Implications of flooding the Pines Beach Wetland

UNIVERSITY OF CANTERBURY
GEOG309 RESEARCH PROJECT REPORT

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Executive Summary

Pines Beach Wetland makes up 36ha of Tūhaitara Coastal Park. Due to climate-induced sea level rise, the wetland is vulnerable to tidal flooding and intrusion of saltwater. This will have implications on community flood risk, wetland sedimentation and ecology.

Methods:

- Primary analysis:
    - A drone was used to create a 3D structure from motion model to analyse vegetation dispersal.
    - A CyberScan conductivity meter was used to collect conductivity of the water at 6 different locations.
- Secondary analysis:
    - Secondary data was used to generate a digital elevation model and digital surface model to display elevation and quantify vegetation density.
    - Bathtub flood models of the community and surrounding area, for 0.5m, 1m and 2m flooding scenarios were generated.
    - Historic imagery was used to identify the location of the past opening.
- **Key findings:**
    - Increased flood risk to Pines Beach community, ability to mitigate against this risk depends on economic capabilities of Te Kōhaka o Tūhaitara Trust.
    - The wetland is susceptible to infilling, which may need expensive dredging to mitigate against.
    - Based on previous research it is inconclusive as to whether the wetland will infill at the same rate as sea-level rise.
    - The intrusion of saltwater will have several benefits on the ecology of the wetland.
- **Shortcomings or limitations:**
    - Scope of the research question: several implications are covered in broad detail due to time restraint and limited resources.
    - Sampling method: Convenience sampling was used to decide where to take water samples.
    - Bathtub model: A bathtub model is a simplistic model that does not factor in other variables that will affect the severity of flooding.
- **Suggestions for future research:**
    - This is only the beginning of the research that needs to be done to answer the question. Research needs to be built upon to determine whether Pines Wetland should be reopened.

Introduction

This report investigates the potential impacts of opening the Pines Beach Wetland to the ocean. This project was posed and presented by the Te Kōhaka o Tūhaitara Trust (TkoT), the management body of the wetland and its surrounding land. The scope of this report includes consideration of impacts on flood risk, sedimentation and ecology.

Study Site

Pines Wetland is a 36ha palustrine ecosystem located within the Tūhaitara Coastal Park, in the Waimakariri District of Canterbury (Figure 1). In the late 1960s, the wetland was manually closed off from the ocean to prevent flooding of the local Pines Beach community (Figure 2). Before it was closed, the wetland was a shallow lagoon, part of the Pines Beach back-beach system, periodically flooded by Spring tides and events of high water (A.Crossland, personal communication, August 10, 2020). It is believed that the closing of the wetland involved the establishment of tall foredunes between itself and the ocean. The coastal park is a site of both ecological and cultural importance, with the northern Tutaepatu lagoon holding mahinga kai status and its surrounding land containing the Urupa for Turakautahi, who founded the Kaiapoi Pa.

Figure 1. Map of East Canterbury and the Pines Beach Wetland.
Images from Google Maps.

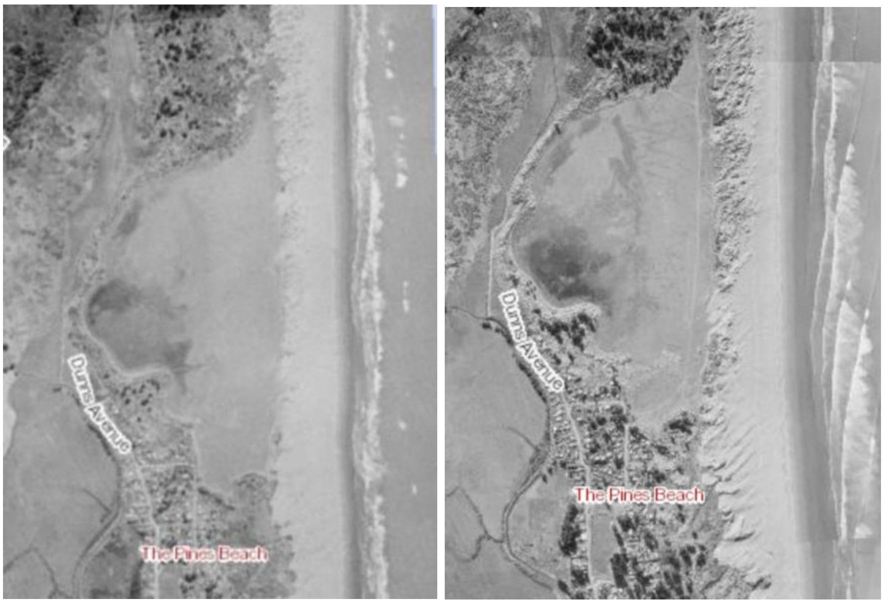

Figure 2. Aerial photographs of Pines Beach Wetland depicting its state from 1955-59 (left) and 1960-64 (right). (Canterbury Maps, 2018)

The park has been managed by TkoT since the late 1990s, after it was returned to Ngai Tahu by the Crown in a Treaty of Waitangi land settlement (Te Kōhaka o Tūhaitara Trust, 2015; Whitelaw, 2011). The vision of the trust is to restore the park to a mature indigenous coastal ecosystem, representative of a natural Waitaha. Their plan considers management strategies for up to 200 years from now.

