An Investigation into Sand Dune Variation and Stability at Tūhaitara Coastal Park

GEOG309 Group Report – October 15th 2018

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1. Executive Summary

Context:

- Tūhaitara Coastal Park (TCP) is a 10.5 kilometre stretch of protected land in Pegasus Bay.
- A site of economic, environmental and cultural significance.
- Dune shape and stability appears to vary spatially at the site.

Research Question:

- What are the key factors that influence the spatial variation of dune stability at Tūhaitara Coastal Park?

Methods:

- Used a combination of fieldwork and secondary data analysis.
- Fieldwork methods included:
    - Drone based Structure from Motion techniques.
    - Spatially distributed Sediment Sampling.
    - Ground Penetrating Radar (GPR).
- Secondary data analysis included analysing:
    - 50 years of aerial photography of the two beach sites.
    - 27 years of beach-profile data from Environment Canterbury (ECan).

Key Findings:

- Trends in beach-profiles and historic analysis suggest the restricted recession of dune migration leads to over steepening of dune profiles.
- Sediment analysis suggests that sediment availability is the same throughout TCP, with variations in sediment supply.
- GPR findings suggest long term erosional trends at Waikuku beach and vertical accretion. While Pines beach displays small erosion and accretion features.

Limitations:

- Broadness of the research question.
- Limited by the quality of secondary datasets available.
- Results are only indicative of decadal changes in dune shape and stability.

Suggestions:

- Investigate how anthropogenic processes influence the variation of the beach.

2. Introduction

Located in Pegasus Bay, Tūhaitara Coastal Park (TCP) is a 10.5 kilometre stretch of protected land from Pines Beach near the Waimakariri River Mouth to Waikuku Beach adjacent to the Ashley River mouth. The land was gifted to the Ngāi Tahu iwi from the government due to its cultural significance and it also hosts a diverse range of native flora and fauna. As such, environmental changes at the site can have significant consequences on its sustainability and may adversely affect the communities living nearby. Spatial variation of the TCP sand dunes represents one sign of environmental change at the park. Pines Beach appears to have healthier dunes that are more developed than the dunes at Waikuku Beach, which appear to be eroding. Therefore, this paper attempts to identify some of the key factors that are influencing the spatial variation of dune stability at TCP.

The research framework had two aims: to firstly identify the shape of the dunes, and to then evaluate how their shape has changed over time; resulting in their change of stability. The paper begins with a review of relevant literature that adds insight into what processes operate on and around sand dunes or other processes that may contribute to the observed phenomena. Next, the research methods are stated before the results and discussions. Lastly, the conclusion summarises the key findings of the report and reflects on future research that may be done in the area.

3. Literature Review

Beach gradient and morphology plays an integral part in how coastal environments withstand storm events. Incoming waves begin to interact with the seabed at a critical depth where they begin to shoal. This interaction causes energy to dissipate from the waves due to seabed-friction (Masselink, Hughes, & Knight, 2014). If this process occurs over a shallow beach gradient, more energy can be dissipated from the incoming wave before it breaks over the shore.

Alternatively, at steeper beaches, wave-runup is comparatively shorter. This limits the capacity for a coast to dissipate incoming wave energy. As a result, waves break onshore at these beaches more forcefully, resulting in higher levels of erosion. (Puijenbroek et al., 2017; Short & Hesp, 1982; Wright & Short, 1984). Clusters of smaller storms in rapid succession can cause beach erosion that resembles the levels of erosion induced by single larger storm events with higher return periods (Karunarathna, Pender, Ranasinghe, Short, & Reeve, 2014).

Sudden changes in beach steepness reduces the effectiveness of the aeolian transport of sand (Hesp, 2002). Dunes build up over time as a result of aeolian (wind-driven) sediment deposition. Reconstruction of a beach after a storm initiates as berm reconstruction, and recovery and effective build-up of dunes is dependent on the transportation of sediment onto the beach from the nearshore environment, and eventually onto the dunes (Houser et al., 2015). Due to the aeolian process involved, the sand needs to dry out in order to be transported. Afterwards, wave [and wind] action will sort the sediment resulting in grading;

with the sediment becoming finer from the beach to the dunes (Çelikoğlu, Yüksel, & Kabdaşli, 2006)

The introduction of exotic plant species such as Marram grass (*Ammophila arenaria*) and Pine trees (*Pinus radiata*) has significantly changed the structure of sand dune complexes in New Zealand. Hilton (2006) states there was a 70% loss of the total area of sand dunes in New Zealand between 1950 and 1990. This is due to the changes made in vegetation and human developments on the dunes such as conversion for farming. Marram grass creates sand dunes which tend to be more stable and larger than dunes with native plants, which is due to Marram being an efficient binding plant to aeolian transport (Petersen, Hilton, & Wakes, 2011).

Sea-level rise around New Zealand is an important factor which should be considered. Available tide gauge data in Lyttelton from 1925 to 2004 has shown an average sea-level rise of 2.0 (±0.15) mm/year (Hannah & Bell, 2012). Globally the sea level has increased at a rate of 3.2 ± 0.4 mm yr^{-1} between 1993 and 2009 (Ackerley, Bell, Mullan, & McMillan, 2013). This rising trend could have implications for the future of the coastal dunes at the TCP.

Luisa Martínez, Mendoza-González, Silva-Casarín, and Mendoza-Baldwin (2014) define 'coastal squeeze' as "the process in which coastal ecosystems are threatened by the combination of sea-level rise and the presence of a physical barrier, such as human infrastructure" Consequently, this process can lead to degradation of dune complexes by significantly compressing the dune width, which increases their vertical growth and enhances dune instability (Lucrezi, Saayman, & Peet van der, 2014).

4. Methods

4.1 Primary Data

4.1.1 Structure from Motion

A camera mounted Phantom Drone Quadcopter was used to survey predetermined sites at both Pines and Waikuku beaches. The drone was tasked to fly a set track at an altitude of 40 m, to capture a series of photographs with approximately 70% image overlap. Within the study sites were up to ten high contrast, numbered Ground Control Points (GCP's) which were georeferenced to the Global Navigation Satellite System (GNSS), by manual data point entry of Trimble Rovers to a local Total Station. Appropriate notice of drone flight was given to the public by use of caution signs for the duration of the survey.

The series of photographs were then uploaded to Agisoft PhotoScan software to be processed into a 3-dimensional point cloud and calibrated to the GNSS data. The corrected point cloud was then interpolated into a series of rasters to generate the 3D Digital Surface Models. All data was formatted to the New Zealand Transverse Mercator projection coordinate system to maintain consistency throughout the data processing steps.

4.1.2 Sediment Sampling

Sediment samples were obtained from specified points at four different locations. These locations were: (1) Pines Beach, (2) Woodend Beach, and Waikuku Beach, with different sample sets obtained from (3) the dunes north of the Waikuku Surf Club, and (4) from the dunes south of the surf club. The specific points at each location from which the sediment was sourced were the beach foreshore, the berm, the dune toe and the crest of the most seaward dune structure (foredune). This added up to sixteen samples in total.

Once the sediment was sampled, it was returned to the laboratory and placed in a sediment oven for approximately 5 days to dry off the moisture. Once dry, the sediment samples were each run through a Dry Image Analyser (DIA). The DIA used rapid digital photography to track each grain of sediment as it fell past the camera. This allowed the variables of grain length and grain width to be captured for each grain. The DIA then automatically calculated the mean width and mean length of the sediment grains for each sample.

4.1.3 Ground Penetrating Radar (GPR)

The internal structure of sand dunes at the TCP were investigated by using a Ground Penetrating Radar (GPR) system. This method collects imagery of the subsurface, essential for quantifying the state of stability within the sand dunes, as well as how they have built up over time. Literature by Bristow and Pucillo (2006) proves that GPR is a valuable method for investigating both accretion and erosional surfaces within dunes. Throughout our project, a pulseEKKO GPR system was used. The equipment consisted of a digital video logger, a transmitter, a receiver and interchangeable antenna with variable bandwidths.
At both Pines beach and Waikuku beach, 100 MHz antennas were used with 1 m spacing as measurements were taken at 25 cm intervals along the respective profiles. Due to the dune complexity at Waikuku beach, further measurements were taken along the same transect line using 200 MHz antennas. These 200 MHz antennas were set at 50 cm spacing, while measurements were made every 10 cm. The profile lines that the GPR followed extended perpendicular to the coast, from the foreshore to the stoss side of the dunes. This range allowed for a cross-sectional view to be produced for visualising the influence of coastal processes.

The GPR data was processed using the Reflexw software. Automatic gain control (AGC), was used to magnify the trace signals horizontally, thereby enhancing the signals and highlighting reflective surfaces. Energy decay processing was applied to correct for the loss in energy with depth. Static correction (also known as air removal) was applied to ensure that the signals recorded were from the ground rather than the air or vegetation. The velocity was also determined using the Reflexw software, allowing for the calculation of depth within each profile. To correct for the changes in dune topography when the signals were transmitted, the topography was corrected using elevation profiles, which were produced with a theodolite and reflective staff. These elevation profiles are shown in Appendix C.

