Ripples in the Estuary: Anthropogenic Stress and Avon-Heathcote/ Te Ihutai's Ecological Function

N. Carter, H. Fairweather, M. Palmer, A. Thompson, and B. Rodger

Final Project Report, 2023
Dept. of Geography University of Canterbury
Project supervisor: M. Single
Community Partner: L. Bolton-Ritchie, from The Avon-Heathcote Estuary Ihutai Trust Board

Keywords: Anthropogenic, Ecological function, Estuary, Climate change, Ecological health

1. Executive Summary

- Estuaries are under continuous threat from human activities and the long-term impacts of climate change. A comprehensive understanding of the cumulative effects of these threats is critical to maintain the ecological function of the estuaries.

- The purpose of this project is to use mapping techniques to identify and highlight the key anthropogenic and natural stressors on the ecological function of Te Ihutai. Additionally, it has highlighted the areas that require proactive protection measures to ensure long-term ecological health of the estuary.

- The research question we produced as a direction of the project's undertaking was "*What is the extent of the impact of the anthropogenic and natural stressors on the ecological function in the Avon-Heathcote Estuary/ Te Ihutai?".*

- A literature review was conducted to identify existing information on the estuary and to obtain data relating to vegetation, soils, sediment, flora, sea level rise, and hard infrastructure to assist with developing the maps.

- The results were created through ArcGIS pro software. Through these we identified four major relative hotspots, predominantly concerning the relative proximity between stormwater drainage and estuarine wildlife habitats.

- This project was limited by the absence of a comprehensive field study to gather all the required data sets on the anthropogenic and natural environments of the estuary. There were also initial communicative limitations between us, our community partner, and our supervisor.

- This project has been produced in a format to be understood by a variety of interested parties providing them with a visual representation of the impacts of human activities and climate change on the natural environment in the present and future.

2. Introduction

This project has been requested by the Avon-Heathcote Estuary Ihutai Trust ('the Trust') to identify the relationship between anthropogenic and natural stressors in the Te Ihutai. Estuaries are dynamic and sensitive environments, where freshwater mixes with salt water from the ocean in a partially enclosed location (NIWA, 2017). They are influenced by the physical and chemical characteristics of tidal inflow from the ocean, rivers and drains and land runoff (Gadd, 2015). These environments are under significant threat due to the cumulative effects of human activities and the impacts of climate change (Murray et al, 2015). Te Ihutai, located adjacent to Christchurch City, is under significant pressure from runoff containing excess sediment, contaminants, nitrogen inputs, and anthropogenic stressors that have negatively impacted the ecological function and natural processes. There is little public awareness of the negative impacts of hard-engineered infrastructure and stormwater outlets. This project investigates the relationship between anthropogenic stressors and the natural environment in Te Ihutai. It identifies locations where there are many stressors interacting, so vulnerability is increased. The outcomes of this project will be modelled on maps created on ArcGIS Pro so future research areas can be identified.

2.1 Objectives and Scope

The purpose of this project is to use mapping techniques to identify and highlight the key anthropogenic and natural stressors on the ecology of Te Ihutai. The project has four objectives that define the study scope:

- Review and summarise existing literature on anthropogenic stressors, sea level change, ecology, and the natural environment of the estuary.
- Collaborate with data sets from experts in Christchurch to be used in map development.
- Develop maps in ArcGIS Pro to emphasise significant features that create the estuary's natural environment.
  → Model the location of hard infrastructure around the estuary margins
  → Model the impact sea level rise will have on the estuary
  → Identify the key hotspots in the estuary where hard infrastructure and the natural environment overlap in a map
- Report the findings and outline recommendations for future research to ensure the longevity of the ecological health of the estuary. Additionally, an infographic will be created with a simplified version of the findings obtained from the maps for public use.

The investigative question that directed this project was *"What is the relationship between the anthropogenic and natural stressors in the Avon-Heathcote Estuary/ Te Ihutai?"*.

3. Relevant Literature

We conducted quantitative research on existing knowledge of 5 key stressors with anthropogenic influence on the estuary. This literature was reviewed and has been summarised below.

3.1 Sedimentation

Sediment dynamics within estuarine systems are intricately connected to nutrient and organic patterns which directly influence the biota, either positively or negatively (Burge, 2007; Gadd, 2015). Studies have indicated that sediment stratification occurs in estuaries due to the influence of wind and tides. Silt and clay concentrations are the greatest at the river mouth, where they serve as sinks for nutrient and heavy metal deposits due to industrial and residential runoff from the inflowing rivers. Sediment types transition to higher sand concentrations at the estuary mouth (Burge, 2007). Organic matter follows a similar pattern to nutrients, peaking near the river mouth (3-7%) compared to the estuary mouth (1-1.75%).

Mapping the locations of stormwater drainage in the estuary could help identify the primary pollution sources. This knowledge is essential for establishing appropriate mitigation and management strategies to reduce pollution loadings. Thompson's (1994) study noted that the Ōtākaro (Avon) and Ōpāwaho (Heathcote) rivers are important stressors to this estuary as they receive stormwater from surrounding residential and industrial areas. Sediment deposition was measured to be around 2600t/year for the Ōtākaro and 4500t/year for the Ōpāwaho with the sediment size decreasing with distance from the river mouth (Hicks, 1993).

3.2 Stormwater

During heavy rainfall events, large quantities of stormwater are produced and flow through Christchurch City accumulating contaminants. These include copper, lead, zinc, hydrocarbons, pesticides, bacteria, phthalates, and surfactants (NIWA, 2012; Environment Foundation, 2018). Unlike wastewater which gets treated, stormwater flows directly into the Ōpāwaho, Ōtākaro, Huritini (Halswell), and Pūharakekenui (Styx) rivers. This is then discharged to the Te Waihora (Lake Ellesmere), Te Ihutai, and Brooklands Lagoon (Watts, 2011).