Purpose

TkoT believes that over the next 200 years, climate change-induced sea-level rise (SLR) will cause the ocean to flood the wetland. They wonder whether it would be worth establishing an opening now, to introduce saltwater back into the ecosystem and manage the wetland as a brackish environment. This may ensure its resilience to SLR in the future and reduce the damage that saltwater may do if this wetland continued to establish and mature as a freshwater environment.

Literature Review

An assessment of papers concerning the susceptibility of Christchurch to climate change discusses the importance of acting hard and fast for community protection and mitigation of SLR (Harman, et al. 2015; Hirabayashi, et al; 2013). Mitigation methods include soft and hard defence structures (Harman, et al. 2015), both of which are likely to be required in the Pines Beach community in the future due to the areas' susceptibility to flooding (Donnelly, et al. 2016; Hart & Knight, 2009). Limitations to the use of these structures include their high installation costs. Therefore, while mitigation is important to consider for this project, mitigation alone will not be a sole solution to the potential flood impacts that opening the wetland may cause.

Whitelaw's thesis (2011) is the most substantial existing literature that investigates the effects that SLR will have on sedimentation in this area. Levieveld et al. (2018) and Whitelaw (2011) agree that the park is an area of high sedimentation. However, the rate of SLR versus sedimentation has not been determined. Shulmeister & Kirk (1993) found that fluvial processes dominate sedimentation in Pegasus Bay, and in Whitelaw's thesis (2011) the vulnerability of the coastline to the effects of SLR will depend on the Waimakariri River as a reliable sediment source.

Reports of the Pines Wetland biodiversity from (A.Crossland, personal communication, August 10, 2020), Parker (2012) and (G. Byrnes, personal communication, September 23, 2020) all discuss the increased benefits that reintroducing saltwater may have on the ecology of the wetland. Such benefits include the reintroduction of migratory aquatic fish and invertebrate species and an increased abundance of birds. While these predictions are supported by research from Portnoy (n.d.) and O'Donnell (2000), they rely on profiles of the biological state of the Pines Wetland while it was still (at least partially) saline and do not consider the potential benefits from allowing the freshwater regime to further establish. Without a thorough understanding of the species profile currently, it is hard to say how much benefit will occur (i.e. is the biodiversity degraded to begin with?). If the ecology is already diverse, then the introduction of saltwater could decrease biodiversity, at least initially, as discussed by Pierfelice et al (2015).

The transition from a freshwater environment to a saline environment will significantly change the species of flora present in the Pines Wetland area. Increased rates of saltwater intrusion and inundation could cause changes in the composition of plant communities by modifying rates of growth and seed germination (Neubauer, 2013). Grey willows (Salix cinerea) and pine trees (Pinus radiata) have salt tolerances that range from sensitive to moderately tolerant (Mirck & Zalesny, 2015). The introduction of saltwater will kill off these invasive plants and make way for the re-establishment of salt-tolerant native plants.

Methodology

Primary data analysis

Structure from motion (SFM)

Aerial imagery was captured using a DJI Phantom 4 RTK unmanned aerial vehicle (UAV). This drone was selected as it has a high accuracy onboard global navigation satellite systems (GNSS) receiver to geolocate the images, and it has a high definition 20-megapixel camera, leading to an aesthetic and accurate model. Before the UAV was in flight, a DJI D-RTK 2 GNSS receiver was set up as a base station; this receiver was left running throughout the flight and could be used for post-processing afterwards to improve location accuracy. To gather the data, an autopilot was set up using the DJI Ground Station Pro app. Sufficient overlap between photos is needed to produce a quality SfM model. Usually, 70% overlap is optimal, however, due to masses of thick vegetation, 80% overlap was required to provide a smooth model.

The aerial UAV data was processed in Agisoft Metashape to produce the SfM model. Images were stitched together to produce an orthomosaic of Pines Wetland. Stitching was done automatically due to the onboard GNSS receiver, otherwise, ground control points would have been required and the images would have to be manually stitched. This would have been a time-consuming process as there were over 600 images, therefore, the DJI Phantom 4 RTK was an obvious choice. A point cloud was formed from the orthomosaic, which was then used to produce a digital surface model. The orthomosaic was draped over a digital surface model to add a 3D aspect to the image. The SfM model was vital when analysing the vegetation dispersal across Pines Wetland. As vegetation was too thick to easily access some areas on foot, an aerial 3D SfM model proved beneficial to familiarise the group with the area.