4.2 Secondary Data

4.2.1 Beach-Profiles

Analysis of beach profile data is a method that can be used to track the changes in beach morphology over time and making comparisons thereof (Cheng, Wang, & Guo, 2016; Zhang et al., 2015). The data of the beach-profiles was sourced from ECan and had been collected over a series of annual surveys from November of 1991 to November of 2017. The beach-profiles were produced and analysed using Excel, and various characteristics of the beach were then found by analysing the shapes and behaviour of the profiles. Examples of these behaviours included sea-level excursion, beach cross-sectional morphology, and beach gradient.

Sea-level excursion refers to the movement of the point where the beach-profile reaches sea-level. Shoreward movement indicates a loss of beach area while seaward movement indicates a gain in beach area. In this study, the sea-level excursion for each site was obtained by finding the horizontal distance from the original survey point. This was carried out for each individual survey that had been carried out on each beach. Some profiles did not have a zero-point in the vertical axis but, since all the points in each profile were corrected to the same geographic coordinate system, the zero-point could be located by linear interpolation. The results were then graphed (Figure 1), which allowed for any trends in the sea-level excursion data to be found.

Beach gradient refers to the average steepness of the beach in terms of vertical distance over horizontal distance. In this study, the equation in Appendix A defines the beach gradient. Graphing of the results (Figure 2) then allowed for the identification of any trends toward steeper or shallower beach morphology at each location.

Qualitative comparisons and contrasts of the beach morphologies in 1991 and 2017 were also observed in the profile data. This gave a raw comparison of each of the beaches as they appeared in those years, which represented end-members of the beach-profile datasets. Interest was taken in any clear seaward or landward migration on the beach during. The beach-profiles that were used for these comparisons can be viewed in Appendix B.

4.2.2 Aerial/Historic Photographs

Photo analysis data consisted of historic imagery provided by Canterbury Maps (2018), where images from the 1970-74, 1990-94, and modern coast line (2017) were compared across the two sites at Pines and Waikuku beaches. These images were calibrated and overlain so that it was possible to track shoreline migration, dune positioning, and level of development from anthropogenic sourcing.

5. Results

5.1 Beach-profiles, Excursion and Steepness

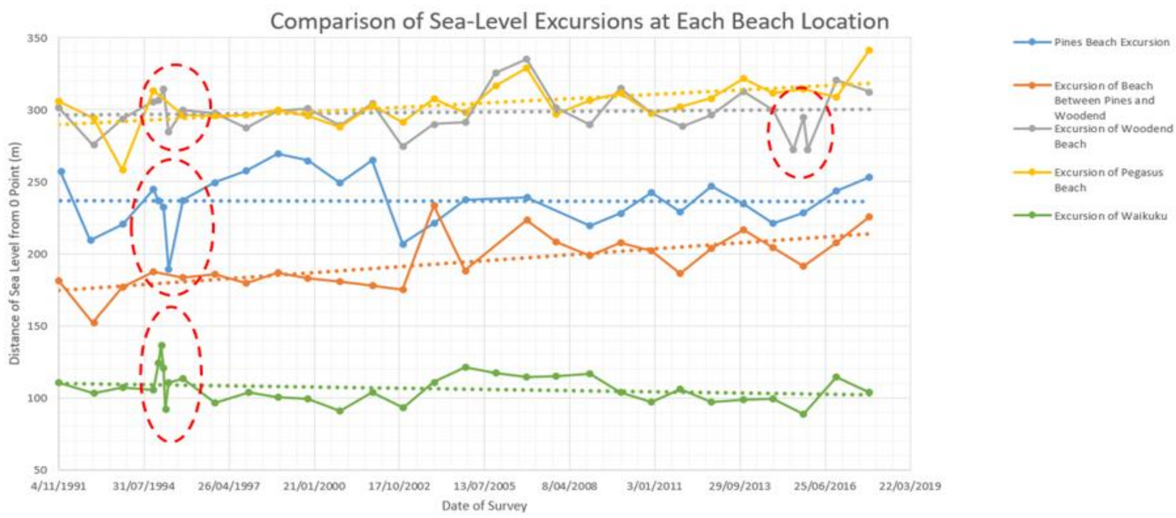


Figure 1. A graph comparing the sea-level excursion trends and behaviour at each of the beach locations from 1991 to 2017. Note the circles around the excursion data in 1995, and 2015 when more data points were taken.

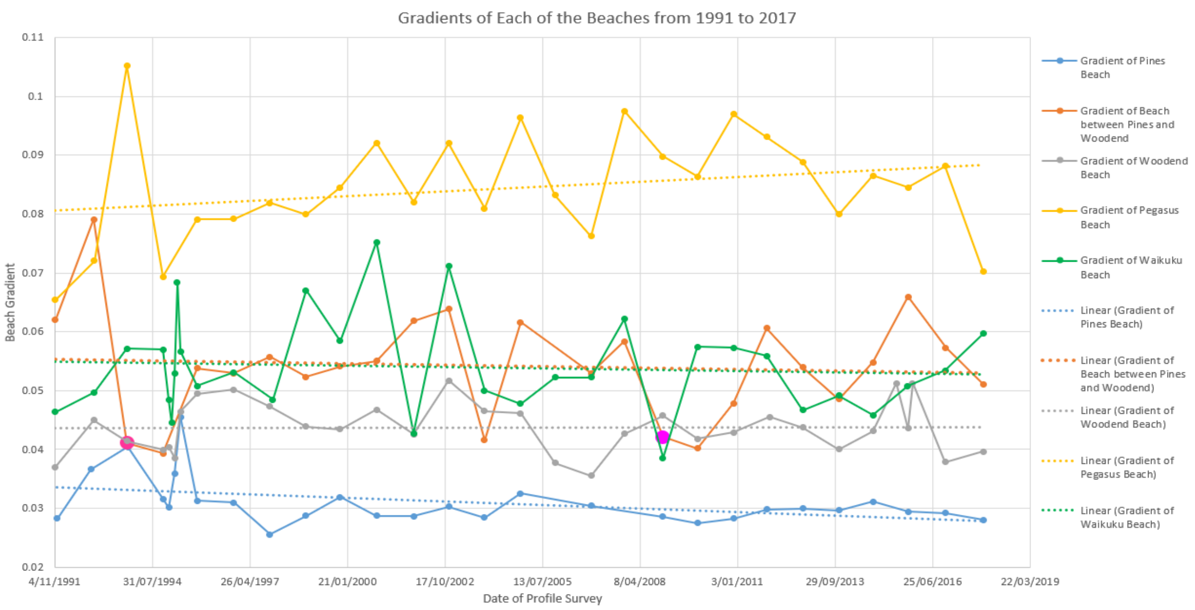


Figure 2. A graph comparing the trends and behaviour of beach steepness at each beach location from 1991 to 2017. The points marked in pink on beach profile between Pines and Woodend signifies when new foredunes structures began to develop at this location.