Until the 1950s, stormwater and wastewater were directed into the same pipe system and transported to the Bromley Sewage Plant (Wilson et al., 2003). The piping network has since been separated due to overflow from heavy rainfall events. In addition to the water separation, development of Christchurch's city has prompted an increase in stormwater runoff as it is unable to infiltrate through the impermeable ground (Hughson et al., 2009). Macropollutant traps (MPT), vegetated swales, and soakage basins are now preferred stormwater treatment and reduction methods. MPT's remove larger debris, and swales use grass as a filter to remove downstream contaminants in a channel structure. These methods are only 40% effective at removing phosphorus, nitrogen, and bacteria; and 60% effective at removing solid particles and trace metals (Christchurch City Council [CCC], 2012). Soakage basins are nearly twice as effective by allowing water to infiltrate through the ground and providing extra storage during heavy rainfall to prevent further stormwater runoff (CCC, 2012).

3.3 Excess Nutrients

Te Ihutai has been receiving Christchurch's wastewater since the arrival of Pakeha. It wasn't until the 1960s that Christchurch's wastewater treatment system was established, complete with six oxidation ponds. Up to 500,000 cubic metres of treated wastewater was released into the estuary each day (Environment Canterbury, 2007). Of this wastewater, 30% was municipal, 20% was industrial, and the remaining 50% was infiltration accumulation (groundwater) (CCC, 2018). Finally in 2010, the discharge of wastewater into the estuary ceased and is now discharged 3 km out into Pegasus Bay. Skelton (2013) suggests that 90% fewer nutrients are being discharged post diversion. Regrettably, nutrient levels are still high from inflow of the Ōtākaro, Ōpāwaho, and stormwater drains. Nutrients negatively influence Te Ihutai's biodiversity values and have dramatically changed the habitats of estuarine wildlife. High levels of nutrients (particularly phosphorus and nitrogen) cause eutrophication- a process in which excess nutrients exacerbate plant and algal growth in the estuary. This process reduces water quality and light penetration, depletes dissolved oxygen levels, and is the cause of large green and brown algal mats that can be seen and smelled throughout the estuary.

3.4 Land Reclamation

Land reclamation of Te Ihutai has both positive and negative effects on the estuary's natural processes and surrounding communities. Most of Te Ihutai's margins have been reclaimed by sea walls with some areas experiencing greater levels of tidal pressure than others. The reduction of natural estuarine margins promotes changes in the water circulation and impact tidal flows and sediment movement. Changes in estuarine function can be detrimental to the local ecology by altering breeding and migration sites and inducing changes in the structure of the boundary sand banks. Cheng (2020) studied the introduction of artificial infrastructure in an estuary and reported a notable increase in tidal choking, a reduction in tidal range, and stronger tidal currents which resulted in stronger mixing processes. The current state of the damage caused by land reclamation in Te Ihutai is not yet known but with climate change and rising sea levels, these impacts become more worrying. Yang (2017) investigated the combined effects of land reclamation and rising sea levels. It was indicated that land reclamation further magnified the effects of sea level rise on hydrodynamics and solute transport. This introduces a major issue as the estuary is no longer able to naturally roll back, increasing the chances of severe flooding due to sea level rise in the future. Identifying areas where land reclamation has had the greatest influence on the estuary's natural function as well as the areas most susceptible to flooding may be used to guide future research towards mitigating these effects on natural habitats and our communities.

3.5 Human Effects

Te Ihutai has sustained human life for 600 years; in the past it has been an essential location for making kai, recreation, and strongholds for Maori tribes (Fisher & Vallence, 2010). However, due to current increasing population, technology, and resources, species have been driven away and anthropogenic changes have been carried out to create a more convenient habitat for modern-day humans in the environment. A study on the Tamsui estuary[1]Taiwan found through results of a social-environmental analysis that coastal environments suffer extensive damage from a wide range of human activities and processes of disturbance (Seng et al., 2021). Te Ihutai is like the Tamsui estuary, because it is in Christchurch, an urbanised area, and the second most densely populated place in New Zealand (Stats NZ, 2018).

In a study carried out by Birch and Olmos in 2008, it was found that heavy metals in sediments measure human-induced change, and act as an indicator for biological stress. This is likely taking place in Te Ihutai, due to the processes of wastewater discharge until recently, stormwater drainage and road runoff taking place around the estuary's perimeter (Birch & Olmos, 2008).

In the future, Kennish predicted anthropogenic effects being habitat loss and alteration, continued eutrophication, sewage, and chemical contaminants. Accelerated population growth and increasing urbanisation and industrialisation are likely to continue compromising the ecological integrity of many estuaries (Kennish, 2002). The study by Seng et al agrees with this, because possible future improvements suggest that societal responses and management measures can be implemented to increase education, wetland conservation, and the development of circular economies to sustain not only the Tamsui estuary, but estuaries globally, for longer. Education will be a significant factor because of the motivation and drive it can give a population (Seng et al., 20221).

4. Methodology

The methodology used in this project is shown chronologically in Figure 1 and is summarised in depth in the sections below.

[1] Tamsui's estuary's river catchment was in the middle of a significant urban centre of Taiwan

Figure 1

Flow Chart of the Various Methodological Stages Involved in the Project. 3.1.

4.1 Literature Review

Necessary research was identified in anthropogenic stressors, the natural environment, and the estuary ecology. The literature review explored five subthemes: Sedimentation, Stormwater, Oxidation ponds, Land reclamation, and human impact on the health of the estuary. The literature review was ongoing through the project, and the research provided datasets and extensive knowledge for the creation of the maps.

4.2 Dataset Collaboration

Based on the information collected from our literature review, several datasets were modified into shapefiles with appropriate coordinate systems. The NZGD 2000 New Zealand Transverse Mercator coordinate system was selected, because past studies have indicated this is the best coordinate system to use. It accounts for sub-meter accuracy and local deformation in New Zealand (Toitu Te Whenua LINZ, 2022). The three datasets we selected were 1m DEM elevation model (Landpro LTD, 2022), AHEIT vegetation and native birds datasets (ECAN, n,d), and stormwater datasets (Canterbury Regional Council, 2021).