Water testing
Water conductivity was measured using a CyberScan conductivity meter. Convenience sampling was used when measuring water conductivity near the road on the Eastern side of Pines Wetland. Six areas of the wetland were tested for conductivity. The water was tested twice at the Southern end of the road, twice at the Northern end and twice from the middle of the wetland. Three water samples were also gathered along the road; however, it was decided that conductivity was sufficient for predicting salinity and these water samples were unnecessary.

Secondary data analysis

Digital Elevation Model (DEM) / Digital Surface Model (DSM)
Secondary DEM and DSM data were gathered from Land Information New Zealand (LINZ) (2014). DEM and DSM are computer-generated models that display the elevation of topography. A DEM will display elevations of the ground surface and a DSM will factor in other reflective surfaces (e.g. vegetation/buildings). The DEM proved that Pines Wetland is only 1m above sea level, detailing how at-risk this area will be to sea-level rise. The DEM and DSM were also used to quantify vegetation density in Pines Wetland. This was done by using the raster calculator tool in ArcMap to find elevation differences between the DSM and the DEM. As the DEM will show elevation of the ground surface, and the DSM will show elevation of the vegetation, the difference layer will show the height of vegetation.

Flood modelling

The LINZ (2014) DEM was used to produce bathtub flood models of the Pines Beach community and areas surrounding Pines Wetland. The raster calculator tool in ArcMap was used to produce the flood model. The reclassify tool was used to remove areas of non-flooding from the model so that an aerial image could be seen. It was specified in the calculator that flooding of 0.5m, 1m and 2m should appear on the model. It was decided that a 3m water level would be unrealistic so a 2m maximum flood was displayed.

Historic photography

Historic aerial imagery named the 'black maps' was sourced from the Canterbury Maps (2018). In the late 1960's Pines Wetland was once open to the ocean, before closing naturally. The black maps provide insight into where this opening was located. As none of the residents were able to provide information around the characteristics of the wetland when it was open to the ocean, the black maps were invaluable for our analysis.

Results

The SfM model (Figure 3) depicts the layout of the wetland. It shows the fringes of the Pines Beach community to the south-west and a body of permanent standing freshwater in the west. The wetland is partially vegetated by introduced species, such as grey willows (Salix Cinerea), and a mixture of invasive grasses.

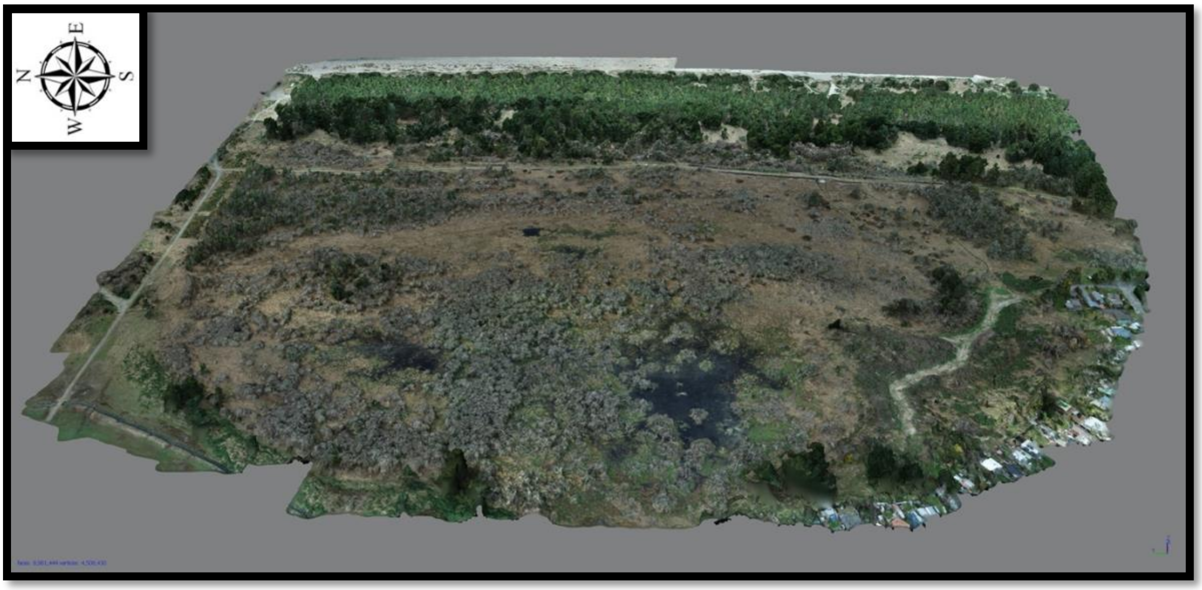

Figure 3. A Structure from Motion (SfM) model of the Pines Beach Wetland.

The DEM map in Figure 4 shows the elevation of the wetland, marked out in red, compared to the elevation of the ocean. The wetland and the current sea level appear to lie at comparable elevations, approximately 1-2m (±1m). The dunes between the Pines Wetland and ocean have an approximate height of 8-10m, which lie to the right of the wetland.