5.2 Aerial/Historic photography

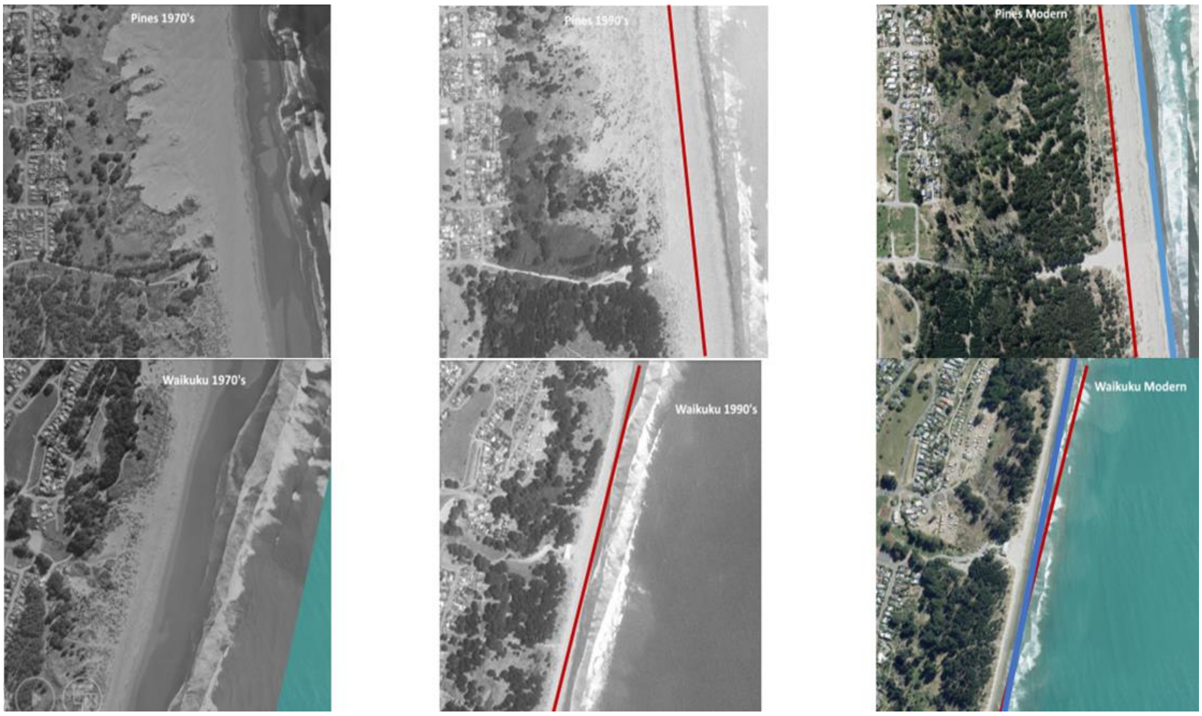


Figure 3: ABOVE, Pines Beach. BELOW, Waikuku Beach. Both series of images are from 1970, 1990, and 2017 from left to right respectively. Red line = relative position of 1970's shoreline, Blue line = relative position of 1990's shoreline.

5.3 Structure from Motion-Beach-profiles

5.3.1 Point Clouds

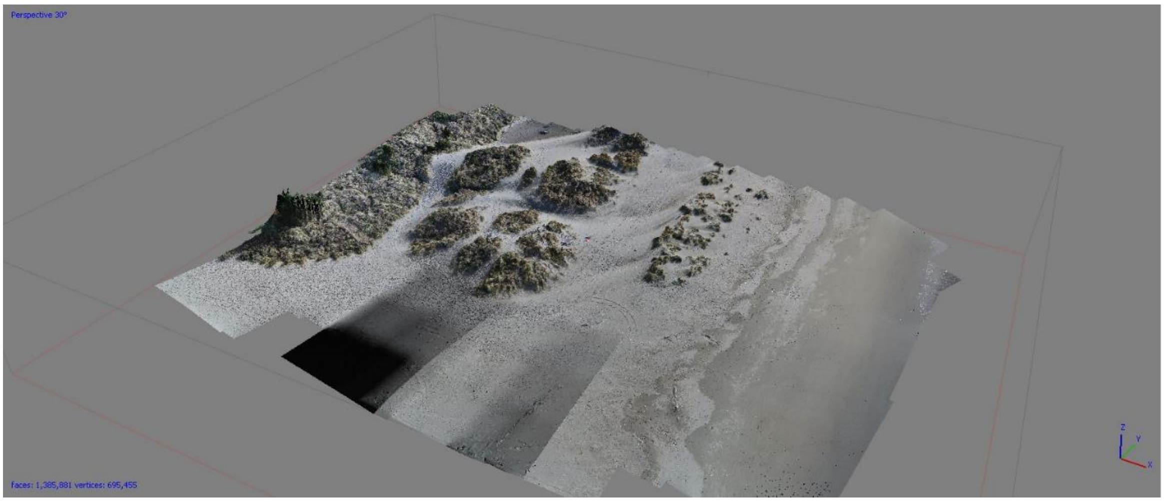


Figure 4: Dense Point Cloud model with mesh of **Pines Beach** in Agisoft.

Figure 5: Dense Point Cloud with mesh model of **Waikuku North** in Agisoft.

5.3.2 Digital Surface Models and Beach-profiles

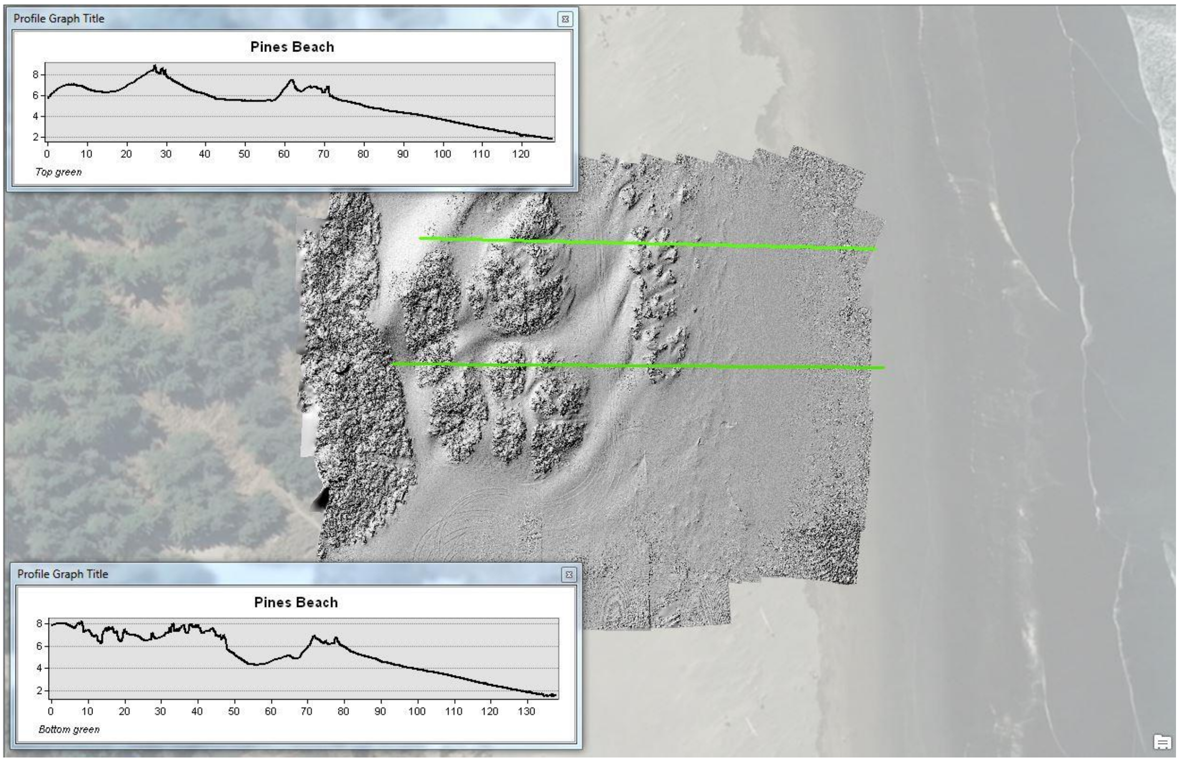


Figure 6: Digital Surface Model of **Pines Beach** with upper and lower transects and Beach-profiles.

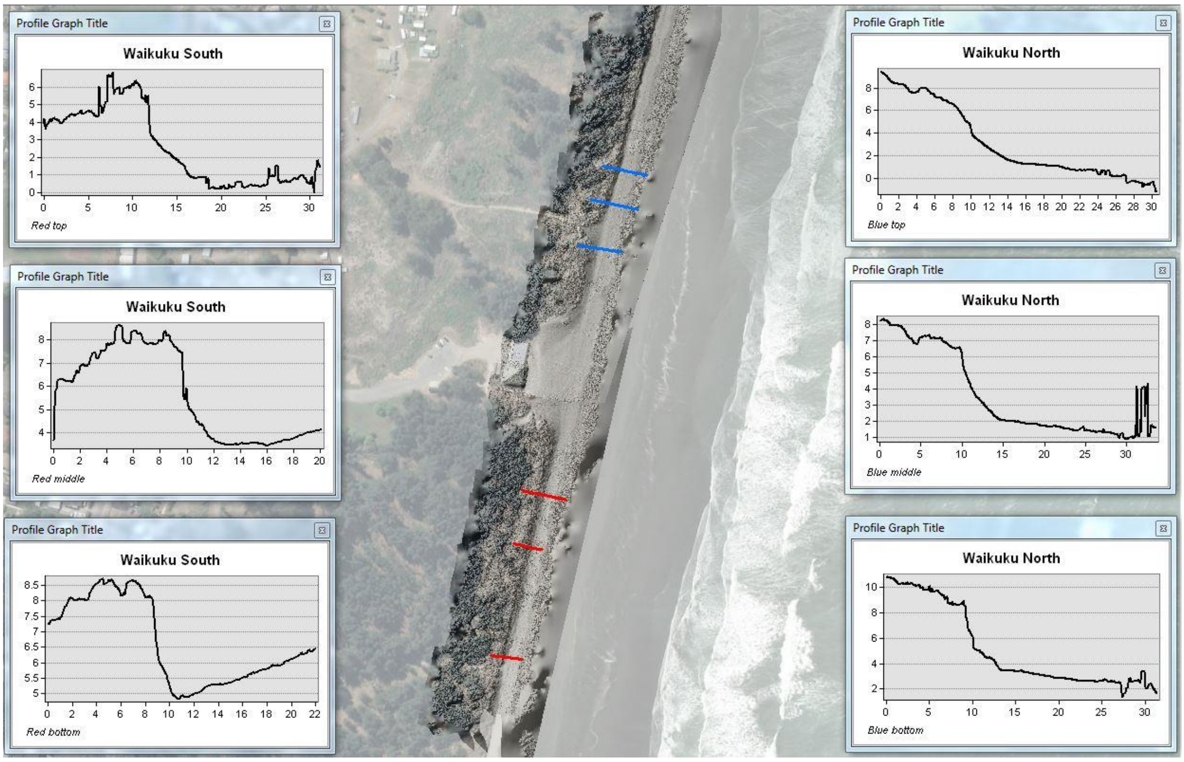


Figure 7: Digital Surface Model of both **Waikuku North** in blue, includes Beach-profiles. Includes the warped data of **Waikuku South.**

