The spatial distribution of soil characteristics and topography within the transect at Tūhaitara Coastal Park

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Executive Summary

- Te Kōhaka o Tūhaitara Trust has been supplied with Department of Conservation funding to set up a 3-year restoration project within Tūhaitara Coastal Park. This restoration project involves restoring a 1.5 km by 50 m coastal transect from Woodend Beach to 1.5 km inland.

- Our community partner, Te Kōhaka o Tūhaitara Trust, wanted our research group to produce a digital model of the transect. This will then be used to help aid their restoration planning through allowing them to be better informed of which types of vegetation would best suit the different environmental conditions. Therefore, the aim of this research was to contribute to our community partners restoration planning by analysing the spatial variation of soil characteristics and elevation within the transect and turn this information into digital models which they can view.

- The research question: “What is the spatial distribution of soil characteristics and topography within the transect at Tūhaitara Coastal Park?”

- Our methods involved taking 11 soil samples along the transect to analyse particle size, pH, moisture content and organic matter. The soil data was then analysed using geographic information system (GIS) software and interpolation techniques were applied to create different models of the transect showing the spatial patterns of different soil characteristics. We also used structure from motion, a photogrammetric technique to produce a 3D model of the transect land and a digital surface model (DSM).

- This research showed that soil particles size decreases going from the coastal dunes to the wetlands as more sediments and finer soil particles were found near the wetlands. It was also shown soil moisture increases as soil particle size decreases. Analysis of soil pH indicated more acidic soil at the wetlands and in areas with more present vegetation.

- This project was limited by the topography and vegetation growth, which resulted in us only taking 11 soil samples. Due to the limited soil samples, our interpolation methods may not accurately show the true soil characteristics in areas where samples were not taken. Furthermore, the LINZ Dem model was 6 years old which may cause slight inaccuracies if the landscape has been altered since then.

- For future research it would be recommended to take more soil samples to help strengthen our interpolation models. It may also be beneficial to analyse more soil characteristics which can effect vegetation growth such as nitrogen and phosphate.

Introduction

The Tūhaitara Coastal Park is a 575 hectare coastal park which is located along Woodend Beach, North of Christchurch. This land is managed by Te Kōhaka o Tūhaitara Trust and they have just been supplied with Department of Conservation funding to set up a 3-year restoration project within Tūhaitara Coastal Park. This restoration project is being set up along a transect that is 1.5 kilometers long and 50 meters wide. The transect contains various microclimates such as sand dunes, pine forest, wetlands and sand binders and Te Kohaka o Tūhaitara Trust's aim is to restore this transect of coastal land back into a native coastal forest sequence. To aid with this restoration, our community partners have asked us to produce a 3D digital model of the transect land. Spatial planning is important when it comes to restoration projects to reduce cost inaccuracies and ensure organism success and our models can help this process (Cordell et al., 2017). To do this we have come up with the research question of

"What is the spatial distribution of soil characteristics and topography within the transect at Tūhaitara Coastal Park?"

To answer this question, we aim to find out the elevation changes along the transect and measure the changes in soil characteristics. We can then use this information to create digital models of the restoration site. Restoration and fixing degraded land requires a cost-effective technique of restoring that minimises risk and considers context-specific conditions (Barbosa & Asner, 2017). Therefore, we used soil sampling and elevation methods outlined in this report to produce a digital 3D model of the transect. Soil analysis included measuring particle size, pH, moisture content and organic matter. These are known to be the influential factors on vegetation growth; therefore, it is important to know the distribution to create a successful restoration project. This report analyses the results and is followed by a discussion, conclusion and outlining the limitations.

The data gathered will help inform our community partner on the next stages of the restoration project. The project is particularly significant as native forest in New Zealand are spaces used for recreation, self-reflection, development and adventure. This park holds special culture value to the local mana whenua, Te Ngāi Tūāhuriri Rūnanga, as part of their national identity.

Literature Review

This study focuses on mapping elevation and specific soil characteristics which were found in previous studies to be influential in determining native plant growth and success of restoration projects (Sobanski & Marques, 2014). Finding suitable methods for interpreting data was recommended by our group supervisor.

Soil properties

There are multiple relevant key findings stated across articles with a similar outcome. pH decreases when heading further inland, this is mainly due to inland areas having low leaching rates and decomposition of organic material causing the soils to become acidic from organic acids (Smith et al., 1985). Soil salinity near the ocean is caused by salt spray which can lead to osmotic stress for vegetation (Land et al., 2008). Organic accumulation, nutrients and soil moisture increases with distance from the coast (Land et al., 2008) (Smith et al., 2016). Organic material is higher in older soils and vegetation coverage, however, is scarce in sand dunes due to their high-water drainage ability and less vegetation present (Smith et al., 2016). Less species can tolerate the harsh conditions at shore sand dunes, as a result there is a decrease of plant species diversity and abundance in these coastal habitats (Isermann, 2005). Large size grains, such as sand, are highly porous which causes more drainage and less moisture absorption (Magni, et al., 2008). As these factors are shown to have an impact on plant growth and establishment, it is important that we try to map changes in the transect to help aid the restoration planning.

Elevation methods

Unmanned Aerial Vehicle (UAV) based Structure from Motion (SfM) is one of the cheapest and fastest methods for producing a 3D model for a 1 km^2 landscape (Tarolli, 2014). However, there some limitations such as SfM performing poorly in forested areas with greater than 50% canopy cover (Mlambo et al., 2017). Another method is Light Detection and Ranging (LiDAR) which can overcome the highly dense vegetation as it provides highly accurate ground elevation measurements (Pearse et al., 2018). This technique, however, requires expensive equipment and the only data available was from 2014.

Methods

Elevation

A plethora of field methods exist to map topography, some of which are: differential Global Positioning System (dGPS), Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS), Terrestrial Laser Scanning (TLS), airborne-LiDAR (Light Detection And Ranging), Unmanned Aerial Vehicles (UAV), Total Station (TS), etc (Łabuz, 2016).

However, due to cheaper, faster and ease of data collection from UAVs, especially using Structure from Motion (SfM) techniques, they have become popular in the scientific community and are replacing traditional methods (Tarolli, 2014).

Structure from Motion utilises a collection of 2D-overlapping images (e.g. from a UAV mounted camera) to construct a 3D point cloud model, and its accuracy has been compared to that of the highly accurate LiDAR.

SfM

Using the SfM method was well aligned with our goal of producing a 3D model of the transect land at Tūhaitara Coastal Park. A DJI Phantom 4 RTK (Real Time Kinematic) drone was used to capture 2D images of the transect land with 75% overlap in the images. The drone was linked to a Trimble base station that was set up before flying the drone to capture images. This results in the drone knowing its exact location by communicating with the base station and correcting for GPS inaccuracies. Therefore, ground control points (GCPs) for post process image geolocation were not required to be set up. The drone captured approximately 250 photos of our study site. These images were then loaded into Agisoft Metashape, after which the images were aligned to produce a 3D point cloud (Key point limit: 40000; tie point limit: 4000). A dense point cloud of the landscape was created by using the ‘build dense cloud’ option, and then a shaded view using the ‘build mesh’ option to best visualise the 3D model of the transect. All the 2D images were put together to also produce an orthomosaic image.