4.3 Map Development

Six maps were developed in ArcGIS Pro to meet the study objectives. ArcGIS Pro was selected over other GIS platforms like ArcMap due to its ability to use multiple maps and layouts within one project: a key part of presenting the project findings (Price, 2017). Throughout development, maps were updated as new datasets were obtained. A variety of geoprocessing tools were used in the creation of these maps. It was important to the Trust that we also considered the public in our output, so printable and interactive infographics were created. The estuary was hand-drawn on a digital note-taking platform called Notability. The drawings were then superimposed with additional text on Canva, a free creative website. The interactive infographic was developed similarly on ‘Genially’ due to its broad capabilities and its ability to be copied onto the Trust’s website. Both maps are easily editable.

4.4 Summarise Findings

The information obtained from the maps was used to identify the zones of the estuary that are under the greatest stress due to anthropogenic stressors and to highlight their current state. Conclusions were drawn and recommendations for future studies were made.

5. Results

5.1 Map Analysis

This project resulted in the creation of six maps, each designed to highlight the spatial relationships between the natural and anthropogenic environment and the most vulnerable areas in Te Ihutai. These maps accumulate complexity to tell a narrative of the stressors affecting the estuary's ecological functionality.

The first two maps explore the natural environment within and around the estuary. Figure 2 below shows the natural environment of surrounding soil and estuarine sediment types. The estuary is made up of six sediments: very soft mud, mobile sand, firm sand, and soft mud. In particular, the areas around the mouths of both the Ōtakaro and Ōpawaho rivers have high soft and firm mud concentrations which is concerning because this sediment is a sink for pollutants.

Figure 2

Soil and Sediment Within and Around the Estuary

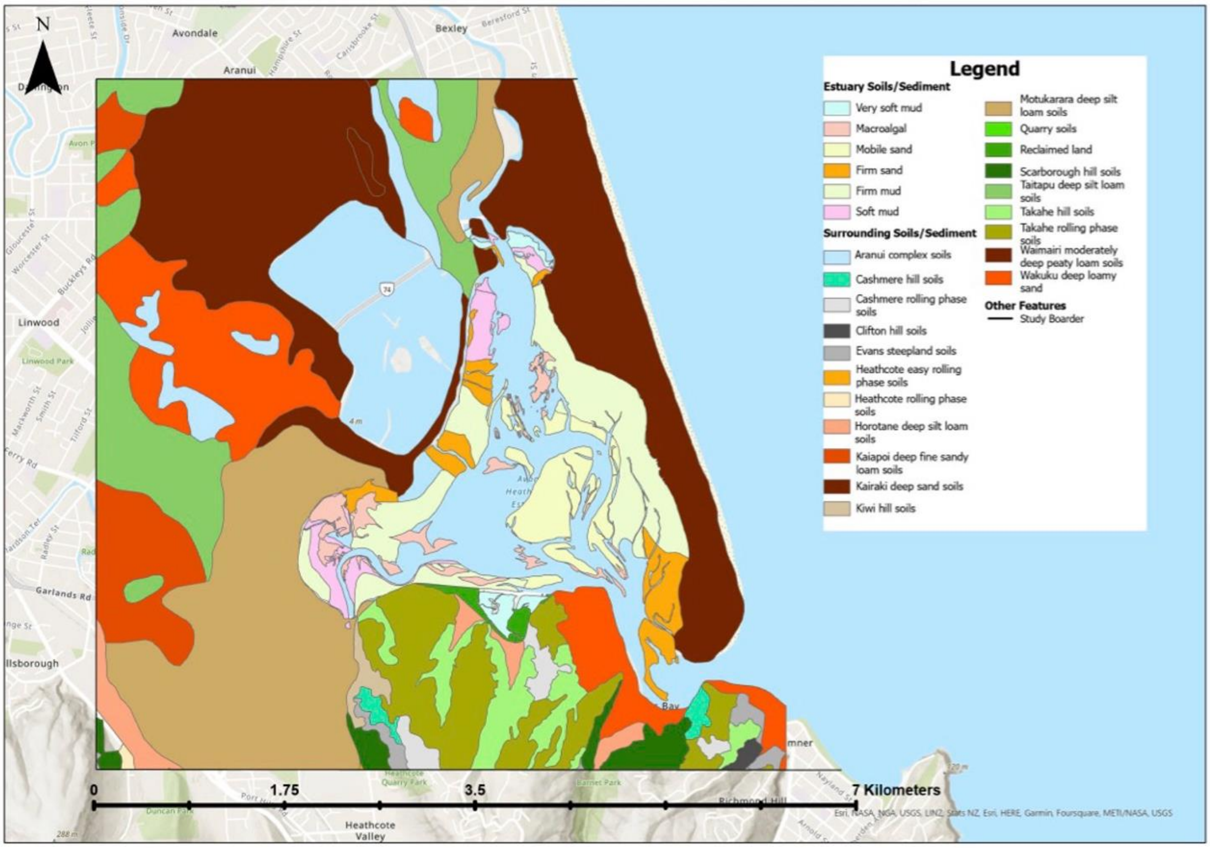
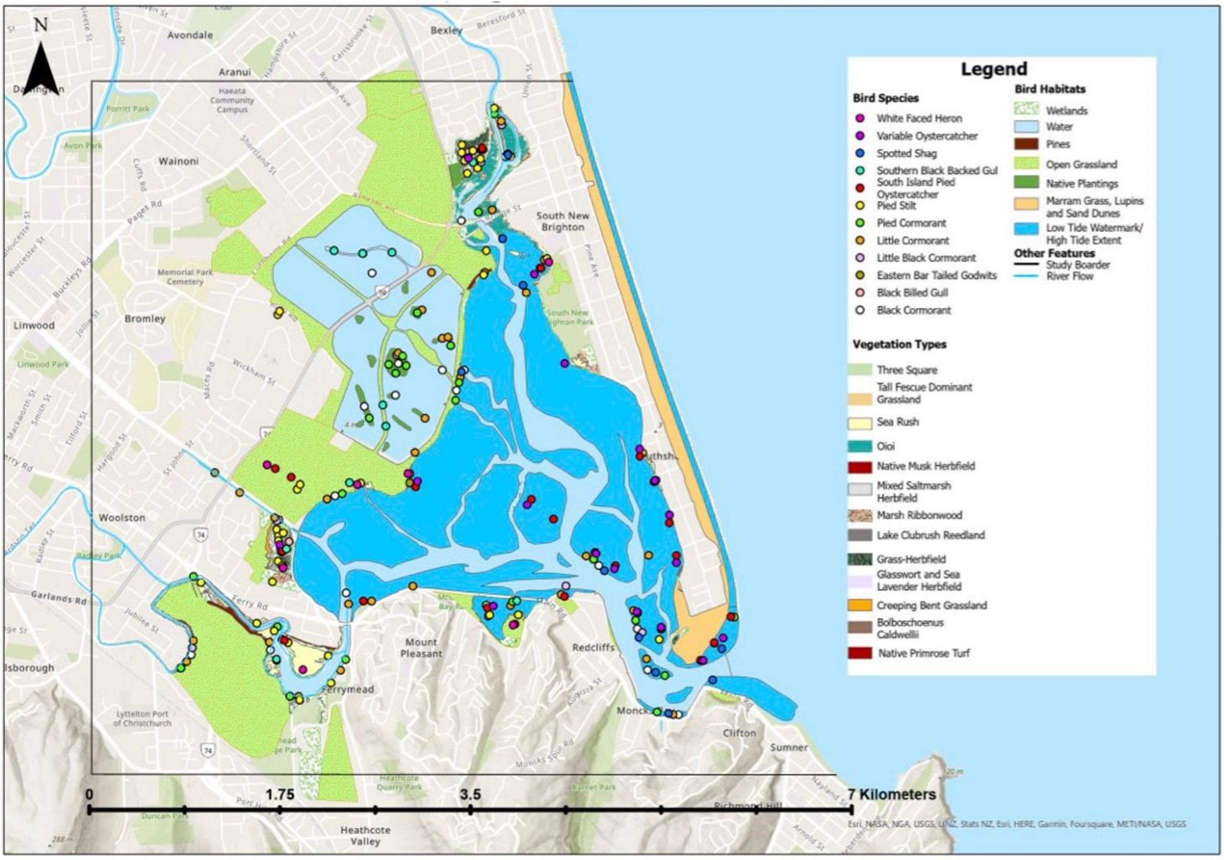