5.4 Sediment Analysis

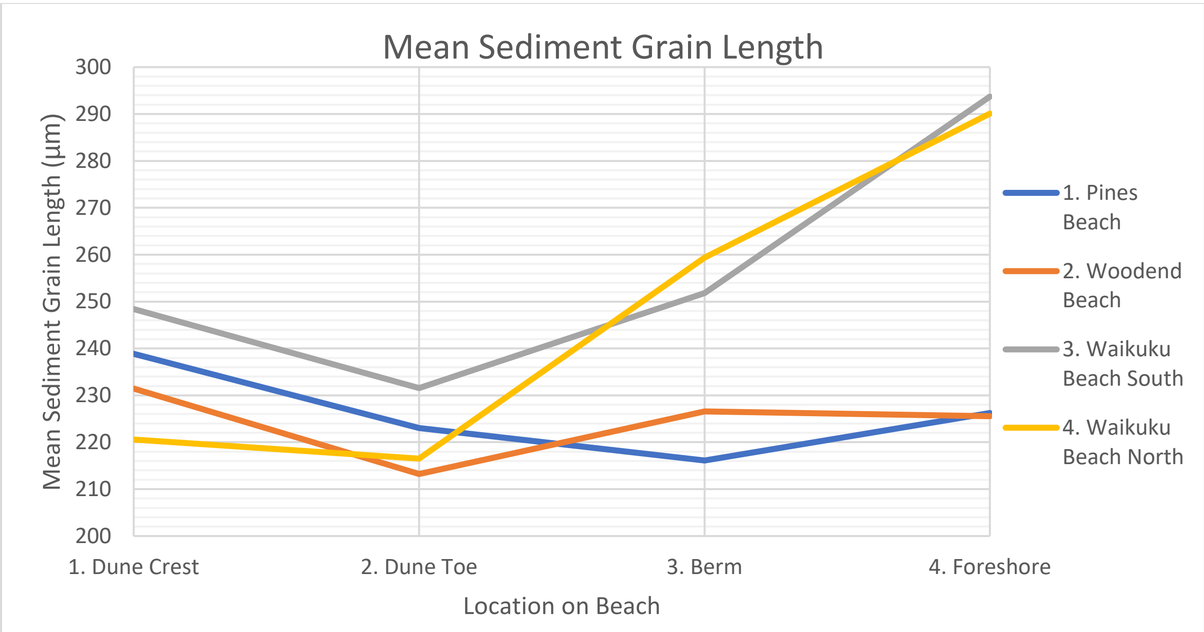


Figure 8: Mean sediment grain length on the foreshore, berm, dune-toe and dune-crest at each beach location.

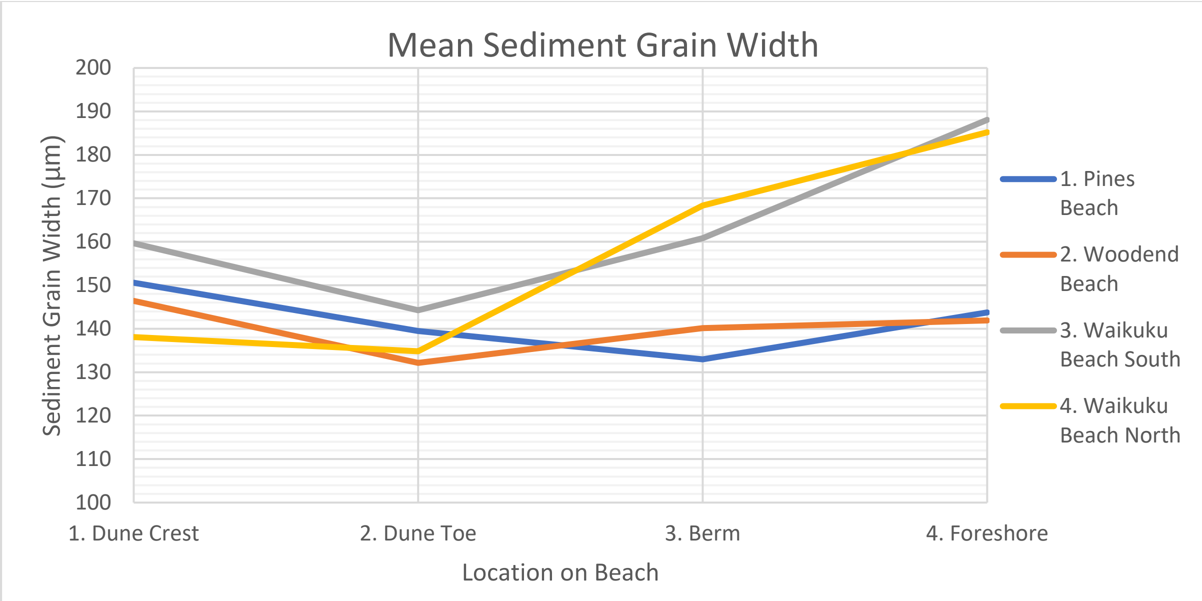


Figure 9: Mean sediment grain width on the foreshore, berm, dune-toe and dune-crest at each beach location.

5.6 Ground Penetrating Radar (GPR) profiles

The Processed GPR data used to interpret the profiles below can be found in Appendix D.

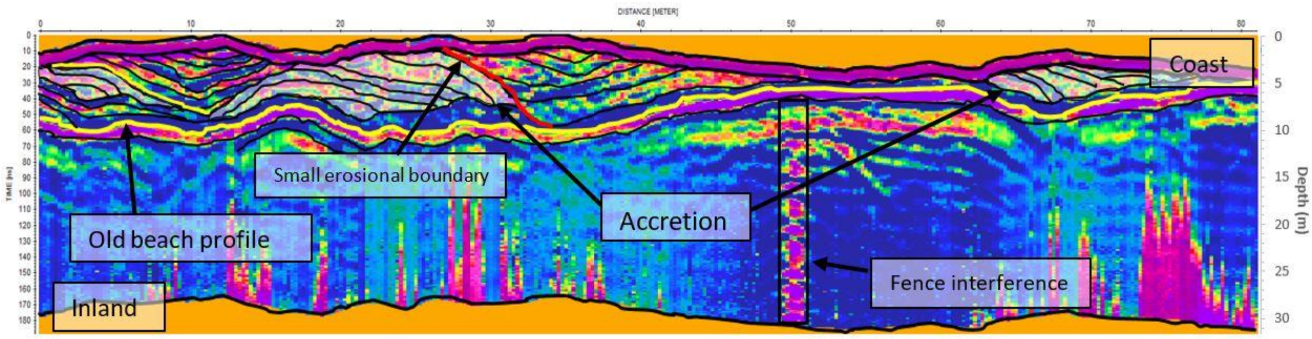


Figure 11: Processed and interpreted GPR data acquired at Pines beach, (100MHz antenna). Red represents erosional surfaces while the white shading represents areas of accretion.

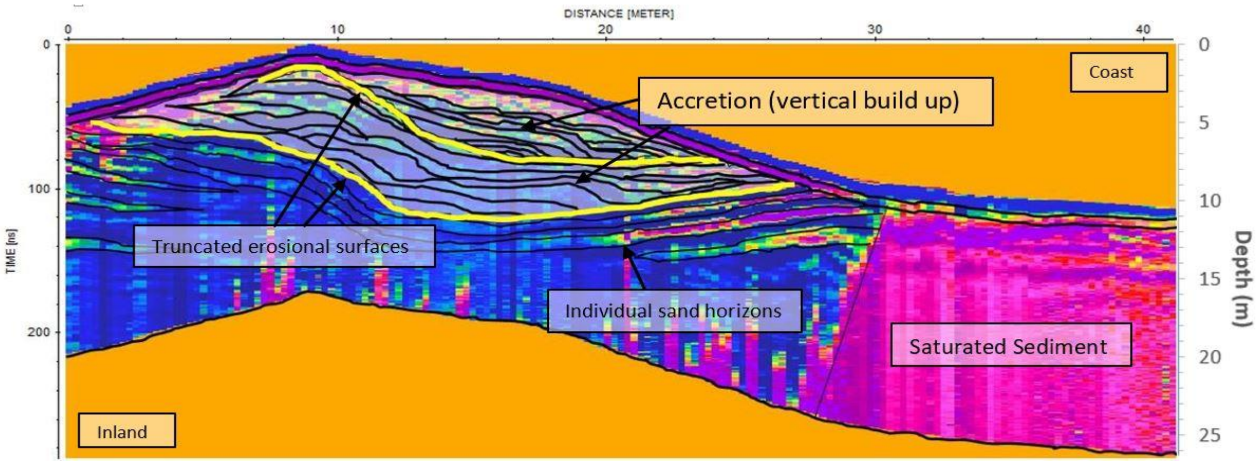


Figure 12: Processed and Interpreted GPR data acquired at Waikuku beach, (100MHz antenna). The yellow lines indicate erosional surfaces while the white shading represents accretion.