This process produces a 3D point cloud and a Digital Surface Model (DSM) which captures topography along with all surface features like trees, buildings, etc. Therefore, this does not give information about elevation. To capture the actual elevation variations, LiDAR is more suitable.

LiDAR

Light Detection and Ranging is an aircraft mounted system that shoots lasers towards the ground and senses the return time of the laser reflection to measure elevation. It provides a high resolution and accurate Digital Elevation Model (DEM), even through dense vegetation. This is important as a significant proportion of the transect area is pine forest-covered sand dunes, and LiDAR

A DEM of the study site was available from the Land Information New Zealand (LINZ) Data Service website. It was dated 2014 and had a spatial resolution of 1 meter. The DEM was uploaded into ArcScene to produce a 3D hillshade layer to aid better visualisation of the topography. The hillshade layer was then made to float on the DEM layer for a 3D perspective. The orthomosaic image was then draped over the DEM to produce a final 3D model of the transect land to visualise elevation.

Soil

Sampling

Every time a change in soil colour was observed, while walking down the transect, a soil sample was taken. Overall, 11 soil samples were taken down the transect. Using an auger roughly the top 20cm of the soil was placed into zip lock bags, then using a Garmin GPS the location was recorded of the sampling site. The samples were then brought to the sedimentology lab for analysis.

Determine soil type

Three methods were used to determine soil type. Firstly, each sample was compared to the munsell soil-colour chart to determine soil type and age. Texture analysis was then used for each sample to determine if sediments are present. This was done by adding water to some soil and rubbing between two fingers. Stickiness indicates sediments are present while grittiness indicates sand is present. To observe the particle size range for the sample a high definition particle size analyzer was used. 10ml of soil was mixed using a magnetic mixer with 30ml of sodium hexametaphosphate solution. Using a pipette some of the solution mixed with the soil was placed into the particle size analyser until there was enough indicated on the computer. This then took roughly 20 minutes to analyse the sample and gave the data and was organised through Excel. The method was repeated for each sample.

pH

For measuring the pH, 5ml of soil was mixed with 25ml water in a beaker for each sample. This was then left for half an hour for the soil compounds to be absorbed into the water. A pH meter was then used, and the pH measurement was recorded. Between testing each sample, the measurement stick was washed in deionized water.

Soil moisture and organic material

To calculate the soil moisture and organic material the crucibles were marked from 1-11 and weighed. Then 15ml of soil from each sample was put into the correct crucible. They were then weighed again and put into a thermotec oven at 105 degrees Celsius overnight to remove any moisture from the samples. The dry soil was then taken out to cool and weighed again. Through measuring the before and after, this calculated the moisture percentage of each sample. The samples were then put into the thermolyne furnace for 3 hours at 650 degrees Celsius. Once this was done, they were taken out, left to cool and weighed again. Through this process, the organic material burns off and the weight difference represents the organic matter percentage.

GIS

After measuring pH, organic matter, and moisture content of each of the 11 soil samples, the data was uploaded as point features into ArcMap, along with the orthomosaic layer produced from the SfM process. The orthomosaic layer also provided a spatial reference to add the point features. To produce a map of the above soil characteristics for the entire study site (transect), an inverse distance weighted (IDW) interpolation technique was used (from the 3D analyst package in ArcMap). This method investigates the spatial pattern of the mentioned soil characteristics to answer our research question.

Results

Elevation

Results related to elevation and topography are divided based on methods accordingly, i.e. results from the SfM and LiDAR.

SfM

Figure 1 shows the dense point cloud produced by the SfM process. The shaded view of the dense point cloud is shown in figure 2, which is a digital surface model, and figure 3 shows the orthomosaic image (a bird's view of landscape).
As SfM produces a Digital Surface Model, it captures only surface level features like trees, buildings, water bodies, and land (if unvegetated). This does not provide information about elevation as noted earlier. Therefore, the coastal dune system is not captured by the SfM process, and the pine trees on the dune system seem to arise from ground up (see figure 3). Additionally, the anomaly (blue spikes) in the forefront of the image in figure 3 is due to the dynamic nature of waves. This results in different wave patterns in each image captured by the drone which the software does not know what to do with.

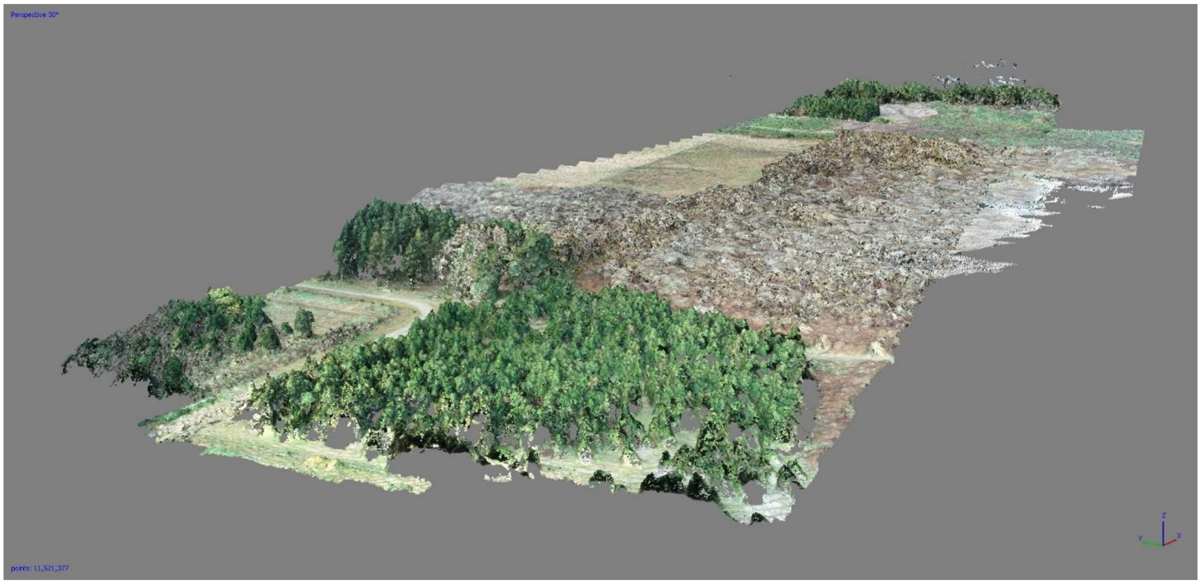

Figure 1: Dense point cloud model of the transect using SfM. The transect runs West to East, with the farther side of the transect in the figure being East.