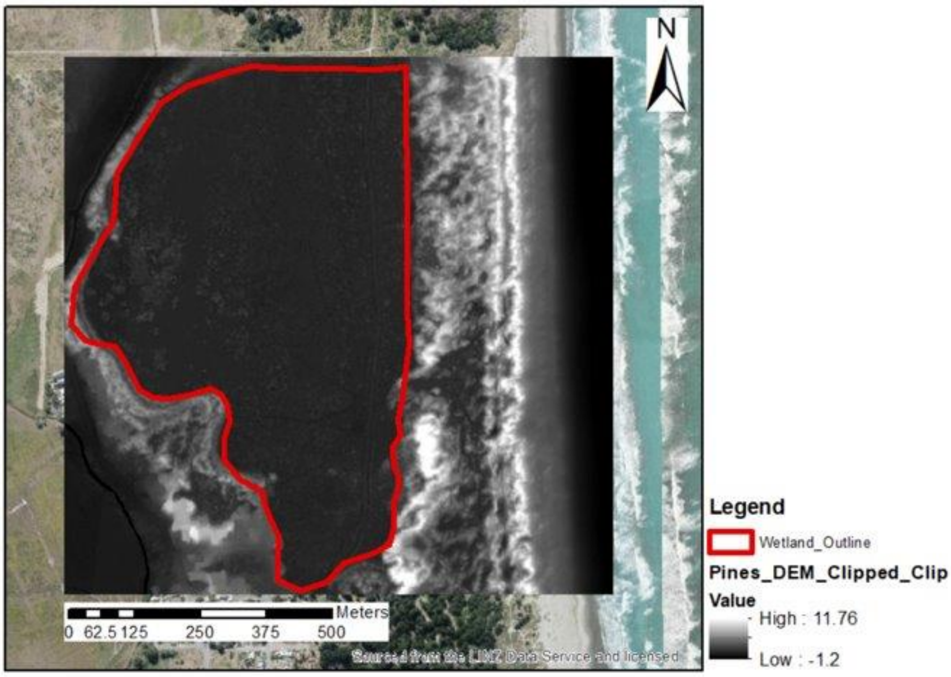

Figure 4. A digital elevation model (DEM) of the Pines Beach Wetland (outlined in red).

The DSM in Figure 5 shows the elevation of the vegetation canopy in the wetland. The pine belt in the east has an elevation of up to 34m, with the wetland lying mostly at around 1-8m in height. Overall, the vegetation in the wetland is low lying.

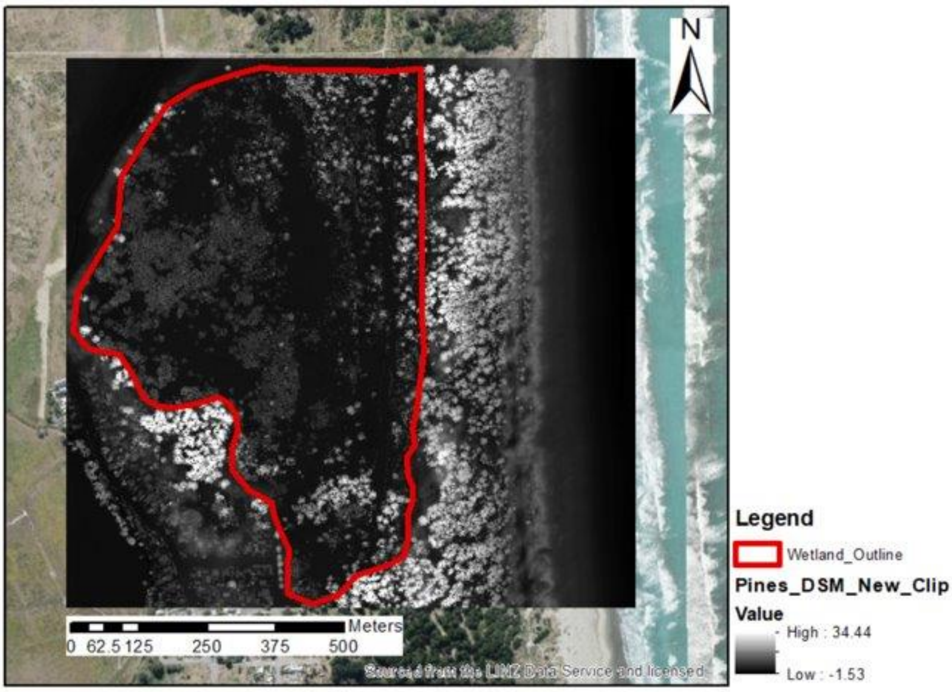

Figure 5. A digital surface model (DSM) of the Pines Beach Wetland (outlined in red).

Based on the bathtub model of flood inundation in Figure 6, it appears that most of the Pines Beach community is 1m above mean sea level (MSL) and at least half is above 2m. The community is at some risk of flooding from SLR directly, and some from the Kairaki Creek running behind the community. It is important to note that the bathtub model does not consider the effects of local hydrodynamics and the accumulation of water during storm events or tsunamis, storm surges and king high tides during the spring months, so this map does not capture the full extent of potential flooding on the community. This is discussed in further detail later.