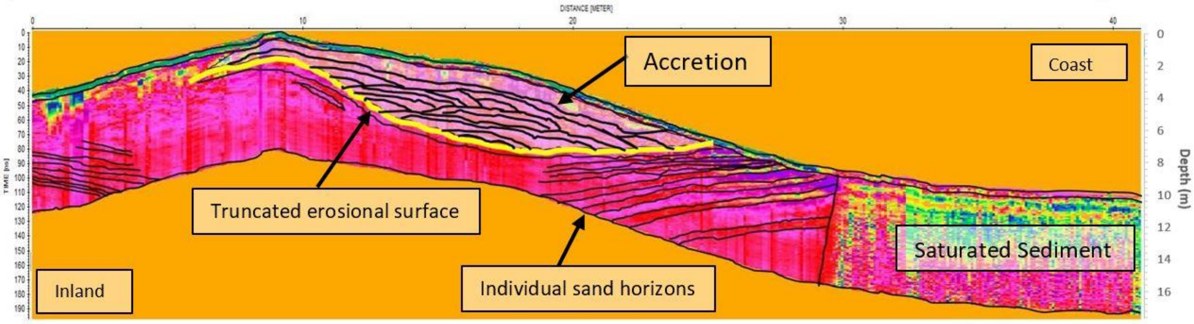


Figure 13: Processed and Interpreted GPR data acquired at Waikuku beach, (200MHz antenna). The yellow line represents an erosional surface, while the white shading shows areas of accretion.

6. Discussion

6.1 Interpretation of Results

6.1.1 Sea-level Excursion

The sea-level excursion plots (compiled in Figure 1) indicated different trends for each of the beaches over the 27-year period over which the profile data had been compiled. Pines Beach and Woodend Beach each recorded trends that were stable overall, with only very small shoreward and seaward trends respectively. The most significant seaward trends were evident in the data for the beach between Pines Beach and Woodend Beach and at Pegasus Beach, while there was an overall landward trend at Waikuku beach. Each of the sea-level trends fitted relatively poorly with the corresponding data; there was significant variation of sea-level position year-to-year for each of the locations. The beaches also had substantial ranges of excursion fluctuation, with ranges of between approximately 40 and 80 metres (Appendix B1). Extra data points were taken in 1995 (Figure 1) which suggest that the variation in sea-level excursion can be considerable over shorter timespans.

6.1.2 Beach Morphology Changes

In a comparison between the 1991 and 2017 profiles of Pines Beach, there appears to be a gain in sediment volume. The berm and upper beach in 2017 appeared to be raised in comparison to 1991, although the upper beach had also retreated somewhat landward; see Appendix B2.

Similarly, it appeared that the beach north of Pines Beach and south of Woodend Beach had also advanced seaward. Two large dune-like structures appear to have developed during the 27-year period, and both the berm and foreshore appear to have advanced seaward as well; see Appendix B3.

Woodend Beach and Pegasus Beach both experienced similar growth patterns, with significant vertical development at both. However, Pegasus Beach, which exhibited more intense vertical growth, has advanced in such a manner that the berm and foreshore sections of the beach have become somewhat narrowed. See Appendices B4 and B5.

Waikuku Beach appears to have lost volume. The beach-profile was noticeably steeper in 2017 in comparison to 1991. There has been some vertical development of the beach, but also a significant loss of volume - see Appendix B6.

Appendix B7 gives a comparison of the latest profiles of Pines and Waikuku Beaches. It shows that Pines Beach is wide and has a well-developed berm and beach face. On the other hand, Waikuku Beach is comparatively steeper and narrower with a poor berm area.

6.1.3 Beach Gradient

Shallowing trends are evident at most beaches along the TCP, however the trend for Woodend Beach appears stable, with a very small but overall negligible steepening trend, thus indicating that the average gradient of this beach has not tended greatly toward becoming steeper or shallower during the past 27 years. However, the data is indicative of considerable variability in gradient despite the stable trend. Pegasus Beach displays evidence of a steepening trend over the 27-year period and it is also the portion of Pegasus Bay that attained the highest values of beach gradient over this period.

The beach between Pines Beach and Woodend Beach had two instances, one in 1993 and the other in 2008, when the gradient of the beach suddenly decreased. These two instances are highlighted in Figure 2 and correspond to the genesis of new foredune structures on the beach ahead of the main dunes. With the reference point for the beach gradient now moved to the new foredune, the gradient was reduced as a result.

There is a significant amount of variability with the annual values in beach-gradient trends which is evident in Figure 2. As such, each of the beach-gradient trends fit relatively poorly with the corresponding data. This suggests that the beaches each tended to transition between steeper and shallower profiles year-to-year.

6.1.4 Historic Analysis

Historic imagery places beach gradient into perspective, as it becomes obvious how much steeper both beaches have become over the near 50-year period. The shoreline of Pines beach has advanced since the 1970's, but appears to have stabilised since the 1990's. The modern beach appears much narrower since the development of the backing Pine forest and other significant infrastructure. Much of the historic dune field is no longer active in the beach-berm system.

The shoreline position of Waikuku has not significantly moved in the 50-year observation period. Despite this, the dunes appear to have migrated seaward. Waikuku beach appears to be narrowing, with the width of the berm significantly decreasing through time.

6.1.5 Structure from Motion

Pines Beach appears healthy as shown in Figures 4 and 6, with the surface models producing transects of the beach-profiles inclusive of many dunes at various stages of their development. The berm is wide and spans spatially an order of magnitude larger than Waikuku. Waikuku North is shown by Figures 5 and 7 and appears to have a large erosion scarp which runs for hundreds of meters in both directions of the shore. This scarp is between 6-8 m tall in most places, and undercuts much of the primary dune. The berm is narrow, with the dunes large and clearly unstable.

The point cloud model of Waikuku South had significant spatial warping due to the inadequate placement of Ground Control Points across the site. This was due to physical inaccessibility of the steep dunes and dense vegetation. Despite this, the digital surface model still represents the large erosion scarp across the beach-profile transects and can therefore be used in analysis.

6.1.6 Sediment Analysis

Analysis of sediment samples (Figures 8 and 9) shows that the mean sediment grain size is larger at the foreshore and berm of Waikuku Beach compared to the beaches at Pines and Woodend (Figures 8 and 9). Since Waikuku Beach is narrower than the other two beaches, finer dune building sediment that would otherwise be deposited from sediment sorting processes is frequently removed by wave erosion (Çelikoğlu et al., 2006). Therefore, there is a greater supply of dune building sediment at Pines and Woodend Beach.

It is worth noting that the difference in mean sediment size is smallest for all the sites at their dune toe and crest. This shows that dune building sediment is present at all the sites and this provides evidence that issues of sediment availability are not causing the spatial variation of dune stability at TCP.

It can also be seen that the mean sediment grain length and width increases for all the sites between the dune toe and the dune crest. Two possible explanations for this include wind blowing finer sediment off the dune crest where it then deposits in the dune toe in a secondary sediment sorting process, and the steepness of the dunes could be making it difficult for this fine sediment to be transported back to the top of the dune by aeolian processes, as supported by the work of Hesp (2002).

6.1.7 Ground Penetrating Radar

The GPR profiles reinforce the variation of stability between the two key study sites, Waikuku beach and Pines beach. Figure 11 indicates a trend of stability at Pines beach. This is evident due to the presence of both small-scale accretion and erosional features. Although the profile does show erosional features, these are spread over a much larger area as the dune field is further developed. At Waikuku beach however, figures 12 and 13 highlight the large truncated erosional surfaces. These erosional surfaces extend to the stoss side of the dunes indicating periods of transgression. Due to the narrow beach shown in the aerial photographs, the accommodation space at Waikuku beach is low. Therefore, between these erosional surfaces, the dunes have been forced to build up vertically during periods of accretion.