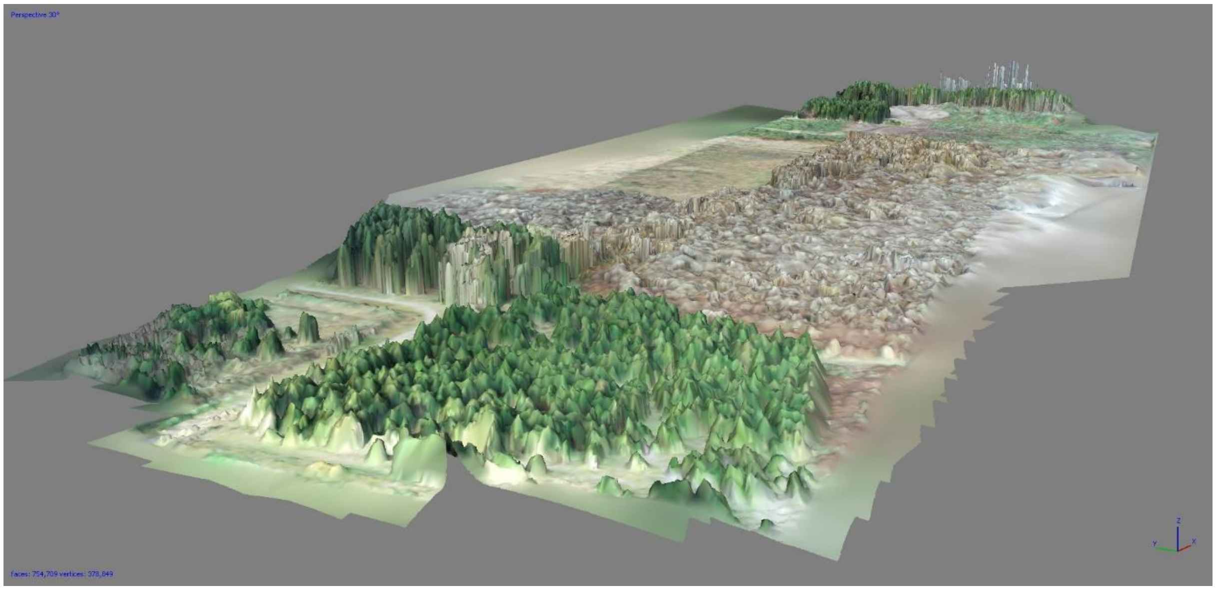

Figure 2: A shaded view (mesh view) of the dense point cloud in figure 1.

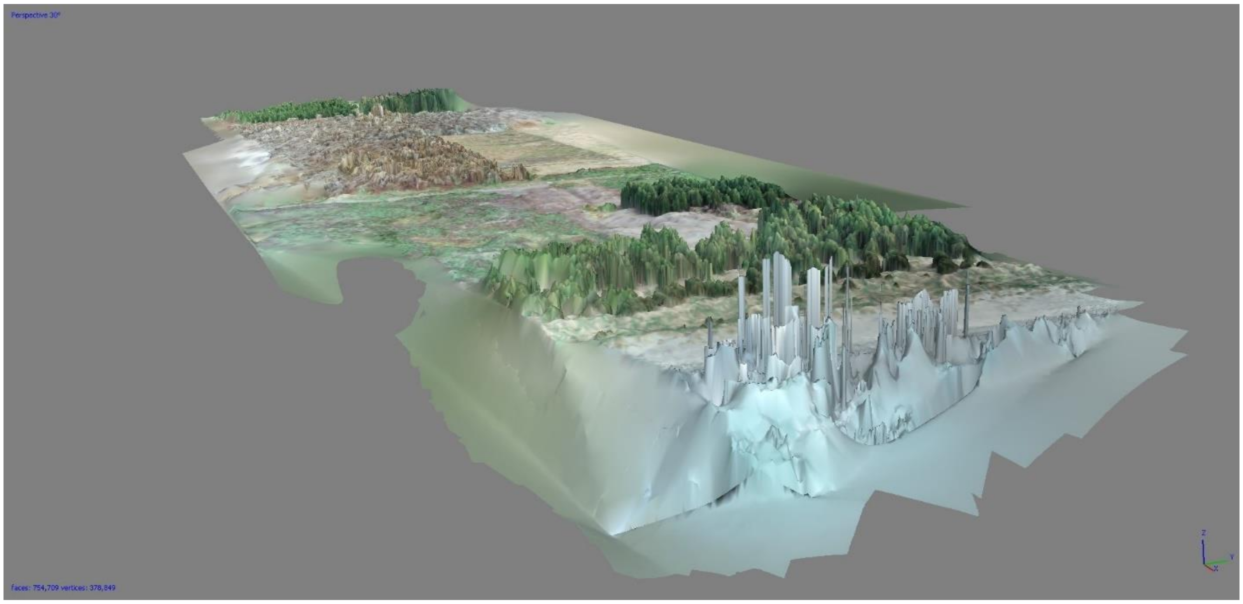

Figure 3: A mesh view of the 3D point cloud of the study site from a different perspective, as viewed from the East, facing West (landwards).

Figure 4: An orthomosaic image of the transect area produced in Agisoft Metashape.

LiDAR

The Digital Elevation Model (figure 4) shows the actual elevation variation of the ground surface, which excludes surface features like buildings and trees, unlike SfM. This is due to LiDAR's ability to "see" through terrain by using lasers. Figure 5 shows clear variation in elevation and the coastal dune system is easily distinguishable from the surrounding terrain in 3D view. Figure 6 shows our final 3D model of the study site, which made use of the orthomosaic image from the SfM process, and DEM by LINZ.