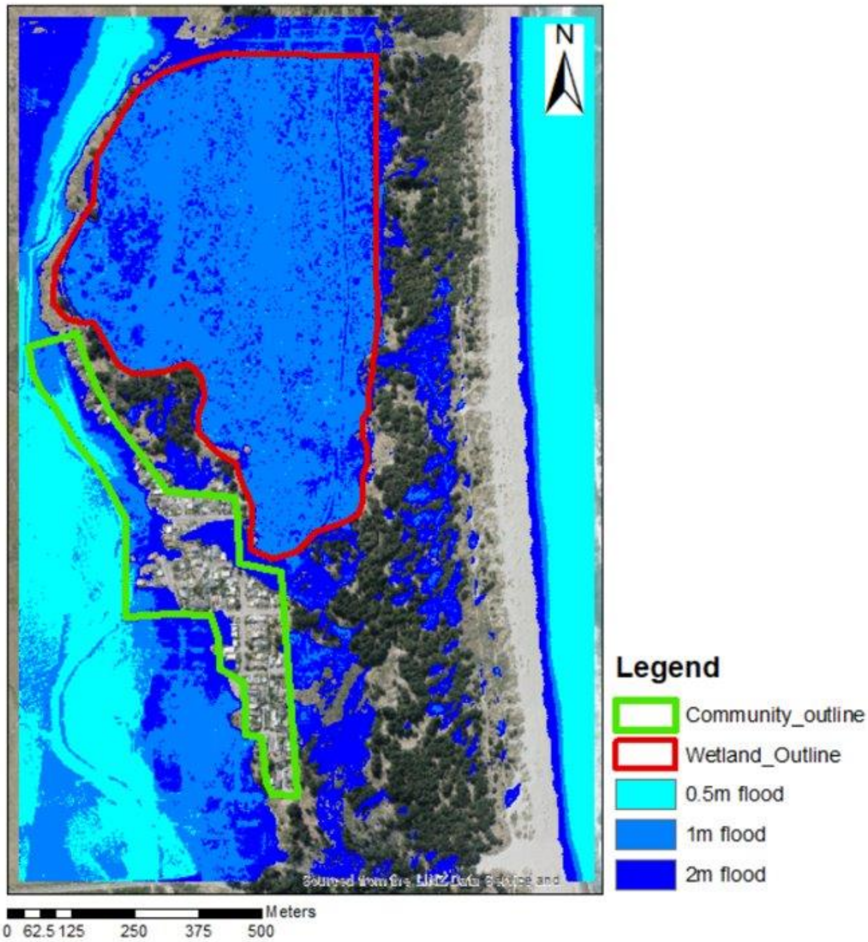

Figure 6. A flood extent map for the Pines Beach wetland showing SLR scenarios of 0.5m, 1m and 2m.

Discussion

Community flood impacts

The Pines Beach community is relatively small, located north-west of the Pines Beach wetland. The community has been established since the settlement of Māori, around the year 1000, therefore, this area holds cultural and historical significance. Most of the community's properties, housing and buildings are only just over the 1m above MSL mark (Figure 6). Figure 4 indicates that even at the lowest levels of flooding (0.5m), the community will be affected by flooding through saltwater intrusion. A high groundwater table coupled with events of high tides and storms also increase the risk of water accumulating in the wetland and causing larger floods. SLR projections for New Zealand estimate that the mean sea level will rise by 0.5m between 2050-2150, meaning that the community may need to act within the next 30 years (NIWA, n.d.).

Mitigation has two approaches, soft and hard defences. Soft defence involves retreat/relocation or building the houses onto higher foundations/piles. Hard defence involves civil engineers planning and constructing structures like levees, groynes, stop-banks and channelling for floodwaters to exit the area. Both approaches are very expensive, with costs for moving a house in-land by 7km costing approximately $170,000 (NIWA, n.d.). Hard engineering can cost from hundreds to millions of dollars, depending on the extent of the project. Therefore, mitigation for flooding of the Pines Beach community could be a financial burden for TkoT and will most likely require financial support from other regulatory bodies, which may not be granted.

Allowing the ocean into the wetland could push freshwater springs in-land. This would salinize freshwater reserves underground, turning them brackish and leaving any bores in the vicinity unusable for human consumption and irrigation. The surrounding agricultural land will also be vulnerable to saline intrusion, affecting the viability of these soils for agriculture and cultivation. Weather pattern changes due to climate change are predicted to cause more extreme flooding events, with the frequency of tsunamis, storm surges and tropical cyclones increasing (Walsh et al., 2012). Christchurch is particularly vulnerable to extreme events, as it has the highest red alert days, predicted very high tides and increased coastal flooding potential (NIWA, n.d.).