Figure 3 shows the location of native vegetation and wildlife habitats in and around the estuary. Of the 12 native bird species, we identify the estuary's largest bird population to be oystercatchers (both South Island Pied and variable). The darker blue shading on the map emphasises the large area of the estuary that is submerged at high tide and becomes exposed at low tide. This area also serves as a feeding ground for the native bird species in the estuary. The map shows that a large portion of the estuary's boundary has limited habitat capabilities in the South New Brighton region and Mount Pleasant through to Clifton, due to lack of vegetation.

Figure 3

Locations of Bird Species and Vegetation Types Within and Around the Estuary



To specifically address the impacts of the anthropogenic environment on Te Ihutai, we generated two maps. Figure 4 outlines the estuary shoreline composition, which was categorised into three estuary shoreline types. The distinctive red line marks the artificially constructed shoreline while the pink line refers to the remaining natural shoreline, and the brown line marks the eroded estuary shoreline. Additionally, polygons were created to identify areas prone to coastal erosion (yellow polygon) and previously recorded erosion sites around the estuary (pink polygon). Figure 5 identifies the locations of hard-engineered infrastructure within and around the estuary. The map's stormwater layer highlights the pathways of stormwater drainage from areas higher in the catchment to the entry points of drains and culverts into the estuary. Furthermore, human-engineered areas pose a potential threat to the estuary's health, the locations of jetties, ramps, roads, and wastewater treatment plants/ oxidation ponds are indicated with lines and polygons.

Figure 4

Estuary shoreline composition; erosion prone, artificial seawall, natural shoreline

