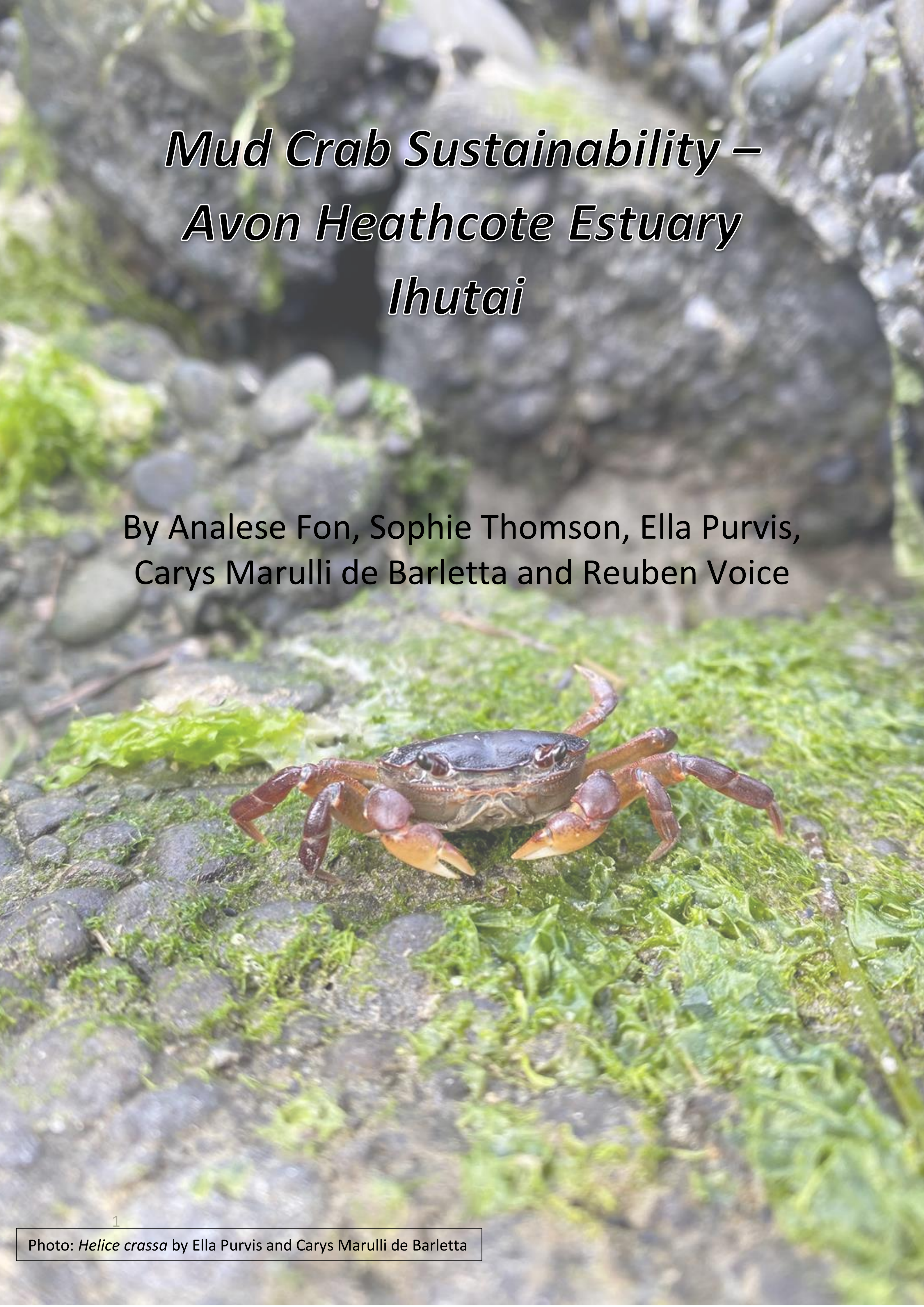

Mud Crab Sustainability – Avon Heathcote Estuary Ihutai

By Analese Fon, Sophie Thomson, Ella Purvis, Carys Marulli de Barletta and Reuben Voice

Photo: *Helice crassa* by Ella Purvis and Carys Marulli de Barletta

Contents

1. Executive Summary

- Climate change induced sea level rise is threatening the habitat of estuarine species including mud crab species; *Halicarcinus whitei, Hemiplax hirtipes, and Helice crassa* in the Avon-Heathcote estuary. If no action occurs, the mud crab populations could suffer local extinction. We conducted a project to answer our research question, *"What are the Avon-Heathcote estuarine margin conditions and are they suitable for mud crab retreat in the face of climate change."*

- We carried out sediment sampling and GIS analysis to quantify the current estuarine margins and make predictions about suitable habitats for the future.