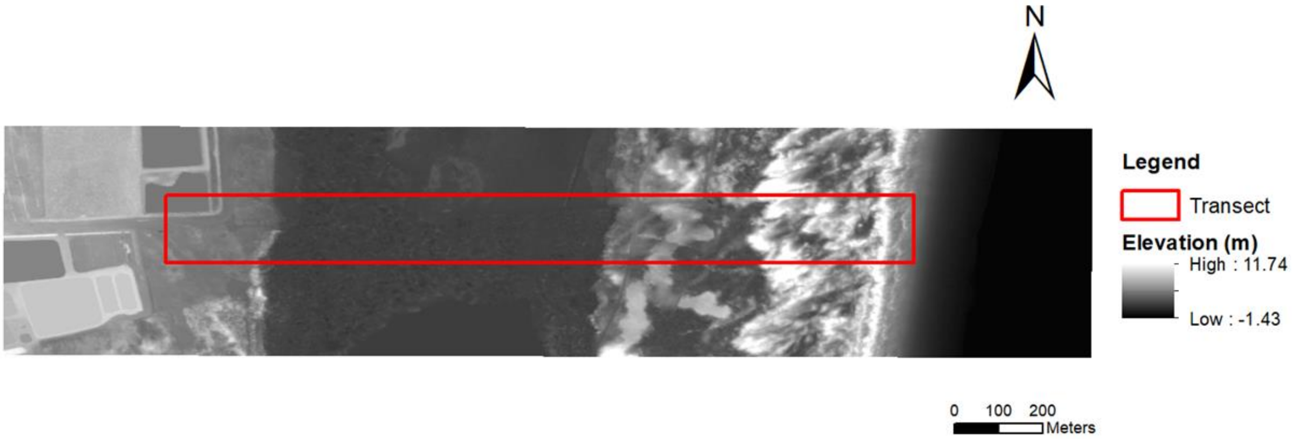

Figure 5: Digital Elevation Model of Tūhaitara Coastal Park, with the transect outlined in red. The highest elevation within the transect was 11.2 m and the lowest was 0.7 m.

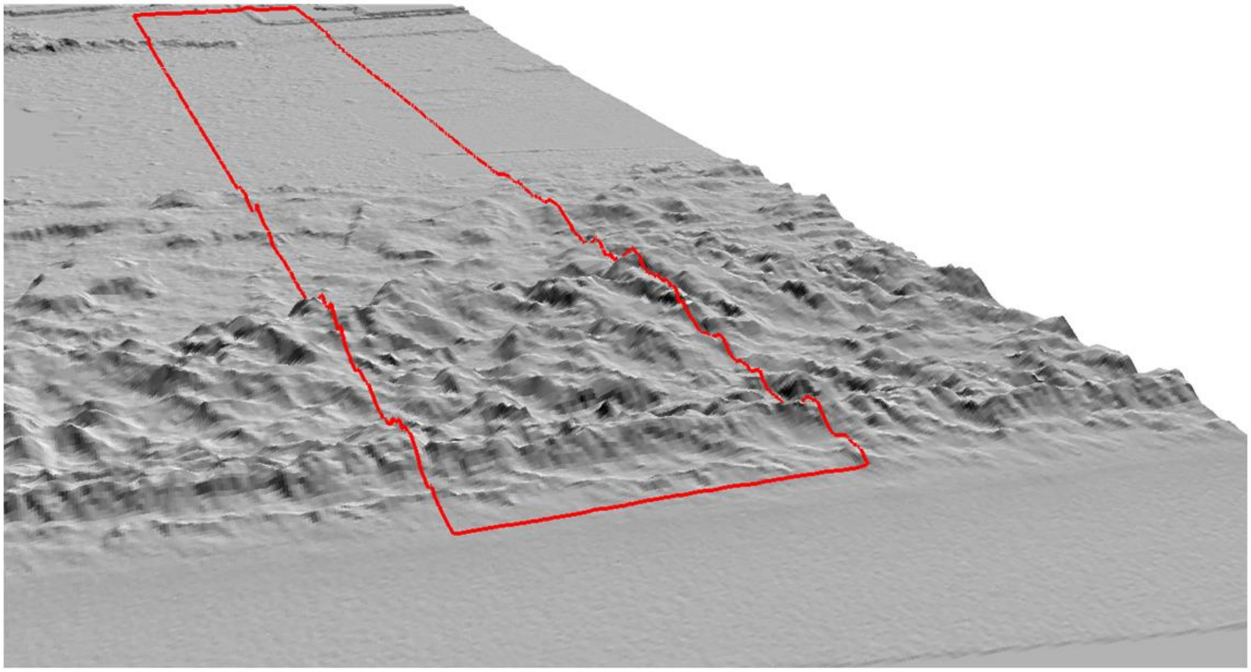

Figure 6: A 3D view of the Digital Elevation Model which clearly highlights the sand dune system that the Digital Surface Model was unable to. The red polygon corresponds to the transect area.

Figure 7: The final 3D model of the transect region, with the yellow points representing the locations of the soil samples. The forefront on the image is East, while the landward end of the transect is West.

Soil

Results show that from the 11 sediment size class graphs show there is a high amount of fine sand within the transect. Finer sediments increased spatially across the transact in samples 6-11 (Figure 12-17). Results found that not all sediment size graphs added up to 100 percent. We assume this was due to other unidentified material such as organic matter which the particle size analyser could not measure.

Note: Categorization of size classification (x-axis) for figures 1-11 are medium sand (0.50-0.25), fine sand (0.25-0.125), very fine sand (0.125-0.0625), coarse silt (0.0625-0.031), medium silt (0.031-0.0156) and fine silt (0.0156-0.0078) which is measured in mm.

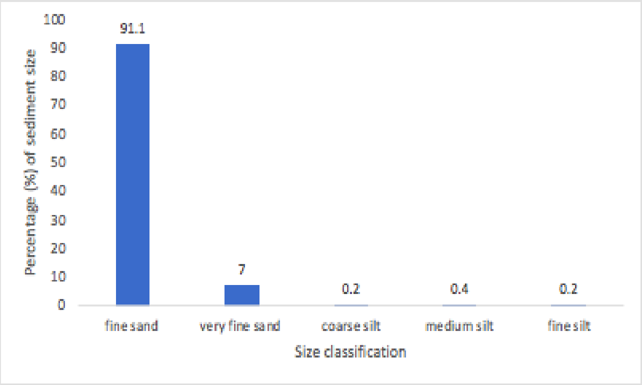

Figure 8 Graph presenting sample 1 percentage of sediment size.

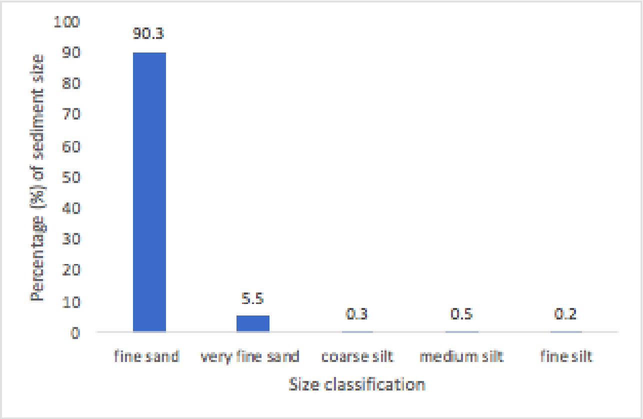

Figure 9: Graph presenting sample 2 percentage of sediment size.