6.2 Discussion of Results

6.2.1 Historic Analysis

Historic imagery and secondary data analysis indicate that the coast of the Tūhaitara Coastal Park is steepening. This is most pronounced in Waikuku Beach, where the backing Pine tree forest limits the inland migration response of the sand dunes to sea-level rise. The concept of coastal squeeze as described by Lucrezi *et al* (2014) supports this observation. Waikuku Beach is the only site that has experienced significant volume loss from 1991 to 2017. However, the vertical growth trends and seaward beach migration displayed by the southernmost beach profile plots (shown in Appendix B) suggest that each beach along TCP may be experiencing a narrowing trend as sea-levels continue to rise, thus resulting in a continual trend of dune build-up to instability.

6.2.2 Sediment Analysis

Sediment analysis demonstrates that changes in sediment size across TCP are not influencing the spatial variation of dune stability at the site. This is a significant result because while it does not answer the research question, it rules this factor out. These results support the wider literature in terms of how sediment sorting and wave erosion is expected to occur along the beach. It also means that no remediation methods need to be carried out at Waikuku beach to improve the quantity of dune building sediment in the area. This has implications for determining the types of native plants that may thrive in the area and aid in its environmental rehabilitation.

6.2.3 Ground Penetrating Radar

Ground Penetrating Radar suggests that the structure of Waikuku's dunes are built upon pre-existing erosional scarps, with wind-deposited accretion hummocks building the dunes up vertically between each erosion event. This is drastically different to the structure of Pines Beach's sand dunes, which appear to be slowly gaining volume over time. The magnitude of the erosion scarps at Pines Beach appear to be less severe compared to the ones at Waikuku Beach, indicating that this is either a more stable beach or that it can recover more quickly after large erosion events. The nature of the dune field at Waikuku beach appears to follow similar trends as discussed in (Lucrezi et al., 2014) as the beach may be subjected to "coastal squeeze" processes. At Waikuku beach over time the dunes have built up vertically. This signature suggests that the dunes have been restricted to a narrow beach area. The coastal squeeze therefore could be a key process influencing this vertical dune build up.

6.3 Suggestions

Further investigation of anthropogenic development is needed to understand its influence on the dune system. Restoration of the dune systems to native vegetation could be considered, however this must be investigated further to understand the full effect of the backing pine trees on the environment.

6.4 Research Limitations

There were some limiting factors to the data of the beach-profiles. Since the beach-profiles had only generally been recorded on an approximately annual basis, the temporal resolution (time between successive recordings) was low. The intervals between each survey may mean that the data does not accurately represent the true behaviour of each beach. Processes such as storm-induced erosion and a certain degree of beach recovery may be missed. Since the beach-profile data simultaneously defines the sea-level excursions and beach gradient, there may therefore be some degree of error for both characteristics.

Dense vegetation and physical inaccessibility of steep sand dunes limited the SfM surveys, especially at Waikuku. The resulting models produced with these limitations had significant distortion of spatial parameters, with the Waikuku South models subject to major spatial warping. Despite this, analysis of the dunes is still possible due to the lack of immediate vegetation on the areas of interest (scarps and active dunes), as supported by Mancini et al. (2013).

7. Conclusions

While shoreline position appears relatively stable over the last 27 years of data, narrowing south-north beach trends along TCP suggest that the adjacent Pine trees are limiting the ability of the dunes to respond to sea-level rise. This has several implications, including the steepening of beach gradients. This steepening can destabilise the primary dunes and act to enhance erosion at Waikuku Beach. Steepening of the beach gradients could also increase the vulnerability of the beaches to significant wave erosion in the event of severe storms. Although the adverse effects of coastal squeezing are most significant at Waikuku Beach, the same trends can be seen across all the Tūhaitara coastal park beaches of Pegasus Bay.

8. Acknowledgements

We would like to thank Dr Sebastian Pitman for being an amazing tutor and giving us guidance throughout the research process.
We would also like to thank Greg Byrnes for his unequivocal enthusiasm and encouraging attitude throughout this project.
Thanks are also owed to John Thyne for allowing us access to the geography research computer so that we could complete our SfM images.
And thank you to Justin Harrison for supplying us with the equipment we needed to carry out our research and coaching us on their use.

Appendices.

Appendix A – Equation for Beach Gradient

$$G = \frac{E}{D}$$

G = Beach gradient

E = Elevation of most seaward high point on beach

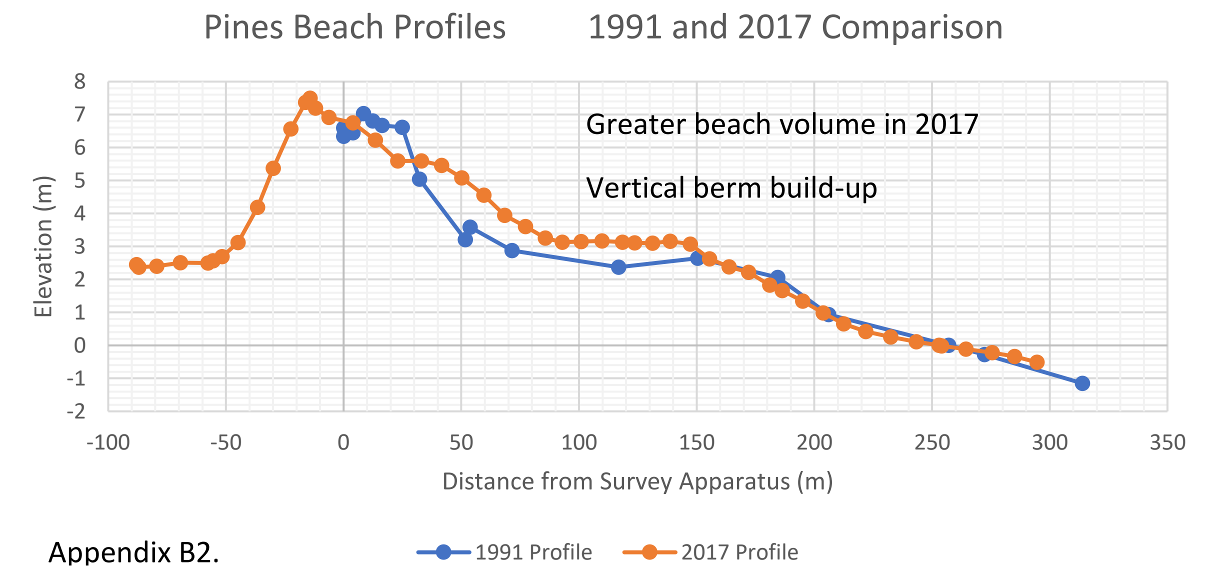
D = Horizontal distance from position of E to the point of sea-level on the beach.

Appendix B – Sea-Level Excursion and Beach-profile Comparisons: 1991 and 2017

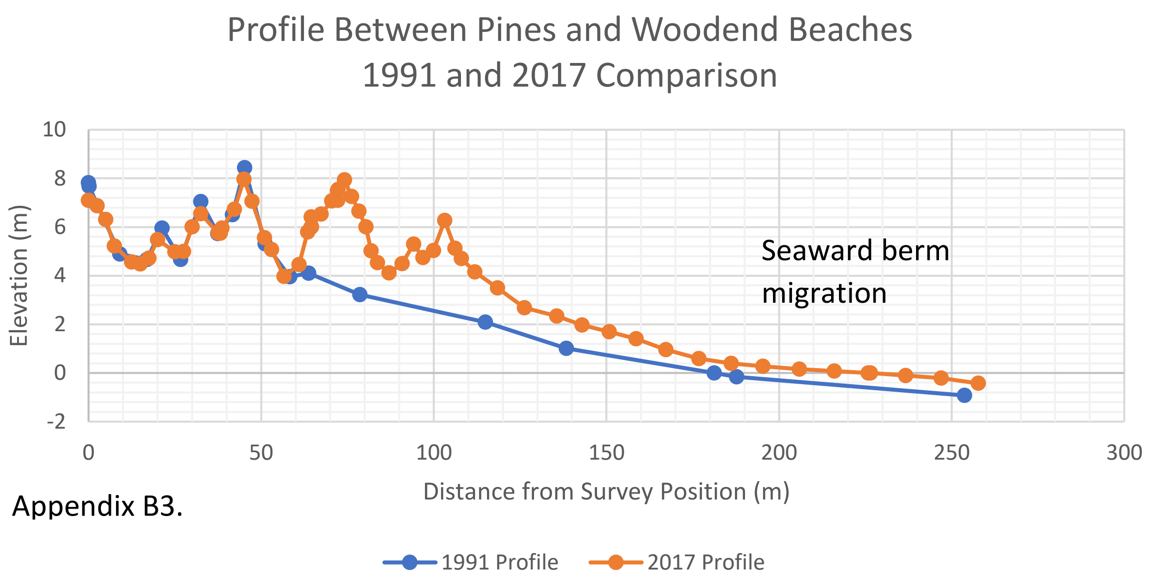
Appendix B1.