- We were able to deduce each mud crab's habitat preference through literature review, reported sightings, and our sediment analysis.

- Using ArcGIS Pro, we created maps of the suitable habitat that each mud crab species could inhabit. The results suggest that the Avon-Heathcote estuarine margins provide suitable habitat for each species. The limiting factor in habitat suitability of the estuarine margins was not substrate preference, but the presence of infrastructure and tidal zones that would dictate where the mud crabs could migrate to.

- We recommend Bexley as a suitable location for migration of the mud crabs. The area meets the substrate requirements for all species and provides the most available space of all the locations we sampled.

- Our research was limited by the inaccessibility of some areas when we were sampling. As well as this, time constraints forced us only to consider slope, soil texture, order and depth, tidal zones, and buildings to determine suitability of the landscape for mud crabs.

- The next steps are to consider how the mud crabs will reach their new habitat. Research needs to be conducted to establish whether the mud crabs will be able to naturally reach this new habitat via range extension or if other actions are required. One such measure is conservation translocation; however, this is a high-risk approach, and a risk assessment report would be required.

2. Introduction

This report addresses the sustainability of three mud crab species, *Hemiplax hirtipes* (Stalk-eyed crab), *Halicarcinus whitei* (Pillbox crab), *Helice crassa* (Tunneling mudcrab) in the Avon-Heathcote Estuary. This research has been petitioned by the Avon-Heathcote Estuary Ihutai Trust to mitigate the effects of sea level rise and inundation on mud crabs.

Climate change is a dominating global issue that has profound adverse impacts on all aspects of life. For coastal environments, climate change induces sea level rise and inundation which threatens the present position of intertidal zones globally. Sea level rise has been described as one of the most significant potential causes of ecosystem disruption, putting many coastal areas at risk of irreversible changes or loss of habitat and distribution (Rullens et al., 2022). Sea level rise is a significant issue for Aotearoa (New Zealand) due to the constant vertical land movement, which directly impacts local sea levels along coastlines.

The effects of sea level rise on the Avon-Heathcote estuary does not look hopeful for mud crab populations. The habitats currently occupied by the mud crabs are expected to be lost. However, relocation is not as simple as it seems. Mud crabs have habitat requirements that must be met for survival.

2.1 Rationale

The project was initially proposed by our community partner Ann Kennedy from the Avon-Heathcote Ihutai Trust Board. The 2013 Tonkin & Taylor report recognised that extensive areas of the Avon-Heathcote estuary intertidal zone would disappear under all sea level rise scenarios (Fig.1). This raised concerns about the loss of mud crab habitat. Tonkin & Taylor identified that sea level rise would be gradual and implied there was time and opportunity to develop adaptation strategies in policymaking. However, no research to date has developed in response to this. Rising sea levels will likely cause species to migrate landward to maintain their position relative to the water level.