What is happening to the Pines Beach community is happening to many coastal communities as pressure from climate-induced SLR threatens their ability to continue to occupy their homes. This has negative effects not only on people's physical security but also their mental health, with the potential for fear and worry of SLR to lead to social disharmony (Asugeni, 2015).

Sedimentation

The coastline along the coastal park has coastal barriers in the form of sand dunes and large pine trees (Figure 3). These features protect the wetland and park against beach erosion processes such as moderate-high energy waves, storm surge and dominant onshore winds (Whitelaw, 2011). Only 5% of the sediment on Pines Beach comes from offshore sources, while 95% comes from the Waimakariri, Waipara and Ashley rivers. The Waimakariri River is the main source of sediment to this coastline, contributing 77% of the 95% to the wetlands' influx (Whitelaw, 2011). Because of the dynamic beach processes and large sediment supply, Pines Wetland is susceptible to infilling if reopened to the ocean. This is an important factor to consider, as infilling may require the wetland to be dredged each year to remove excess sediment from the opening. Dredging is very expensive, with costs for dredging the Styx wetland costing the Christchurch City Council $125 per cubic metre (CCC, 2017). If the same attention were required for Pines Wetland, this project could become an ongoing financial burden to TkoT.

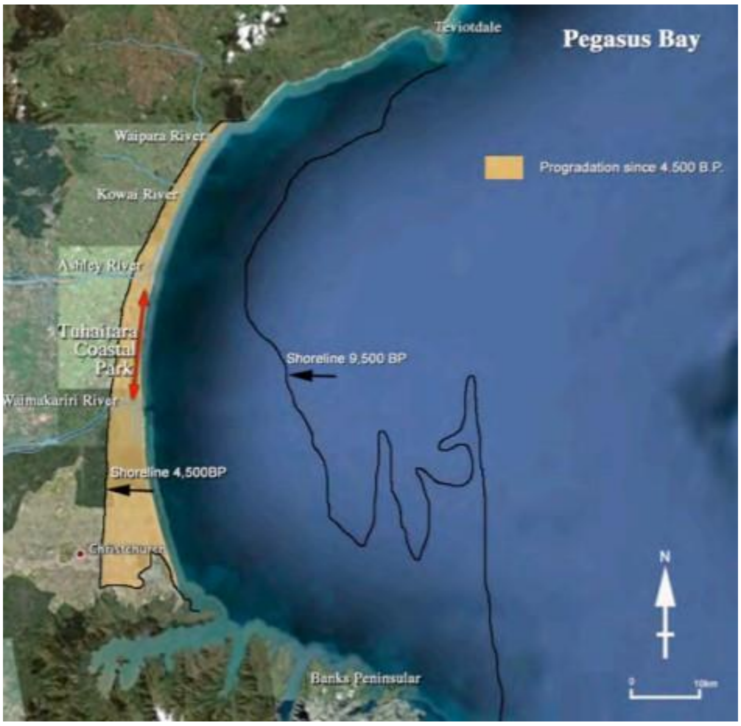

*Figure 7. S*horeline. The shoreline of Tūhaitara Coastal Park 9500 B.P., 4500 B.P., and progradation 4500 B.P.-present. (Whitelaw, 2011).

Whitelaw (2011) describes Pegasus Bay as an ‘enormous sediment trap’ and Levieveld et al (2018) suggest that it has continued to increase in volume since 1991. An increase in salinity in the wetland could increase sedimentation. As found in a study by Craft (2012), salinity drives flocculation, the clumping together of sediment particles. An increase in sediment in the wetland may act as a counter to SLR, which is an important consideration to make, as this will determine the severity of the impacts discussed further in this report.

The historical progradation of Pegasus Bay (Figure 7) has been analysed and compared to the last Holocene maximum sea-levels, which occurred around 6000 yr B.P. (Shulmeister & Kirk, 1993). This will provide an understanding of how sedimentation may respond with future SLR in this area. Progradation refers to the advancing of the shoreline due to accumulation and deposition of sediment from the dynamic beach processes. The shoreline appears to have been in a trend of advance 6000 yr B.P., as the shoreline continued to prograde from 9500 yr B.P. to 4500 yr B.P (Figure 7). This indicates that the rate of sedimentation during this time was occurring at a quicker rate than SLR. Figure 7 shows that Pegasus Bay shoreline has been prograding over the last 4500 years at a rate of 1m/yr. When combined with sea-level rise, it is estimated that the shoreline will prograde at a slower rate of 0.5m/yr (Whitelaw, 2011). In recent years, the shoreline has stopped prograding (Whitelaw, 2011). However, it is still too early to determine whether this is temporary or if the shoreline is beginning to retreat due to SLR (Whitelaw, 2011).

Effects on Flora

Wetlands provide a wide range of ecosystem services. They regulate water quality, mitigate flood risk, and store carbon (Clarkson et al., 2013). They are strongholds of biodiversity and support high populations of threatened plants and animals.