Table 1: Parameters of distance of sea-level position from surveying zero point for each beach, with the net change in sea-level position between the 1991 and 2017 profiles.

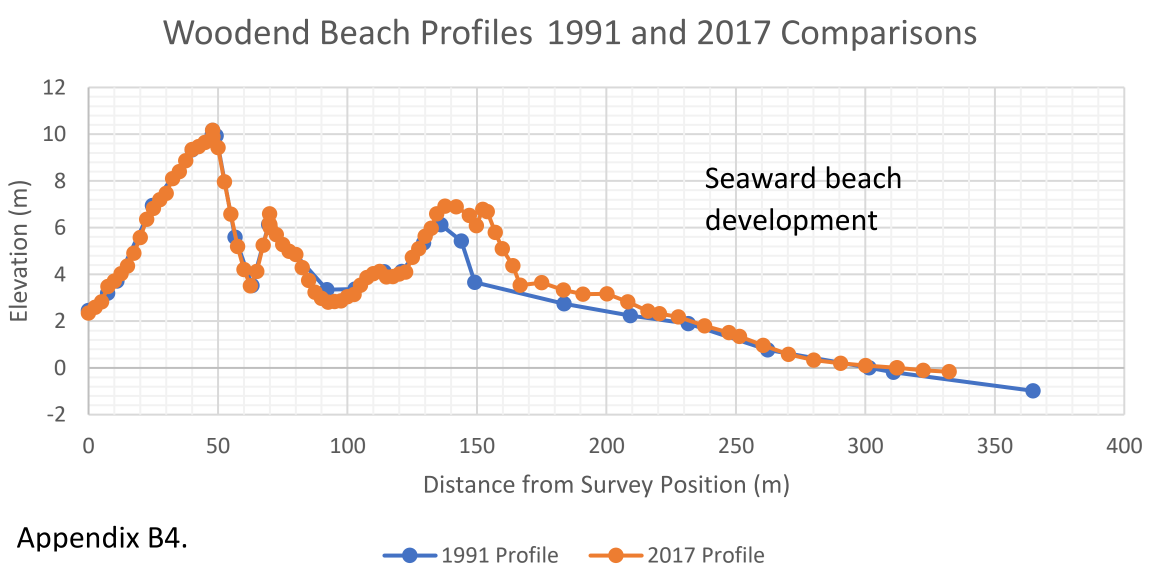
(All units are metres)	**Pines Beach**	**Between Pines and Woodend**	**Woodend Beach**	**Pegasus Beach**	**Waikuku Beach**
Median	237.280	187.973	298.220	302.800	104.691
Mean	236.912	194.142	298.258	303.931	106.722
Maximum	269.550	233.350	334.970	341.020	136.410
Minimum	189.140	151.919	271.990	258.186	88.440
Range	80.410	81.431	62.980	82.834	47.970
Gross SL Position Change	-4.160	44.570	10.880	35.320	-6.975



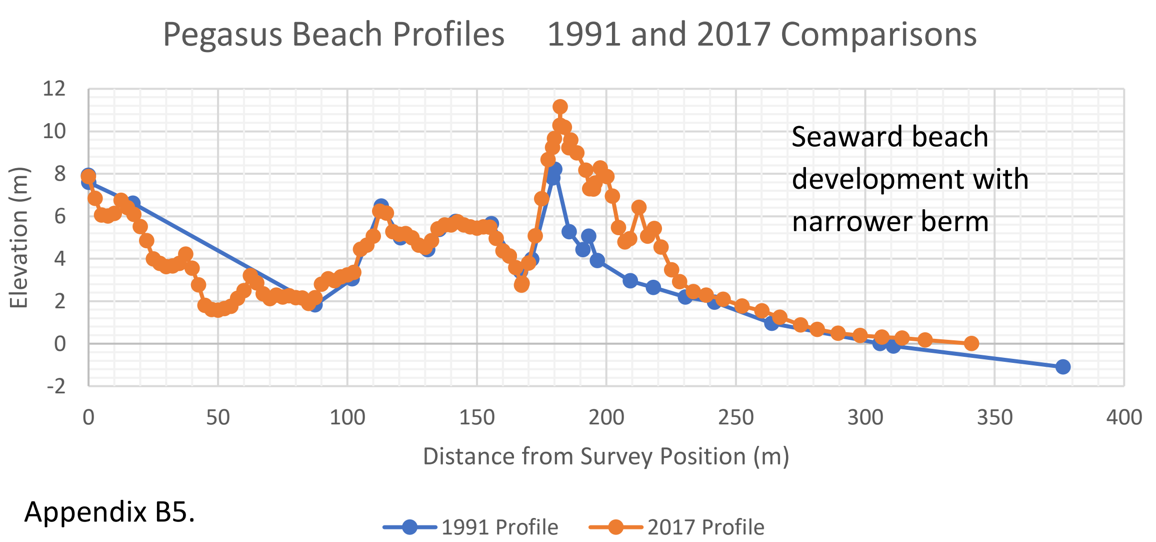
Appendix B2.



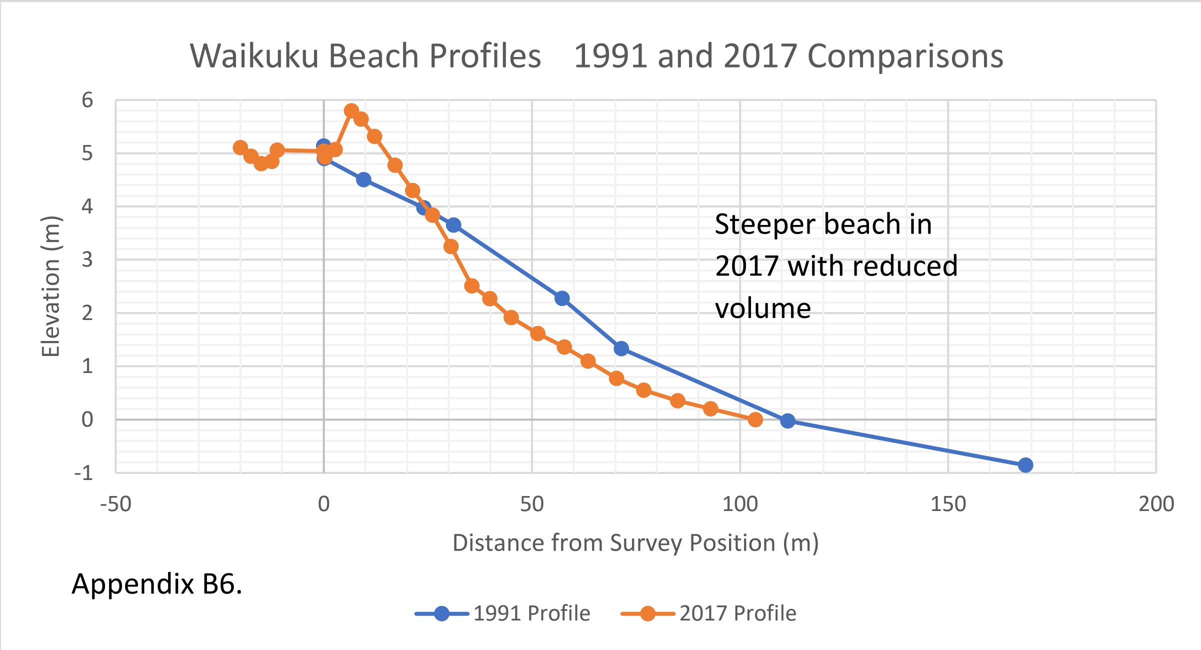
Appendix B3.



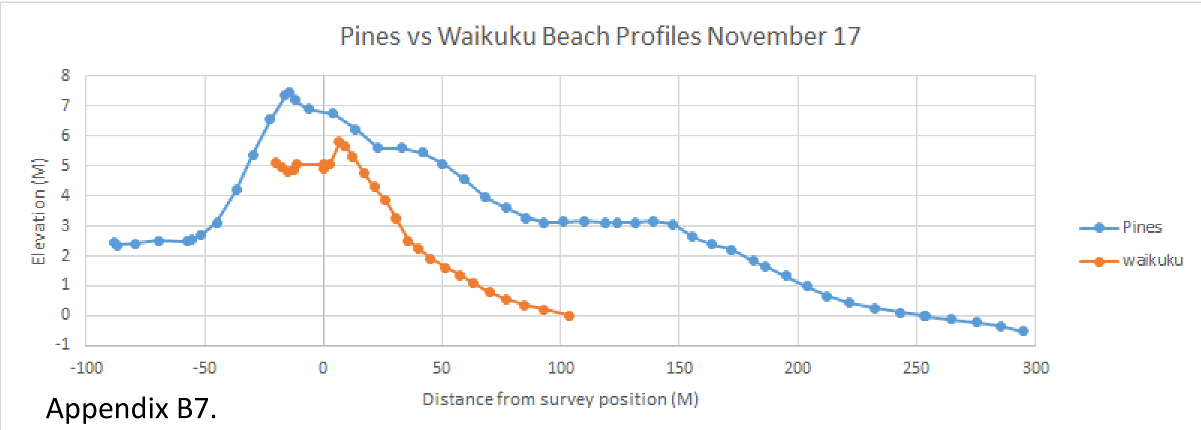
Appendix B4.