Figure 5

Hard Engineered and Stormwater Drainage Infrastructure

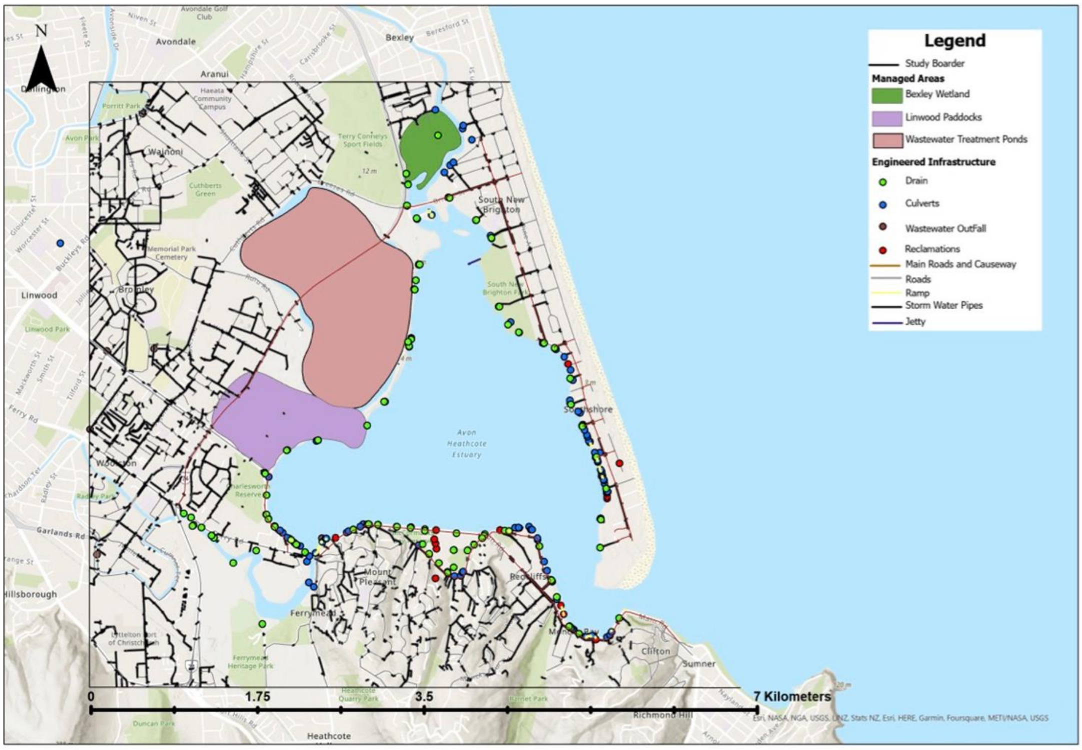
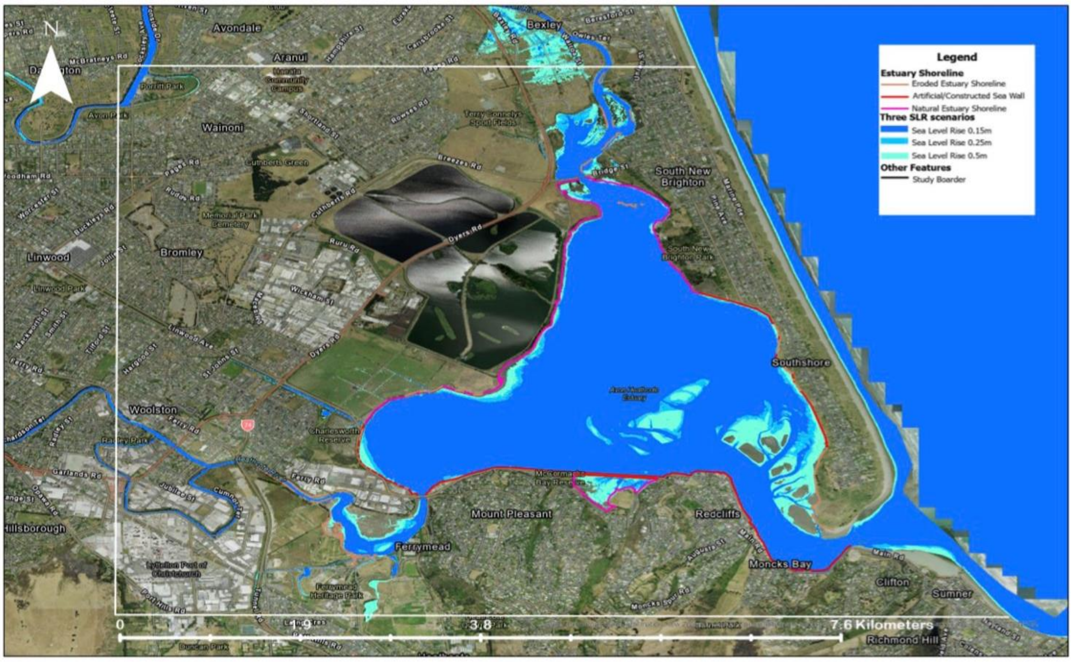


Figure 6 highlights the potential consequences of climate-induced sea level rise on this estuary. This map illustrates three distinct sea level rise scenarios within the estuary, based on IPPC's (International Plant Protection Convention) latest climate change synthesis report, and predicated associated with the SSP1-1.9GHG emission scenario. The emission scenario predicts a sea level rise of 0.15-0.23m of rise is predicted by 2050 (Lee et al, 2023) Hence three specific sea level rise projections chosen for the map are 0.15m, 0.25m, and 0.5m, to reflect IPPC predictions for sea level rise.

Figure 6

Predicted Sea Level Rise Effects on Te Ihutai Under 3 Sea Level Rise Scenarios



The final map (Figure 7) shows the spatial connections between anthropogenic and natural environment datasets when overlayed. Within this analysis, four key areas of vulnerability have been identified. These vulnerability areas should be the focus of future research and proactive protection measures.

The first hotspot can be found in the pop-out section in the upper-right hand corner of the map. At this location, two stormwater drains empty into the estuary, which is home to several native bird species and is highly vegetated. The discharge of stormwater in this area poses a significant threat to both the native bird species and the local vegetation.