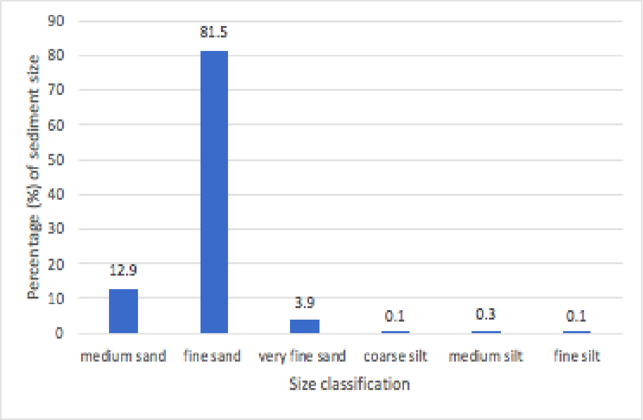

Figure 10: Graph presenting sample 3 percentage of sediment size.

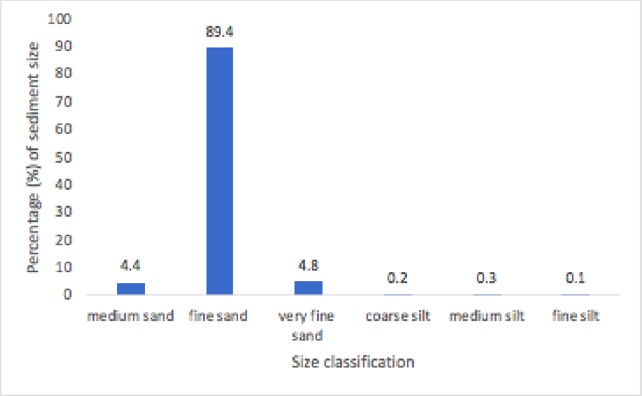

Figure 11: Graph presenting sample 4 percentage of sediment size.

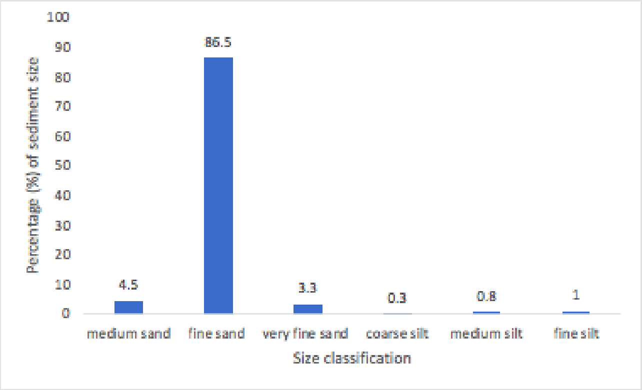

Figure 12: Graph presenting sample 5 percentage of sediment size.

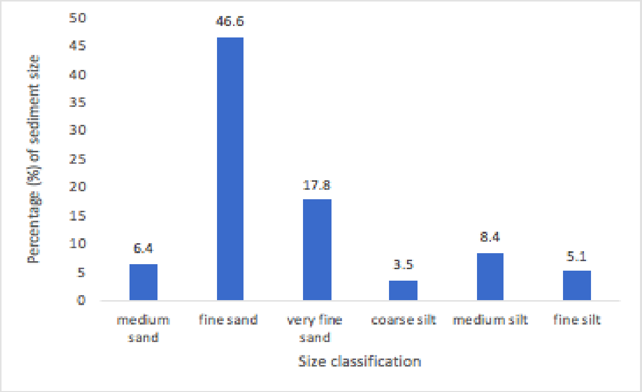

Figure 13: Graph presenting sample 6 percentage of sediment size.

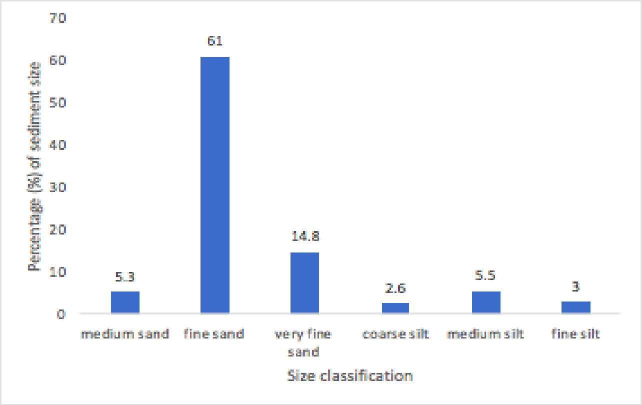

Figure 15: Graph presenting sample 7 percentage of sediment size.

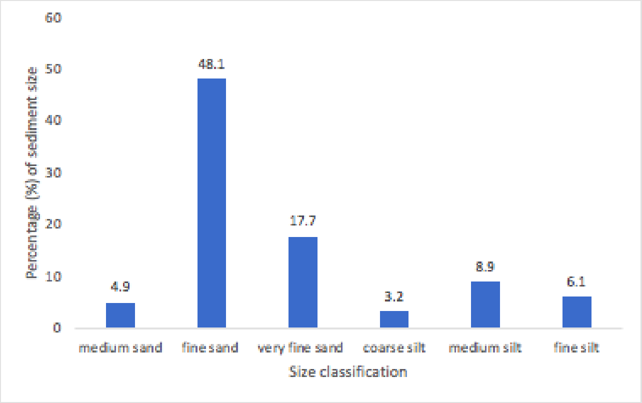

Figure 16: Graph presenting sample 8 percentage of sediment size.

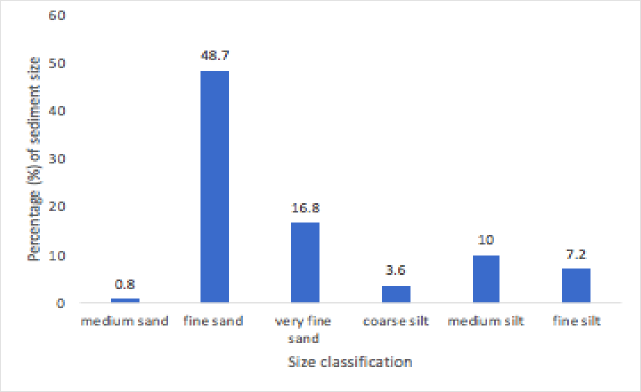

Figure 16: Graph presenting sample 9 percentage of sediment size.

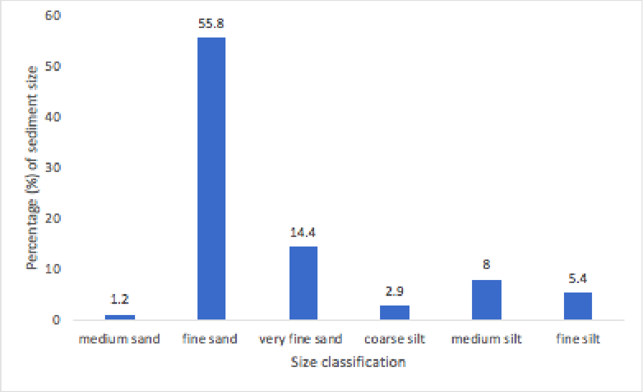

Figure 17: Graph presenting sample 10 percentage of sediment size.