In the mid-1980s, Pines Wetland had dense areas of sea rush (Juncus krausii) and jointed rush (Apodasmia-similis) saltmarsh with several open areas where wide carpets of salt meadow vegetation such as glasswort surrounded brackish pools. By the late 1980s, freshwater ponding facilitated the replacement of dense, healthy saltmarsh vegetation with invasive grasses and the first scattered willows, then subsequently dense willows and pines followed (A.Crossland, personal communication, August 10, 2020).

Pines Wetland is currently dominated by grey willows and invasive grasses like Glyceria maxima. The invasions of introduced plants such as willows, pines and grasses can have negative effects on the wetlands hydrological system, nutrient regime, biodiversity and energy and material exchange between terrestrial and aquatic ecosystems, especially if they are functionally and structurally different from native vegetation (Watts et al., 2012). This causes a ripple-down effect through the wetland ecosystem. Wetlands dominated by native plant species provide resources and habitat for many native insects, however, it is unknown whether wetlands dominated by invasive species provide the same ecological benefits (Watts et al., 2012).

Based on the 3D SfM (Figure 3), it is estimated that invasive grasses cover ~50%; grey willows cover ~40% and pines cover ~10% of the wetland area. If Pines Wetland is re-opened to the ocean, there is a large possibility that it will return to its previous state of being a tidal saltmarsh wetland. This will eradicate most of the current invasive species that are not tolerant to high levels of salinity such as willows, grasses and conifers. Over time, these will then be replaced with wetland flora species that are adapted to saline environments such as sea rush. Wetland flora species are very adaptable and can recover with little to no care. Many coastal wetland species such as glasswort and raupo do not need to be planted as they will regenerate naturally once weeds are removed, and water levels are restored (Auckland Council, n.d.).

Effects on Fauna

Parker (2012) describes the wetland as being in its late stages of transition from an estuarine to a palustrine environment. The term palustrine refers to nontidal wetland systems, with a significant abundance of trees or emergent ground cover and saline soil containing <0.5% ocean derived salts (Figure 8) (Federal Geographic Data Committee, 2013).

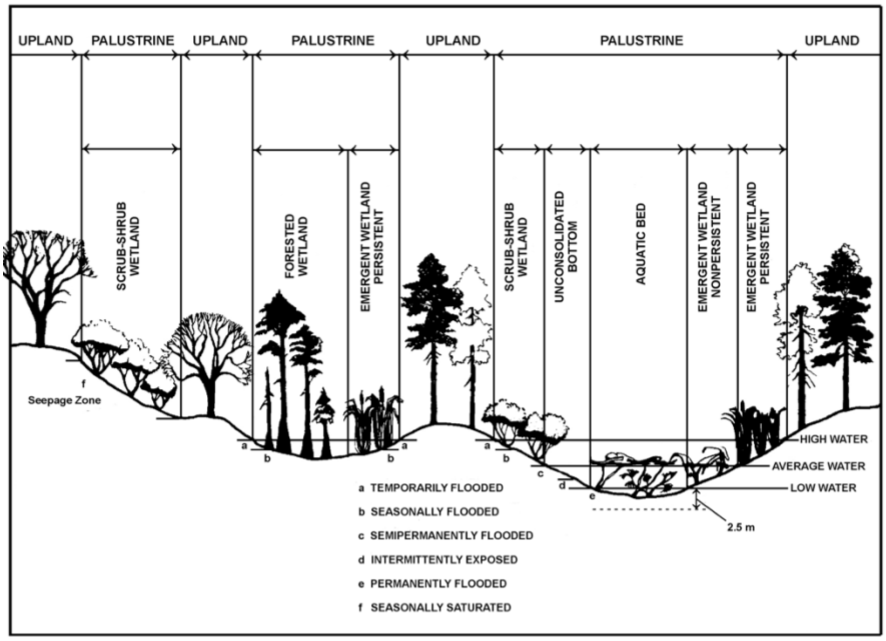

Figure 8. Characteristics and examples of Palustrine ecosystems. The Pines Beach wetland fits closest to “b”. (Federal Geographic Data Committee, 2013).

The wetland almost completely dries up in summer, with its water level fluctuating throughout the rest of the year. The fluctuation of the water level makes it difficult for birds to establish themselves in the wetland for longer periods, as a reduction in water level can leave nests high-and-dry, while an increase can cause them to flood (O’Donnell, 2000). Based on information from (G. Byrnes, personal communication, September 23, 2020), (A.Crossland, personal communication, August 10, 2020) and Parker (2012), the wetland has been a host to a great diversity of birds in the past, with species such as Marsh Crake, Swans, Pukeko, Black-Backed Gulls, Herons and Pied Stilts having been observed in the area. All three sources note that the value of the wetland would be improved if a permanent water level could be established to support the activity of wading birds and waterfowl year-round. The wetland currently has a rating of low significance as a bird habitat (Parker, 2012).