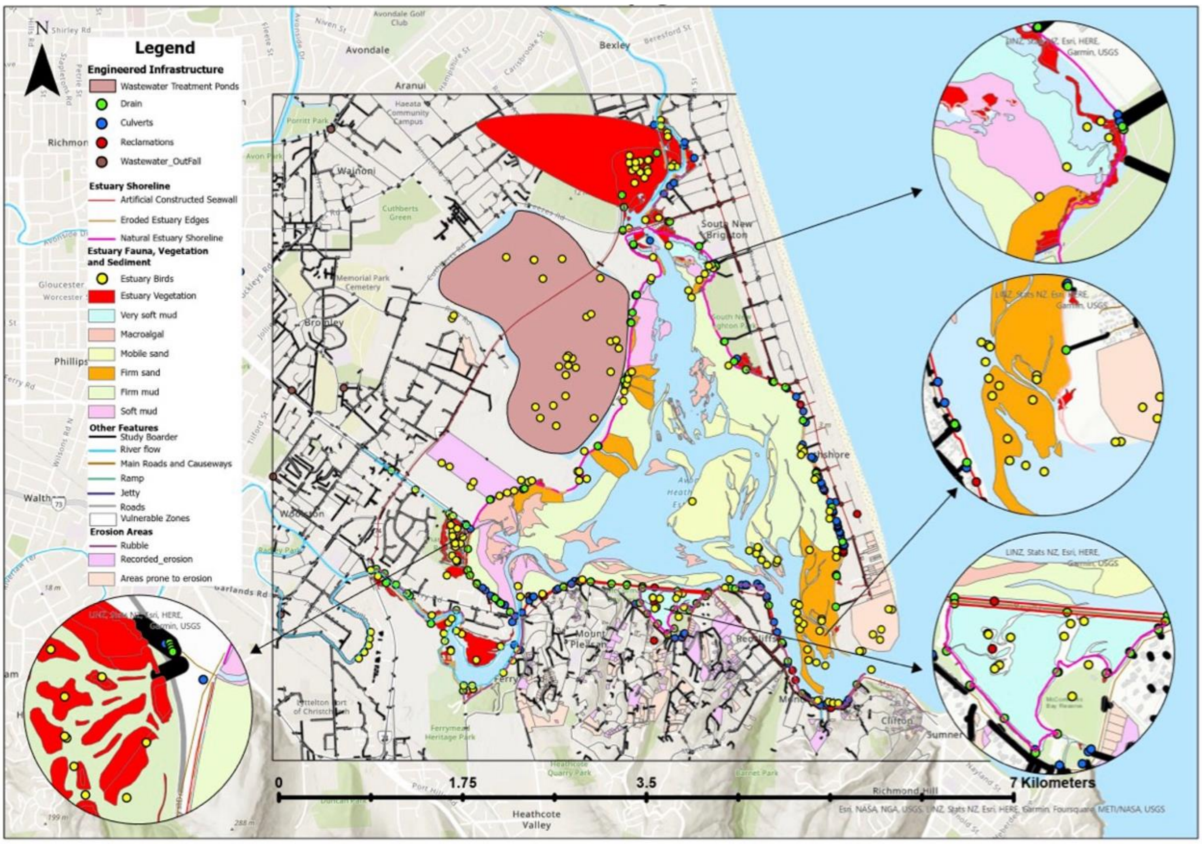
In the second vulnerable area, shown in the pop-out section below the first hotspot, we identify an erosion-prone region that is also an intertidal flat. According to the sea-level rise projections, this area is likely to become fully submerged within the next 50 years. The native species that currently inhabit this area may soon be forced to seek new feeding grounds.

In the bottom-right corner of the map, the pop-up refers to McCormacks Bay. A red line signifies an artificial sea wall that protects the main road. This artificial sea wall obstructs the natural response of the estuary to adjust as sea levels rise. Consequently, it is expected to induce alterations in intertidal flats, natural estuarine movements, and the drainage patterns. In contrast, the pink boundary line depicts the estuary's natural boundary. As only one edge of McCormacks Bay's boundary is artificial, it has more capabilities to adapt in response to sea-level rise.

The final pop-up in the bottom-left corner pertains to the wind-surf spot near Humphreys Drive. This specific area is vulnerable due to the culvert releasing polluted stormwater. The visible grey line represents a causeway that may leach zinc and copper from car brakes. Charlesworth Reserve, which is home to many wildlife species, is located near this vulnerable area and is susceptible to its damaging effects.

Figure 7

Identified Hotpots from Overlayed Interaction Between the Natural and Anthropogenic Environments



5.2 Infographic

Figure 8

Printable Infographic on Anthropogenic Stressors

6. Discussion

The results found on these maps are significant and provide a depth of research for the investigative research question in this project.

The structure of the estuary shoreline is vital to comprehensively understand the extent of the built shoreline around the estuary. The artificial sea wall is shown in Figure 4, as most of the estuary edge. It is significant to note that there is considerable erosion on the estuary shoreline around South Spit, and in the mouth of the Heathcote River. The only section where the natural estuary shoreline is present is across the border of the Bromley Oxidation Ponds. This agreed with the findings of Seng et al in 2021, proving how urbanisation significantly impacts the built environment of the estuary. This built shoreline is expanding, as seen by the current roadworks along Main Road, to improve recreational infrastructure. It is evident that this is not a positive nor sustainable long-term measure, and with expected sea level rise, the estuary is at huge risk. Figure 2 supports this, showing there are increased sediment levels around the river mouths near this large urban area. Figure 6 indicates the predicted sea level rise effects, combined with Figure 4. Interestingly, the sea level is expected to rise in the highest areas near Bexley, Ferrymead, near South Spit, and within McCormacks Bay Reserve. Where there is the significantly built estuary shoreline adjacent to Humphries Drive, there is also an expected sea level rise of >0.5m, as shown in Figure 6. These sections of the estuary shoreline will be significant to the estuary's community groups, particularly the Avon-Heathcote Estuary Ihutai Trust. It will be vital to make note of these and monitor their progress in the future.

These sea walls will have a significant effect on the water circulation within the estuary, including the tidal flows and sedimentation movement. As supported in the literature, it is expected that these walls will increase the potential of tidal choking and therefore increase the strength of the mixing processes taking place within the estuary. Biodiversity can be drastically impacted because of this, with breeding cycles, habitats and nutrient movement affected (Cheng.Z, 2020). The high prevalence of bird species in the identified hotspot areas is shown in Figure 7, and Figure 3 indicates that there are multiple bird species that will be at risk.

Figure 5 outlines the hard-engineered structures and water infrastructure around the boundary of the estuary. There is a significant concentration of drains and culverts on the South-western side of the estuary, near Humphries Drive, which are contributing to the hard engineered structures within the sea wall (Figure 4). South Shore also has a high number of drains and culverts, as well as reclamations. This pattern, while being beneficial to the residents as it allows for clean and drained communities, has a significant impact on the estuary. The high prevalence of these structures provide a route for heavy contaminants to enter the estuary, hence significantly disrupting the biodiversity of the estuary itself. (Characterising Stormwater Quality, 2022).

6.2 Limitations

While we have had a successful project and developed an extensive end product, our journey was marked by challenges that affected our group dynamics, research structure, and results, particularly in the realm of GIS mapping.

