam mortality in soft rather than hard compacted sediment, which had a lower water content. Compactness was not measured directly in the present study, however it was represented by the displacement volume of the tyre tracks. It would be expected that softer substrate would be compressed more than a compact sediment when driven over by a vehicle. In our study bivalve damage was directly related to the displacement volume of the sediment and this was good predictor of clam damage. Sand compactness will vary with the state of the tide and daily weather including wind conditions. This could explain the daily differences in susceptibility to vehicle damage.

On spring tides when the upper shore drift line is shifted landward the zone of maximal shellfish density most likely moves due to bivalve migration (Ellers 1995) and sand movement. The tuatua populations in the higher intertidal comprise mainly of individuals less than 28mm shell length and could at times include newly recruited tuatua less than 5mm. These individuals may be less aggregated during spring tides than they are during neap tides. Bivalve movements could redistribute individuals throughout the intertidal and therefore minimise their exposure to vehicles. It is therefore important to assess whether aggregation is a normal attribute of this population, which is at most risk when individuals are aggregated at the tidal level most likely to be driven on.

From the present study it was clear that off road vehicles could have a detrimental impact on intertidal tuatua. However, it would be unlikely that the beaches would be exposed to the maximal levels of driving pressures used in our experiments. However, experimental vehicle passes of more than 20 potentially can result in tuatua damage. Because of the physical nature of exposed sand beaches, recovery of the sediment following vehicle exposure is likely to be rapid. The present study was deliberately undertaken in the part of the intertidal where there were high natural abundances of juvenile tuatua. In-situ experiments like this are unusual in the literature where many studies have used transplanted bivalves, collected from drift line habitats. Here they may have been stranded by the tide and may not be in good physiological condition.

The location of the juvenile tuatua band on Pegasus Bay beaches was easily determined by subsampling and found some 10-20m below the most recent high tide. At this shore level, for most of the year, the sand remains damp during low tide and juvenile tuatua able to survive aerial exposure within the substrate. However, during the summer on hot days when the sand dries out to levels approaching their burrowing depth, these bivalves especially the smallest individuals would be susceptible to drying conditions. At this time if shellfish were stressed then additional pressure due to vehicle passes could increase mortality.

While it is now accepted that vehicles can affect the survival and behaviour of intertidal shellfish, the type of vehicle may also important because of their differing effects on the environment. It might be expected that vehicle weight would be important. The vehicle used for our field experiment was intermediate in weight between the heavy and light vehicles used by Sheppard et al. (2009). In their study the authors suggest that vehicle weight was less important than the ground pressure exerted by the vehicles. Thus, a lightweight vehicle fitted with narrow tyres could generate similar impacts to a heavier vehicle fitted with wider tyres. In our experiments the ground pressure exerted by the Holden Rodeo was considerably less than the Toyota Hilux and the Suzuki Jimney used in Sheppard et al.'s study (2009). This suggests that the tuatua damage we recorded may be lower than might be expected for some other off road vehicles.

At certain times of the year and at particular beach locations motorbikes may be more of a problem than test cars and utilities. For example, Moller at al. (2009) investigated the potential impacts of motorbikes taking part in the Burt Munro Challenge beach race on toheroa (*Paphies ventricosa*) on Oreti Beach, Southland in November 2008. Using transplanted bivalves they provided strong evidence of toheroa damage with conservative estimate of between 56 and 71% mortality for toheroa less than 40mm shell length on the motorbike race track. However, the race used only 5% of the 17km stretch of beach and was in the upper 100m of the beach. While the potential damage to toheroa was greater in the upper-tidal level than the mid or low tide levels the authors were unable to determine if vehicle use was likely to affect recruitment. They did however provide advice on how to mitigate the potential effects of vehicles on the beach and assist the long term restoration of the toheroa fishery.

The levels of beach activity on Pegasus Bay beaches can be regarded as low compared with similar beaches in Otago (Moller et al. 2009) and Australia (Schlacher et al. 2007) where traffic volumes regularly are between 300-500 per day and up to several thousand a day during peak holiday times. Such high traffic volumes may have further sublethal effects on bivalves and Sheppard et al. (2009) found that the body mass index of the beach clam *Donax deltoides* from beaches open to traffic was 16% lower than shores where there was no vehicle access. Similar studies could be undertaken in populations along the Canterbury coast where management allows for different intertidal activities including horse riding and training.

5. Conclusions

Tuatua on North Canterbury surf beaches are potentially at risk from damage caused by off road vehicles driven on the sand beach seaward of the most recent high-tide drift level. Tuatua would be most at risk when they are aggregated in a band at a particular shore level. In considering the effects of vehicles on sand beaches, there are several considerations which include shellfish size (length), position on the shore, the type of vehicle and the intensity and type of vehicle traffic. In addition, our research showed both lethal and sublethal effects of the off-road vehicle on the tuatua population. Some of the sublethal effects associated with dislodgement from the sediment can result in mortality due to predation and/or desiccation. In populations where many environmental variables affect mortality and the underlying factors regulating recruitment and growth are unknown, it will be difficult to determine if vehicle use could affect bivalve populations.