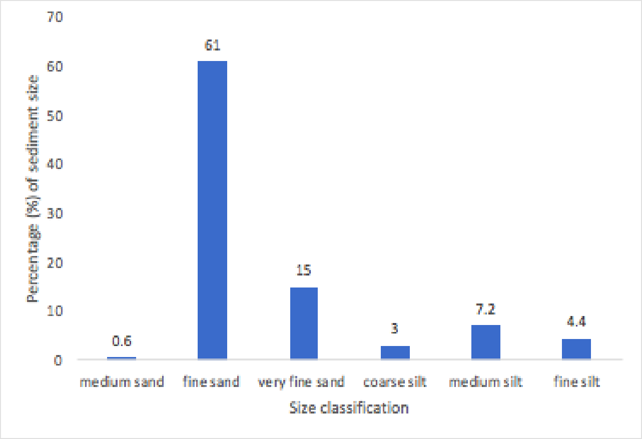

Figure 18: Graph presenting sample 11 percentage of sediment size.

These maps show Inverse distance weighted interpolation technique used to map the transect for variables like pH, moisture, and organic matter (Figure 20, 21 & 22). These maps visually help understand the variability across the transect.

The pH map shows the different pH measurements found across the transect vary from 7.4 - 4.5 (Figure 20). pH is very neutral in the dune section and becomes more acidic across the transect. Acidity greatly increases past sample 4 with a massive jump from 6.68 to 4.53 between samples 5 and 6. pH seems to vary between 5.9 to 6.9 across the wetland area.

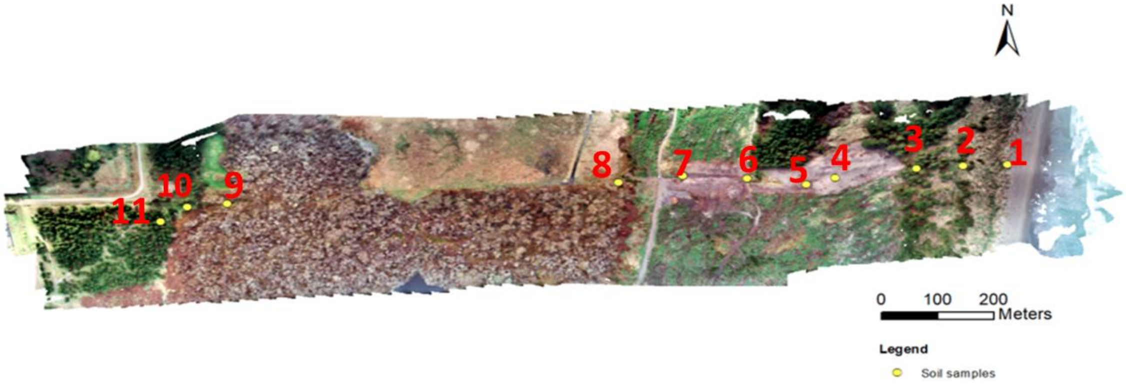

Figure 19: Image showing the soil sample locations along the transect.

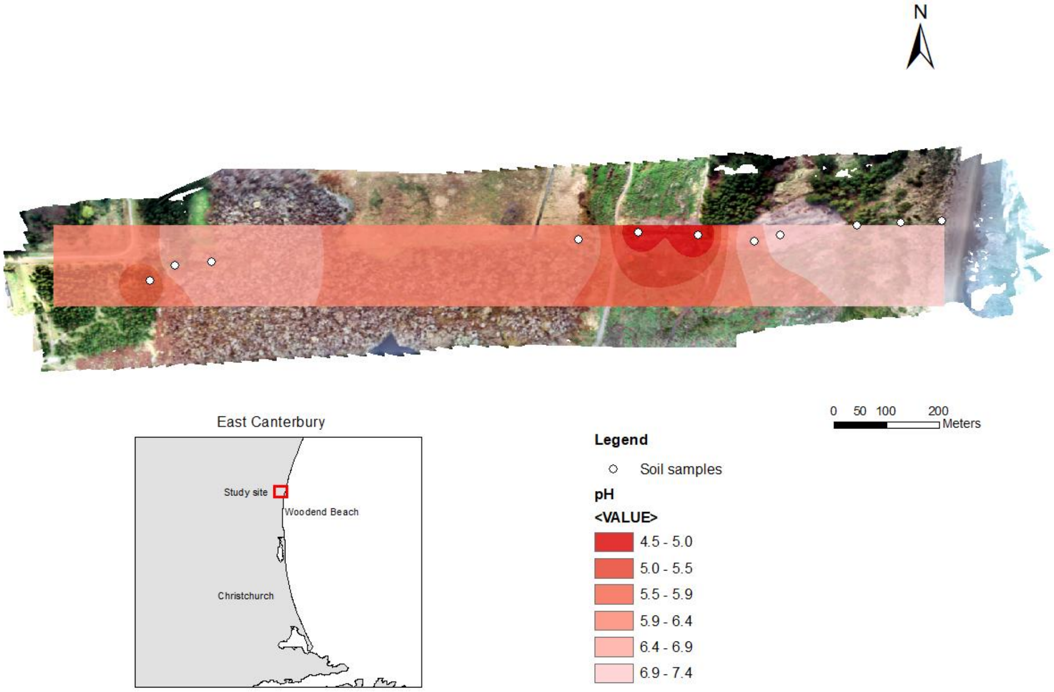

Figure 20: Map showing the Inverse distance weighted interpolated area of the transect measuring pH.

The moisture map shows the areas of moisture in the sediment of the transect. The range of moisture varies from 1.8 to 72.7 % of the samples. Moisture greatly increases around samples 8 and 9 in the transect.