6.2.1 Group Dynamics

We did not have as much contact with our community partner as intended throughout the beginning of the project, altering our understanding of the project objectives from the Trust. We overestimated what we could accomplish and were trying to produce too much information that would have been impossible to do. As our project research refined, we had to make decisions on what maps we were going to produce and how we focused our result. It took a while to realise that most of our project work was going to need to be done by creating maps. Another limitation we came across was that each group member had slightly different ways of portraying the focus. Each of these limitations lead to some stagnant points in our project where confusion hindered our work process.

6.2.2 Research Structure

There was large variance in the literature used; some resources were outdated because of the lack of recent information on the Estuary itself available. Because some datasets used were created before the Christchurch earthquakes (2011), there may be alterations to the estuary post-quake that aren't accounted for. A key limitation of our research structure that we learnt during the research process was that much of our project would rely on already existing data and we would have to draw conclusions from this.

6.2.3 Results/GIS

Several limitations were encountered in our GIS methods, notably in the creation of the sea level rise map for the estuary. Our study used a bathtub flood model, which assumes uniform flooding or sea-level rise (SLR) at a fixed elevation with a continuous inflow of water. However, it is important to acknowledge that this process is influenced by many factors including topography, ground cover, duration, intensity, and soil conditions (Rahayu et al., 2023).

Drainage capabilities of various materials like soil, sand, mud, and concrete systems vary leading to differences in water retention in different areas (river mouths, McCormack's Bay, and South Shore). Consequently, the use of the bathtub flood model offers an unrealistic prediction of the estuary flood dynamics. These findings offer insights into the impact of SLR but highlight the need for researchers to improve these methods.

7. Conclusion

7.1 Future Research Opportunities

There are future research opportunities that could improve the long-term sustainability of the estuary. This could include the creation of a nutrient concentration map, focusing on areas of the estuary with the highest concentrations, so that it highlights sections where upstream mitigations need to be undertaken to reduce nutrient loading. Our initial plan was to complete this task within the project timeline, but we were not able to gain access to this dataset from NIWA. Furthermore, it is necessary to identify locations in the estuary catchment susceptible to combined stormwater/sewage overflow or that are contaminated by industrial processes. Development of methods for an effective on-site management or a treatment system to prevent or treat these flows during storm events would be beneficial. The implementation of treatment systems (such as wetlands or stormwater retention ponds) in these locations could reduce contaminated runoff, and result in increasing estuarine biodiversity/water quality by reducing the number of contaminants or nutrients entering the water.

To improve the accuracy of the maps it is critical to refine the estuary shoreline mapping, by calculating the distances of shorelines that are made of artificially constructed sea walls, eroded estuaries, and natural shorelines. Historical aerial photographs and presenting this information in a series of overlays over time would also highlight how changes in land use have affected the shoreline of the Heathcote estuary and how built areas may have increased runoff to the estuary as less land/vegetation cover is available for soakage of contaminants and nutrients. This information will highlight how it is important to take into consideration in future planning how land use changes can negatively impact the estuary.

An additional focus in the future is to develop our group's research findings into story maps for a comprehensive user experience, allowing people to explore both community graphics and maps simultaneously. We aim to establish a mechanism for selective editing access to these Arcpro maps within story maps, limiting it to specific parties (CCC) while excluding the public from editing.

7.2 Reliability

The findings from this research project are as reliable as data sets allowed for, since datasets were sourced from 3 past research projects.

With the benefit of hindsight and more time resources we consider that a comprehensive field study should have been conducted to acquire all the necessary datasets.

7.3 Concluding Remarks

this project addressed our investigative question, as we were able to identify the relationship between the natural and anthropogenic environment and display this relationship across 6 maps. The Trust's ambitions for us were to quantify and assess the impact of hard infrastructure around the estuary margins on estuary processes and ecology as sea levels rise due to climate change. This was achieved through these 6 maps and our community-based infographic. The maps and the infographic provide a diverse and user-friendly way for a range of people to access our findings. The infographic enables community members to interact and learn about the stressors and ArcGIS Pro maps provides a spatial analysis platform for councils to quantify additional stressors in their ongoing research projects. Additionally, the Arcpro maps enable researchers to edit and copy our layers to guide future research endeavours on Te Ihutai.

8. Acknowledgments

We would like to acknowledge Lesley Bolton Ritchie and Bill Simpson, from the Avon/Heathcote Estuary Ihutai Trust for supporting us through this project and providing our group with the opportunity to carry out research for them. Martin Single, our group's supervisor has been a pivotal part of this project with his expertise on coastal sciences and the estuarine processes. Our acknowledgements extend to Gordon Jiang and Henry Liswoyo for their contribution to datasets that were necessary for the maps.

9. References

Ashrafzadeh, S., Lehto, N. J., Oddy, G., McLaren, R. G., Kang, L., Dickinson, N., Welsch, J., & Robinson, B. (2018). *Heavy metals in suburban gardens and the implications of land-use change following a major earthquake*. Applied Geochemistry, 88, 10–16.

Birch, G. F., & Olmos, M. A. (2008). *Sediment-bound heavy metals as indicators of human influence and biological risk in coastal water bodies*. ICES journal of marine science, 65(8), 1407-1413

Burge, P. I. (2007). Sedimentation in the Avon-Heathcote Estuary/Ihutai–an analysis of past and present studies. Report prepared for Environment Canterbury Regional Council and the Avon Heathcote Estuary Ihutai Trust, 1-55

Canterbury Regional Council. (2021). Storm water [map data]. Canterbury Maps Open Data. Https://opendata.canterburymaps.govt.nz/datasets/1928497136504b8a96499d6113e106d7/explore?location=-42.841143%2c170.976465%2c19.18

Cheng, Z., Jalon-Rójas, I., Wang, X. H., & Liu, Y. (2020). *Impacts of land reclamation on sediment transport and sedimentary environment in a macro-tidal estuary*. Estuarine, Coastal and Shelf Science, 242, 1-21

Christchurch City Council. (2012*). Waterways, Wetlands and Drainage Guide, Part B, Chapter 6: Storm water treatment systems*. Christchurch City Council, 1- 46.