Appendix B5.

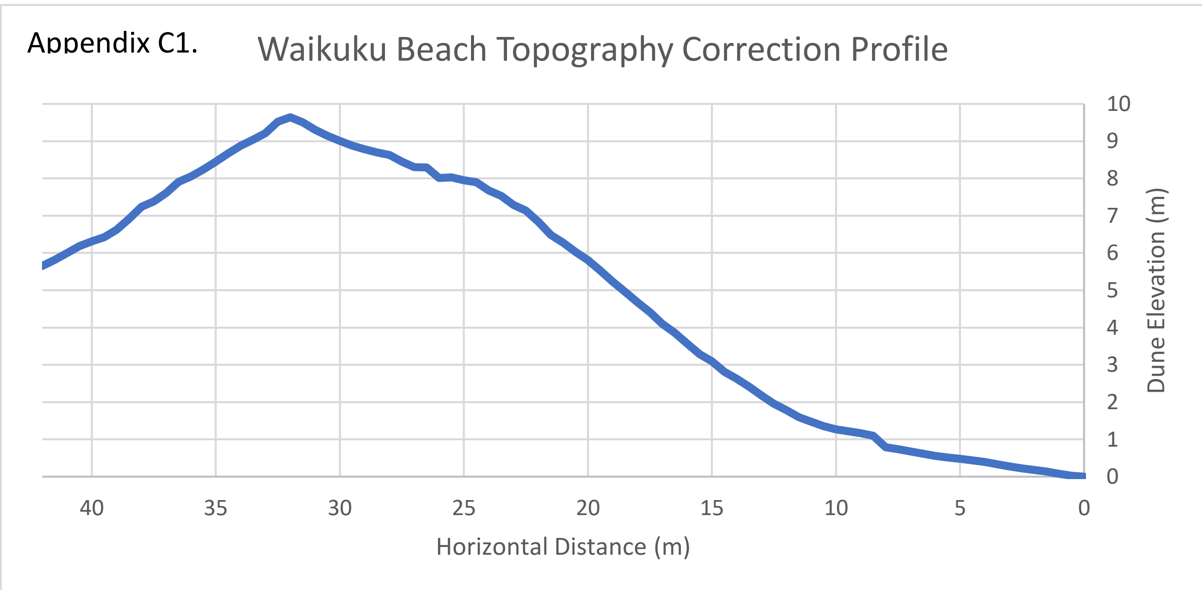


Appendix B6.



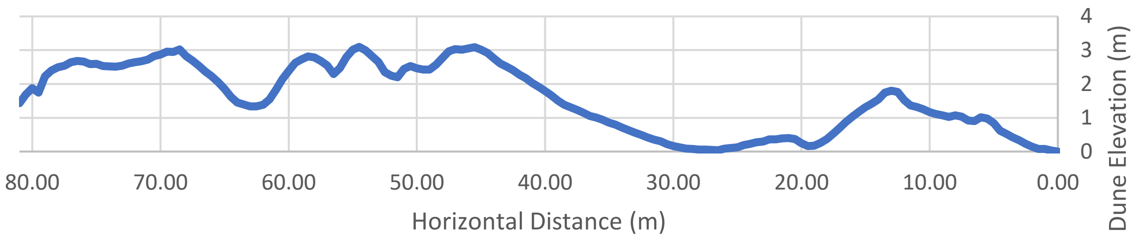
Appendix B7.

Appendix C– Elevation Profiles for Correction of GPR Data

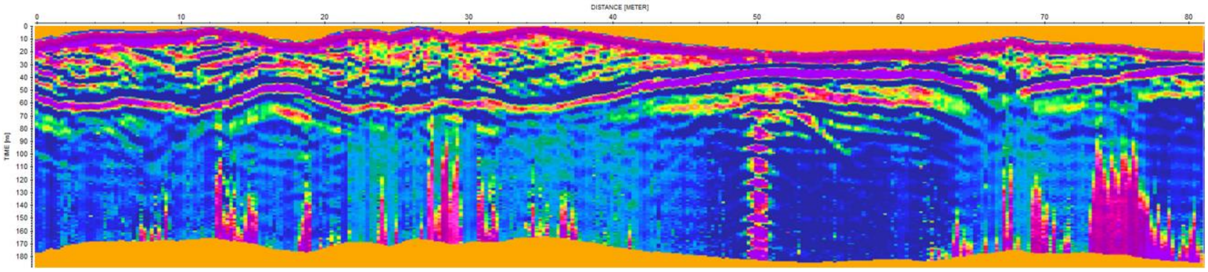


Appendix C1.

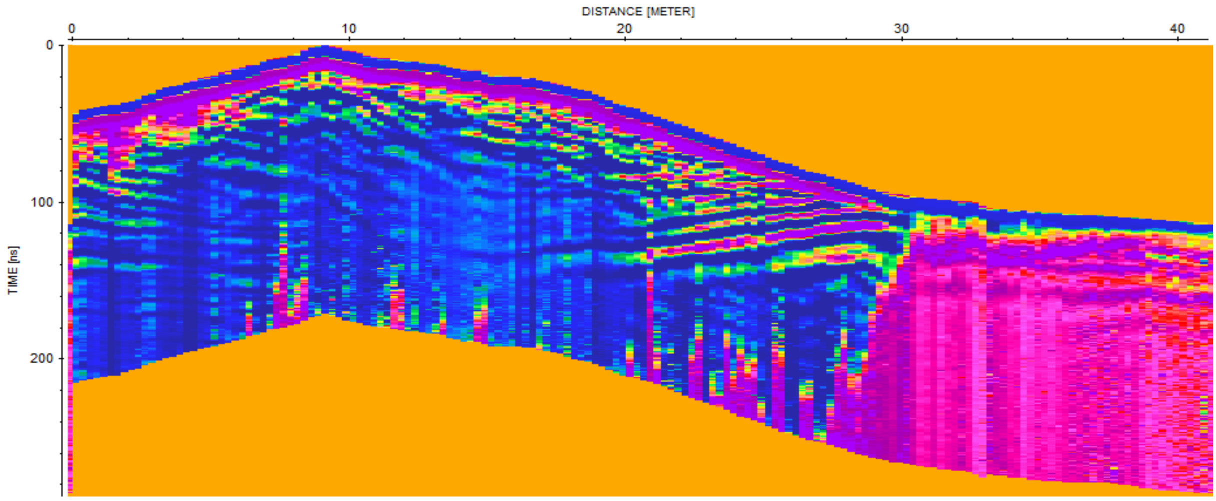
Appendix C2. Pines Beach Topography Correction Profile



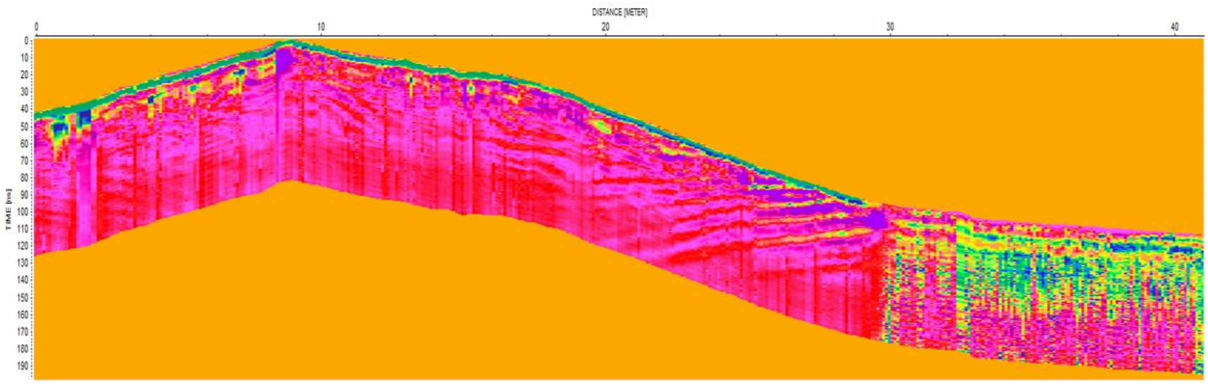
Appendix D - Ground Penetrating Radar Profiles



Appendix D1: Pines Beach (100MHz antenna)



Appendix D2: Waikuku beach (100MHz antenna)



Appendix D3: Waikuku beach (200MHz antenna)

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