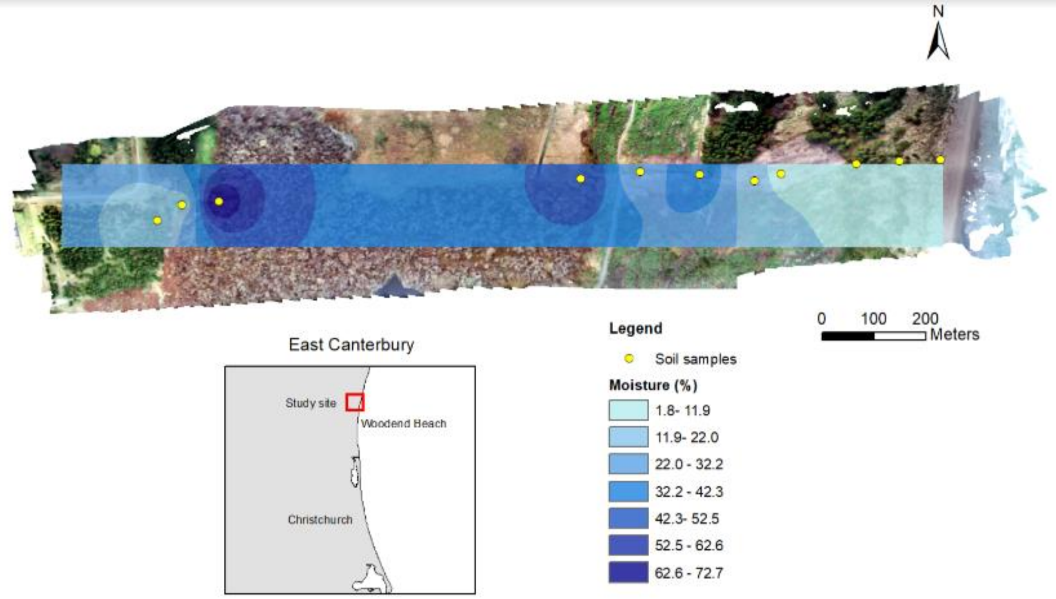

Figure 21: Map showing the Inverse distance weighted interpolated area of the transect measuring moisture

Figure 22 shows the areas of highly concentrated organic matter in the transect. We can see that organic matter is somewhat related to the pH map. The range of organic matter varies from 0.7 to 44.8. Areas with high organic matter and high soil moisture are particularly found near samples 6 and 9.

Figure 22: Map showing the Inverse distance weighted interpolated area of the transect measuring organic matter

Figure 23 shows the soil colour of each sample by using the munsell soil-colour chart. The difference between sand and silty were done by human observations to roughly determine the sediment size. The stickiness was measured to see if there were any clay minerals in the sediment. Sample 6

Soil Sample	Stickiness	Silty	Medium/ fine sand	Soil colour
1			✓	5/1 7.5 YR Gray
2			✓	5/2 10 YR greyish brown
3			✓	5/2 10 YR greyish brown
4			✓	5/2 10 YR greyish brown
5			✓	4/1 10 YR dark Gray
6		✓	✓	3/4 7.5 YR dark brown
7		✓		3/3 7.5 YR dark brown
8	✓	✓		2.5/1 7.5 YR dark brown
9	✓	✓		2.5/1 7.5 YR black
10	✓	✓		2.5/2 7.5 YR very dark brown
11	✓	✓		2.5/2 5 YR dark reddish brown

Figure 23 table showing the soil colour, sediment size and stickiness of the soil samples

Discussion

As you can see on the interpolated map the dunes are very dry with low moisture which explains why we saw a lot of sand binders and grasses thrive in this area (Figure 21). As we get down to the low land, moisture increase as we cross the wetland area of the lagoon. Therefore, we see an increase in finer sediments across this part of the transect as well.

The amount of smaller sediment in the samples increase from having mostly medium sand in the dune section to a variety of fine sand, very find sand, coarse silt, medium silt, and fine silt past the dunes and into the lagoon. Many variables can change the sediment size but the most noticeable is the interaction of the lagoon. Water bodies with low or stagnate energy tend to have finer sediments as morpho dynamics change sediment dispersal through a closed-in lagoon (Watson, 2013). Different sediment sizes in the samples also show the different processes of sediment transporting systems of coastal and fluvial systems. Clay minerals were found in the transect using human methods to distinguish between clay and no clay sediments. Clay minerals are somewhat sticky due to the sediment having a negative charge due to the electrochemical surface interactions increased cohesion in the sediment.

This data shows that there is a larger percentage of fine sand in the dunes but with a lesser percentage of finer sediment smaller than 125 microns. This could occur due to the grasses on dunes reducing sediment erosion on the beach through capturing sand from sediment transport processes like a creep, saltation, and suspension. However, saltation and suspension processes would lift finer sediment off the dunes and deposit them in back dunes or offshore (K. Salgado, 2017; Yokobori, 2020). This explains why we see an increase of these finer sediments in these back-dune areas in between foredunes and the lagoon. These finer sediments may have also been found in the lagoon as it would have been more tide-dominated allowing greater influence by coastal processes of sediment transportation.

In these pH maps, we found that as organic matter percentage increases the pH decreases to become more acidic (Figure 20). There is a strong link between the pH of soil and the types of vegetation that thrives in these areas (Husson, O. 2013). There was found to be a change in places of high vegetation due to plants fluctuating the pH levels in the soil. Plants naturally produce more organic acid and depending on the type of plant can change how acidic or neutral in this case the soil can be.

You can see there is higher acidity around samples 6 and 7 (Figure 20). Sample 6 was taken within a biota node. A biota node is a small micro-climate where the trust has dug a hole until they reached the water table. There tended to be a high-water table due to groundwater systems located near the surface. Once the hole was dug, they then planted a selection of native plants that have now flourished into trees. This was done on a harsh dune-based sand environment with low organic material and moisture levels. Their goal of the biota node is to create a number of these areas in the coastal park to increase native diversity. The plants will attract local birds which will add seed dispersal around the coastal park (M.B.W. Maurer, 2019). Most of the Canterbury region use to be a wetland ecosystem. Studies have been done which show old flood plain and swamp sediment deposits being the main composition of the sediments in Christchurch and with high-water table/groundwater interactions with the surface. This explains why a pool of water is accessible in these dune environments. With further knowledge shown in the study by Zhu J (2017) discusses how the interactions with these groundwater systems can fluctuate depending on the environment. There is a limited understanding of groundwater systems as they are difficult to map.

This project can be used by finding optimal locations using the maps for specific plant species. For example, if the optimal pH, organic matter and soil moisture content for Kahikatea is known, locations on the map can be identified for where these optimal conditions are present using GIS tools like raster intersection. This could potentially be a future GEOG309 project where students find optimal soil conditions for native NZ species. We recommend investigating the spatial pattern of other soil characteristics such as soil phosphorus, nitrogen and salinity, as they can impact plant growth.

The planting for this restoration project has already started. This provided our group with the unique opportunity to create a baseline dataset for this transect as well as a snapshot of the current environment. As the plants mature and the land changes characteristics, we can revisit the data and study the changes that have occurred. Tūhaitara Coastal Park already has a wealth of different studies conducted within the area, and our research project adds to this bank of knowledge. This could be used by future GEOG309 projects to access information about the transect characteristics prior to any restoration. Ultimately, providing an increased understanding of the transect area and its surrounding landscapes.

Many groups within the community such as volunteers and school groups are involved with Tūhaitara coastal park’s different restoration projects. Therefore, our maps can provide the community with a way of looking back at how the landscape was and be able to compare to see their progress.