Environmental Canterbury. (n.d). Community/AHEIT [map data]. Canterbury Maps Open Data. Https://gis.ecan.govt.nz/arcgis/rest/services/community/aheit/mapserver

Environment Foundation. (2018). *Stormwater and Wastewater - Environmental Effects*. New Zealand Environment Foundation. https://www.environmentguide.org.nz/activities/stormwater-and-wastewater/environmental-effects/

Fisher, K., & Vallance, S. A. (2010*). Food gathering practices at the Avon-Heathcote Estuary Ihuta*i. Lincoln University, 1-47

Gadd, J. (2015). *Sediment quality survey for Heathcote river catchment, city outfall drain and estuary drain*. NIWA Client Report: AKL-2015-021 for Christchurch City Council, 1-77

Golding, S. (2008). *Suggested practices to reduce zinc concentrations in industrial stormwater discharges*. Washington State Department of Ecology, 1-34

Hicks, D. M. (1993). *Sedimentation and Erosion in the Avon-Heathcote Catchment and Estuary*. NIWA.

Hughson, G., Dickson, P. (2009). *Water & Sanitary Services Assessments - Stormwater Drainage. Christchurch City Counci*l. Maunsell Ltd. 1-69

Kennish, M. J. (2002). *Environmental threats and environmental future of estuaries*. Environmental conservation, 29(1), 78-107

LANDPRO LTD. (2022). Canterbury - Christchurch 1m DEM (2020-2021) [map data]. Toitū te whenua Land Information New Zealand. Https://data.linz.govt.nz/layer/109641-canterbury-christchurch-1m-dem-2020-2021/

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... & Ruane, A. C. (2023). *Climate change 2023 Synthesis Report: Summary for Policymakers*. IPCC, 1-34

Liswoyo, H. (2022). Mapping the effects of sea level rise on salt marsh Avon Heathcote estuary[map]. University of Canterbury

Murray, C. C., Agbayani, S., & Ban, N. C. (2015). *Cumulative effects of planned industrial development and climate change on marine ecosystems*. Global Ecology and Conservation, 4, 110-116.

NIWA. (2012, September 19). *Characterising stormwater quality*. NIWA. https://niwa.co.nz/freshwater/stormwater-management/characterising-stormwater-quality

NIWA. (2017, June 6). *Estuaries*. NIWA. https://niwa.co.nz/education-and-training/schools/students/estuaries#:~:text=An%20estuary%20is%20a%20partially,%2C%20sounds%2C%20wetlands%20and%20swamps.

Price, M. (2017). Managing Multiple Layouts in ArcGIS Pro. ERSI, 50-55

Rahayu, R., Mathias, S. A., Reaney, S., Vesuviano, G., Suwarman, R., & Ramdhan, A. M. (2023). *Impact of land cover, rainfall and topography on flood risk in West Java*. Natural Hazards, 116(2), 1735-1758

Robb, J. A. (1974). *An ecological study of the Bromley oxidation ponds and surrounding environs* [PhD Thesis].

Seng, H. C., Newton, A., Gong, G. C., & Lin, C. C. (2021). *Social–environmental analysis of estuary water quality in a populous urban area*. Elem Sci Anth, 9(1), 1-18.

Skilton, J. E. (2013). *Invertebrate Responses to Large-Scale Change: Impacts of Eutrophication and Cataclysmic Earthquake Events in a Southern New Zealand Estuary* [PhD].

StatsNZ (2018) *Census place summaries*. Stats NZ. (2018). https://www.stats.govt.nz/tools/2018-census-place-summaries/christchurch-city

Toitu Te Whenua (2022, January 7*). Which Coordinate System to use in New Zealand?*. Land Information New Zealand. https://medium.com/on[1]location/which-coordina te-system-to-use-in[1]new-zealand-510e10c2c7c

Thompson, G. (1994). *Morphology of the Avon-Heathcote Estuary Mouth*. University of Canterbury, 1-153

Watts, R. H.(2011). *The Christchurch Waterways Story.* Manaaki Whenua Press, Landcare Research Science, 38, 1-55

Wilson, J., Dawson, S., Adam, J., Mathews, J., Petry, B., & O'Keefe, M. (2005). *Contextual historical overview for Christchurch city*. Christchurch: Christchurch City Council, 1-324

Yang, Y., & Chui, T. F. M. (2017). *Aquatic environmental changes and ecological implications from the combined effects of sea-level rise and land reclamation in Deep Bay, Pearl River Estuary, China*. Ecological Engineering, 108, 30-39.

10. Appendix

Printable Infographic

The link below allows the user ‘View Only Access’ to the infographic created on Canva. This can be downloaded with the following instructions.

1. When the link has been opened, click ‘Share’ on the editor menu bar
2. Click download
3. On the dropdown, choose a file type for your download
4. Click download again

https://www.canva.com/design/DAFvJHcqZ44/IZfB5bk9-HvyIg0SVPYqxg/edit?utm_content=DAFvJHcqZ44&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton

Interactive Infographic Access

The interactive infographic can be downloaded to the Trust website if desired through this iframe in HTML.
Iframe code is a way to embed a dynamic website into an existing website.

```
<div style="width: 100%;"><div style="position: relative; padding-bottom: 77.42%; padding-top: 0; height: 0;"><iframe title="Our impact on the estuary" frameborder="0" width="3295" height="2551" style="position: absolute; top: 0; left: 0; width: 100%; height: 100%;" src="https://view.genial.ly/650bc5ab86f81a0010479a13" type="text/html" allowscriptaccess="always" allowfullscreen="true" scrolling="yes" allownetworking="all"></iframe> </div> </div>
```

A non-interactive PDF version of this infographic version can be viewed on Google Drive by following the link below.
https://drive.google.com/file/d/1-g6jfxhkwahSPVZ7VglczTAZdzD0YS2o/view?usp=drive_link