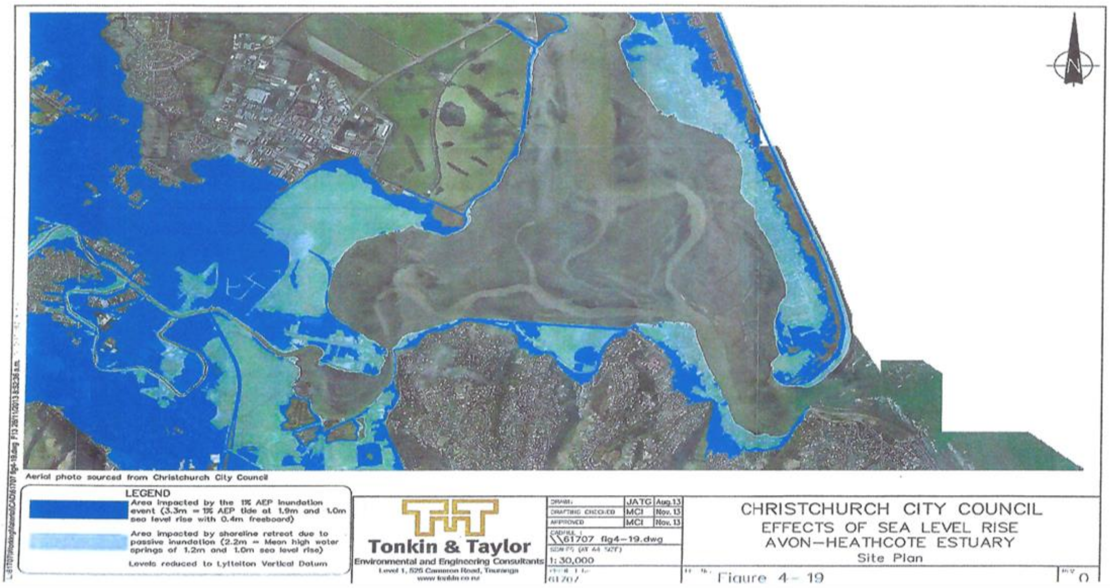

Figure 1: *Predicted effects of sea level rise for the Avon-Heathcote estuary - 100 year projection. The light blue represents passive inundation, and the dark blue represents extreme inundation.*
Note. From Effects of Sea Level Rise for Christchurch City by Tonkin & Taylor Ltd, 2013, *Christchurch City Council,* p.63, *(*T&T Ref: 61707).

2.2 Significance of research

The disappearance of the Avon-Heathcote Estuary intertidal zone under all sea level rise scenarios means that the current mud crab habitat will disappear. This will require them to be relocated. However, if this is unsuccessful, it poses the risk of local extinction of mud crab species. Sustaining mud crab populations is essential because they play a crucial role in the functioning of ecosystems. As bioturbators, their burrowing aerates the soft sediments of the estuary, resulting in increased nutrients which drives primary productivity and microbial activity (Shull, 2009). Furthermore, crabs are ecosystem engineers, and their presence indicates a healthy ecosystem. Thus, maintaining populations of mud crabs is vital to attaining sustainability in the Avon-Heathcote Ihutai estuary.

In response to their concerns, the Avon-Heathcote Estuary Ihutai Trust has requested research to investigate the estuarine margins for new suitable mud crab habitat. The research will include an analysis of the estuary margin slope and elevation of the land immediately adjoining the estuary, as well as an assessment of the substrates along the estuary margins and available adjacent land. This research will include both GIS analysis and data collection.

Research question:

The project's investigative question is, *"What are the Avon-Heathcote estuarine margin conditions and are they suitable for mud crab retreat in the face of climate change?".*

Research design:

Descriptive research design with a non-experimental quantitative approach

Research aim:

Classify and map the different substrate types and assess which areas are suitable for the retreat of the *H.hirtipes, H.crassa and H.whitei.*

2.3 Context of the project

The Avon-Heathcote Estuary (8 km^2 (Hunter et al., 2022)), located in Bexley, Christchurch, is a freshwater and saltwater estuary semi-enclosed by a sandbar deposited by fluvial processes (Figure 2).