There was a significant positive statistical relationship between increasing vehicle intensity and tuatua damage. However, there was high variability and on some days, even with more than 70 vehicle passes, there was little or no shellfish damage. It would therefore not be possible to predict accurately the extent of tuatua damage from vehicle passes. One of the major findings from the research was that the compactness of the sediment affected the ability of the tuatua to resist crushing by the vehicle (Figure 8). In wet conditions or on an outgoing tide the sediment would be quite compacted and favour tuatua survival. Conditions for tuatua would be least favourable in the intertidal in drying conditions when the sand had been stirred up and vehicle passes resulted in deep depression of the sediment. To confirm these predictions it will be necessary to undertake further research. We hope that by undertaking research, examining the effects of season and location on damage by off road vehicles, we can provide a clear predictable assessment of how the intensity of vehicle traffic might affect tuatua mortality and behaviour.

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7. References

Allan, J.C., Kirk, R.M., Hemmingson, M., Hart, D. (1999). Coastal processes on southern Pegasus Bay: a review. Report for Christchurch City Council, 90p.

Anders, F.J., & Leatherman, S.P. (1987). Effects of off-road vehicles on coastal foredunes at fire island, New York, USA. *Environmental Management 11*: 45-52.

Ansell, A,D. (1983). The biology of the genus *Donax*. In Sandy Beaches as Ecosystems Eds McLachlan, A., Erasmus, E. 607-635.

Braje, T.J., Kennett, D.J., Erlandson, J.M., & Culleton, B.J. (2007). Human impacts on near shore shellfish taxa: A 7000 year record from Santa Rosa Island, California. *American Antiquity 72:*735-756.

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, 24p.

Dawson, E.W. (1954). Studies on the biology of *Amphidesma* in an inter-tidal mollusc of the sea shore, with particular reference to certain aspects of population distribution fluctuation and taxonomy. MSc Thesis , University of Canterbury, 222p.

Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., Scapini, F. (2009). Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science 81*:1-2.

Ellers, O. (1995). Behavioral Control of swash-riding in the clam *Donax variabilis. Biological Bulletin 189*:120-127.

Hull, P.J., Cole, R.G., Creese, R.G., Healy, T.R. (1998). An experimental investigation of the burrowing behaviour of *Paphies australis* (bivalvia: Mesodesmatidae). *Marine and Freshwater Behaviour and Physiology 31:*167-183.

Kingett Mitchell Ltd (2003). Fisheries Resources of Pegasus Bay, 28p

Kirk, R.M. (1980). Mixed sand and gravel beaches; morphology, processes and sediments. *Progress in Physical Geography 4*:189-210.

Luckenbach, R.A., & Bury, R.B. (1983). Effects of off-road vehicles on the biota of the Algodones Dunes, Imperial County, California. *Journal of Applied Ecology 20:*265-286.

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

Marsden, I.D. (2000). Variability in low-tide populations of tuatua, *Paphies donacina* in Pegasus Bay, Canterbury, New Zealand. *NZ Journal of Marine and Freshwater Research 34*:359-370.

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.

McLachlan, A., Jaramillo, E., Defeo, O., Dugan, J.E., de Ruyck, A., Coetzee, P. (1995). Adaptations of bivalves to different beach types. *Journal of Experimental Marine Biology and Ecology 187:*147-160.

McLachlan, A., Jaramillo, E. (1995). Zonation on sandy beaches**.** *Oceanography and Marine Biology: An Annual Review 33*:305-335.

Moller, J.S., Moller, S.I., Flutter, J.M., Harvey, J.P., White, H.A., Stirling, F.F., Moller, H. (2009). Potential impacts of vehicle traffic on recruitmentof Toheroa (*Paphies ventricosa*) on Oreti Beach, Southland, New Zealand. *He Kohinga Rangahau 5* 61pp.

Priskin, J. (2003). Physical impacts of four-wheel drive related tourism and recreation in a semi-arid, natural coastal environment. *Ocean & Coastal Management 46*:127-155.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., Defeo, O. (2007). Sandy beaches at the brink. *Diversity and distributions 13*:556-560.

Schlacher, T.A., Morrison, J.M. (2008). Beach disturbance caused by off-road vehicles (ORVs) on sandy shores: Relationship with traffic volumes and a new method to quatify impacts using image based data acquisition and analysis. *Marine Pollution Bulletin 56*:1646-1649.

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

Schlacher, T.A., Thompson, L.M.C. (2007). Exposure of fauna to off-road vehicle (ORV) traffic on sandy beaches. *Coastal Management 35*:567-583.

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. (2008). Mortalities caused by off-road vehicles (ORVs) to a key member of sandy beach assemblages, the surf clam *Donax deltoides*. *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.

Short, A.D. (1991). Macro-meso tidal beach morphodynamics **-** an overview. *Journal of Coastal Research 7:*417-436.

Thompson, L.M.C., Schlacher, T.A. (2008). Physical damage to coastal dunes and ecological impacts caused by vehicle tracks associated with beach camping on sandy shores: a case study from Fraser Island, Australia. *Journal of Coastal Conservation 12*:67-82.

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