There is a chance that the removal of tidal influence from the wetland in the 1960s has played a role in reducing the biodiversity of birds and aquatic species over the years. Based on a case study of the blockage of seawater from coastal salt marshes in Cape Cod National Seashore, it is likely that the removal of tidal influence from the wetland eliminated a marine connection for some aquatic species. Such organisms lost may have included migratory crustaceans, shellfish, near-shore fish and benthic invertebrates (Portnoy, n.d). Tides also contribute to natural chemical cycling, and a change in chemical structure in the wetland due to its closure may have made the habitat less suitable for fish. A reintroduction of the tides would improve the ability of the wetland to flush and regulate nutrient concentrations.

These potential benefits are based on a few existing resources describing the past biological state of the wetland, with none describing its current biodiversity. Therefore, it is difficult to establish the value of its biodiversity now. Based on a study by Ballentine and Schneider (2009), it can take a wetland anything up to 55 years to re-establish itself after a disturbance. If this is the case for the Pines Wetland, it may be only now that it is starting to act as a fully functioning freshwater ecosystem. Opening the wetland would create a disturbance that may take up to 55 years for the wetland to adjust to, and any part of it that may be benefiting from the freshwater conditions would be disadvantaged. It would be beneficial to conduct further research into the current ecosystem and its services before deciding on opening.

Recommendations

The opening of the Pines Wetland is a complex decision, with potentially negative social implications for the Pines Beach residents and risks and benefits for its biodiversity. The ability for this report to present a recommendation for or against the decision is limited by existing information that could be found about the wetlands' state. Of particular importance is the behaviour of the sediment processes that would dictate the accumulation or erosion of the wetland if it were to be opened. If infilling were to keep pace with SLR, then the elevation difference between the wetland and the sea level would be insignificant enough for flooding of the wetland to occur, meaning the potential effects discussed in this report may not occur at all. Therefore, to answer this question sufficiently, more research should be undertaken to understand the possible future behaviour of sediment processes in the area, and specifically how they may change if the wetland were to be opened.

Many of the potential benefits discussed in this report pertain to improved biodiversity. However, due to the limited research existing on this topic, these predictions are largely extrapolated from sources that are not specific to this wetland. More study should be conducted to identify the ecological structure of the Pines Beach Wetland to better understand its value now with a freshwater regime. The value can then be compared to the predicted biodiversity benefits under a saline regime.

Finally, the financial and social costs of establishing an opening must be considered, with ongoing maintenance and community flood mitigation costs included.

Limitations

Scope

The scope of the research question is very broad, involving several complex potential implications. We were only given 12 weeks to complete this project, and there has been very little previous research conducted in this area. Therefore, we decided we could only cover several implications in broad detail. To competently answer the research question, more study should be done on the potential impacts in greater detail and with more specificity.

Sampling methods

Convenience sampling was used when deciding where to test the water in Pines Wetland. This was due to dense vegetation making areas hard to access and to a lack of surface water across the wetland. It was difficult to find/access surface water, therefore, sampling was gathered near the main path through the middle of the Wetland. Ideally, a more statistically significant sampling method (e.g. systematic/stratified sampling) would be used to ensure a more representative and robust sample.

Bathtub flood model

A bathtub model is a simplistic model that uses elevation when predicting flooding, e.g. any area under a 1m elevation difference from the ocean will be marked as flooded with a 1m rise in water level. This flood model does not factor in variables such as vegetation, topography, drainage or any other variable that can change flood likelihood. Ideally, a flood model such as the LISFLOOD_FP model would be used as it is more accurate and will account for variables other than elevation. Unfortunately, the skillset required to model flooding to this accuracy was not held by any of the students working on this project.

Conclusion

Drone mapping of the Pines Wetland area and in-depth literature reviews have shown that opening the Pines Wetland to the ocean will have several implications, including an increased risk of flooding to the Pines Beach community and biodiversity changes in flora and fauna species. Due to the dynamic beach processes and the large sediment supply from the rivers in Pegasus Bay, Pines Wetland is susceptible to infilling if it is opened to the sea. Dredging may be needed to mitigate infilling. The community effects of SLR and flooding of the wetland have physical, economic and social implications. Opening the wetland to the ocean will also cause changes in the biodiversity of flora and fauna. Salinity increases will kill off invasive weed species such as grey willows and grasses while increasing bird and mahinga kai species density. Once opened to the sea, the wetland ecosystem is predicted to return to its original state of being a saltmarsh. Based on previous research and literature, it is uncertain whether the rate of sedimentation will be the same as the rate of SLR and this rate will completely dictate the magnitude of the impacts discussed. This report provides a foundation of information about the wetland's current state and should be built upon to further advise TkoT on future action.

Acknowledgements

We would like to thank Greg Byrnes and the Te Kōhaka o Tūhaitara Trust team for proposing such an interesting project topic and supporting us.
We would also like to thank Paul Bealing and Justin Harrison for providing us with drone and water testing equipment as well as helping us with the drone surveying.
Also, a huge thanks to our supervisor Kari Bassett for providing advice and support throughout our whole research process.

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