This transect is being set up as a demonstration site of a restored native coastal forest sequence and is going to be used by the Trust as a guide to help inform other local restoration projects. Due to the transects varied range of habitats, a majority of smaller restoration environments within the Coastal Canterbury region will be represented by our data. Through matching similar soil and topographic characteristics of their site to our data, the transect becomes a guide they can use to predict which plant species would thrive most in specific locations. This will allow them to adjust their plan accordingly and ensure the best circumstances for successful plant growth and establishment. Overtime, the transect and our 3D models will help our community partner be better informed to successfully guide native restoration efforts all throughout the Canterbury region.

Conclusion

The aim of our project was to produce a digital model through mapping the spatial distribution of soil characteristics and topography of the 1.5km transect located at Tūhaitara Coastal Park. Through surveying the land and analysing our data, we have been able to produce maps showing different environmental aspects of the transect. Our results show that the lands soil characteristics and topography does vary spatially across the transect. Therefore, this data can now be used by our community partners as an important tool to help analyse and identify different micro ecosystems located throughout the site.

Due to the transect covering many different environments, it was important for us to map the different spacial variation as accurately as possible. With our maps and data, we can help aid our community partners to identify optimal conditions and locations for successful plant establishment. Our data can also help to accurately plan how many plants will be needed in each area. With the transect ground mapped, our community partners will be able to see exactly how much space each different environment contains and plan the plants accordingly. Through this process, it can reduce costs and time spent on the project. By combining our soil analysis data with the topography and orthomosaic image of the transect to plan the restoration, the likelihood of restoration failure can be reduced considerably.

This is important as the project is a community effort, and everyone wants to see it succeed. With the help of our visuals, we can ensure the right plants are placed within the right location and have nature take care of the rest.

Limitations

Due to the limited amount of time and inaccessibility there were a few limitations regarding the soil sampling and analysis. One of the limitations from this research is only having 11 soil sampling for long the 1.5km transect. This was due to limited amount of time to do all the soil analysis and inaccessibility of the wetland section of the transect. On the day of field data collection, it was raining which caused the wetland to be inaccessible. As a result, we took samples at either ends of the wetland. Therefore, the soil data shown in figure 18, 19 and 20 is not very accurate. For similar future research it would be recommended to do more samples to increase accuracy. Soil analysis of each sampling could have been more accurate by doing multiple tests and finding the average. This could have been done for pH and particle size analysis.

The models of the transect we have produced for our community partners use programs such as ArcGIS and ArcScene. While we have provided images of the map model outputs from different angles, if our community partners wanted to access and manipulate our findings for specific reasons, they would need to have knowledge on the program, and it’s uses. This could be a limitation as Tūhaitara would need to buy the program if they do not have it already and even then, these programs can be difficult to understand without the required skills.

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References

Blossfeld, S. (2008) Plant growth dynamics in relation to soil moisture, oxygen concentration and pH-value [Thesis Dissertation]. University of Dusserldorf.

Cordell, S., Questad, E. J., Asner, G. P., Kinney, K. M., Thaxton, J. M., Uowolo, A., Chynoweth, M. W. (2017). Remote sensing for restoration planning: how the big picture can inform stakeholders. Restoration Ecology, 25(S2), S147-S154. doi:10.1111/rec.12448

Barbosa, J. M., & Asner, G. P. (2017). Prioritizing landscapes for restoration based on spatial patterns of ecosystem controls and plant–plant interactions. Journal of Applied Ecology, 54(5), 1459-1468. doi:10.1111/1365-2664.12857

Husson, O. (2013). Redox potential (Eh) and pH as drivers of soil/plant/microorganism systems: A transdisciplinary overview pointing to integrative opportunities for agronomy. *Plant and Soil, 362*(1/2), 389-417.

Łabuz, T. A. (2016). A review of field methods to survey coastal dunes—experience based onresearch from South Baltic coast. Journal of coastal conservation, 20(2), 175-190.doi:10.1007/s11852-016-0428-x

Magni, P., De Falco, G., Como, S., Casu, D., Floris , A., etl,(2008) Distribution and ecological relevance of fine sediments in organic-enriched lagoons: The case study of the Cabras lagoon (Sardinia, Italy), Marine Pollution Bulletin, (Volume 56, Issue 3,Pages 549-564,ISSN 0025-326X) https://doi.org/10.1016/j.marpolbul.2007.12.004.

Maurer, B.W., Green, R.A., van Ballegooy, S., Wotherspoon, L., (2019). Development of region-specific soil behavior type index correlations for evaluating liquefaction hazard in Christchurch New Zealand, Soil Dynamics, and Earthquake Engineering. (pp. 96-105 volume 117).

Mlambo, R., Woodhouse, I., Gerard, F., & Anderson, K. (2017). Structure from Motion (SfM) Photogrammetry with Drone Data: A Low-cost Method for Monitoring Greenhouse Gas Emissions from Forests in Developing Countries. Forests, 8(3), 68. doi:10.3390/f8030068

Payn, K., Yin, C., Khatri, N., Merfield, G., Fanslow, B., (2017). A study of sea-level rise impacts on landscape and community' Coastal Erosion in the Tūhaitara Coastal Park, UNIVERSITY OF CANTERBURY GEOG309 Project Report (pp. 1–18).

Pearse, G. D., Dash, J. P., Persson, H. J., & Watt, M. S. (2018). Comparison of high-density LiDAR and satellite photogrammetry for forest inventory. ISPRS journal of photogrammetry and remote sensing, 142, 257-267. doi:10.1016/j.isprsjprs.2018.06.006

Salgado, K., Luisa Martinez, M., (2017). Is ecosystem-based coastal defence a realistic alternative? Exploring the evidence, CrossMark, (pp. 1-12). Routledge.

Sobanski, N., & Marques, M. C. M. (2014). Effects of soil characteristics and exotic grass cover on the forest restoration of the Atlantic forest region. Journal for Nature Conservation, 22(3), 217-222. doi:10.1016/j.jnc.2014.01.001

Tarolli, P. (2014). High-resolution topography for understanding Earth surface processes: Opportunities and challenges. Geomorphology (Amsterdam, Netherlands), 216, 295-312. doi:10.1016/j.geomorph.2014.03.008

Yokobori, M., Kuriyama , Y., Shimozono, T., Y. Tajima (2020). Numerical Simulation of Volume Change of the Backshore Induced by Cross-Shore Aeolian Sediment Transport' Marine science and engineering. (pp.1–20, Volume: 8 Issue: 6).

Zhu, J., Sun, G., Li, W., Zhang, Y., Miao, G., Noormets, A., . . . Wang, X. (2017). Modeling the potential impacts of climate change on the water table level of selected forested wetlands in the south-eastern united states. *Hydrology and Earth System Sciences, 21*(12), 6289-6305. doi:http://dx.doi.org.ezproxy.canterbury.ac.nz/10.5194/hess-21-6289-2017