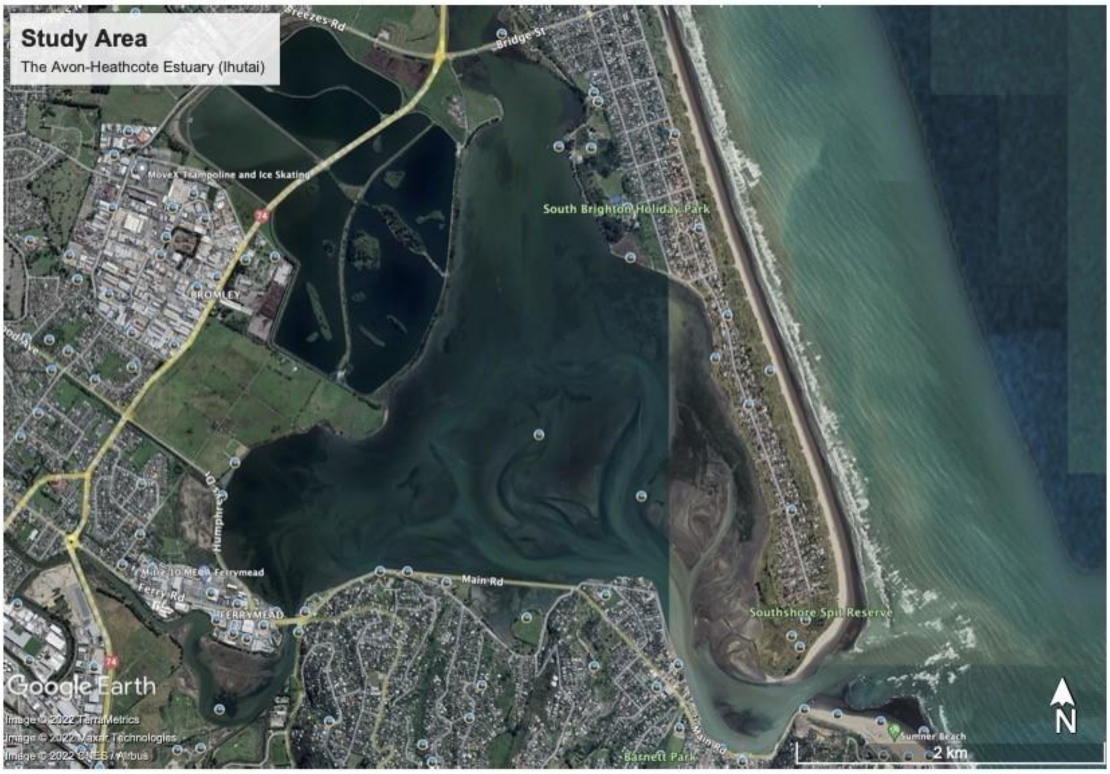

Figure 2: *Map illustrating the study area (Avon-Heathcote estuary). The Avon-Heathcote has a freshwater input from the Avon River/Ōtakaro and Heathcote River/Ōpāwaho, whilst saltwater comes from the ocean (Environment Canterbury, n.d.).*

3. Broad research context

Analysis of relevant literature allowed for a deepened understanding of the broad research context of the project. Reviewing the literature concerning the disturbance effects of climate change, coastal uplift, and landward migration provided a sufficient background for understanding disturbance effects that can be applied to mud crabs.

3.1 The impact of climate change on estuarine systems

Climate change driven sea level rise has effects on the physical properties of estuarine systems. An estuary can be characterised by the rate of saltwater dilution from the freshwater and the strength of vertical mixing. However, sea level rise can disrupt the salinity gradients in estuarine systems (Chua & Xu, 2014). A well-mixed estuary attains a salinity concentration that is constant from the sea surface to the seafloor, this occurs when the inflow of fresh water is slow but the ocean current is strong (Ross et al., 2015). As sea levels rise, estuaries will become more saline and well-mixed (Ross et al., 2015), as well as potential changes to the underlying geomorphology. For example, estuaries characterised by narrow channels are likely to experience decreased tidal ranges (Du et al., 2018). These alterations in the physical properties of estuarine systems are essential for us to understand in research.

3.2 The threat of disturbance on estuarine populations

Coastal uplift is a natural process resulting in land near coastlines being raised above sea level by tectonic forces, occurring gradually or suddenly (GeoNet, 2016). A review of current literature on the disturbance effects of coastal uplift found they are similar to those of sea level rise and inundation. Species are relocated to higher elevations of tidal margins, disrupting population dynamics. Uplift has been known to result in high mortality rates, inducing the disappearance of species (Castilla et al., 2010; Jaramillo et al., 2012; Schiel et al., 2021; Thomsen et al., 2021). Studies have identified this is a result of inadequate physiological or behavioral adaptations to survive (Schwarz, 1994). Emergence from tidal zones results in increased light and temperature in the intertidal zone. Species have a period they can withstand exposure. However, if this period is exceeded, species will undergo desiccation (drying out due to water loss from arid conditions). If the mud crab populations do not adapt well to the new estuarine margins, they will become threatened and ecosystem recovery will be essential.

3.3 Landward migration of estuarine species

Landward migration is the gradual movement of a coastal community's upslope into adjacent low-lying land (Osland et al., 2022). This mechanism occurs in response to changes in environmental conditions, such as salinity regimes and soil moisture caused by rising sea levels and the inundation of tidal mudflats (Wasson et al., 2013). The migration patterns can vary between coastal areas and thus the Avon Heathcote estuary must be assessed individually to decipher reliable recommendations for mud crab retreat. The extent of landward migration is suggested to depend on the availability of surrounding land (Tonkin & Taylor, 2013). For example, surrounding urban development and natural barriers along coastlines hinders landward migration. These barriers that prevent landward transgression of estuaries result in the phenomenon of ‘coastal squeeze’ (Borchert et al., 2018). With the predicted inundation of the Avon-Heathcote Estuary due to sea level rise and flooding events, mud crabs will likely need to migrate landward to survive. As most of the land surrounding the Estuary is largely urbanised, this was important to consider in our analysis to make appropriate recommendations for where the mud crabs could retreat to without suffering the impacts of coastal squeeze.

4. Specific Research Context: Environmental Characteristics of the Avon-Heathcote

The Avon-Heathcote Estuary is enclosed by the New Brighton Spit and accessible to the sea through a narrow inlet at the south (Findlay & Kirk, 1988). The estuary is shallow, with a current mean depth of 1.4 meters and a current tidal range of 1.7 to 2.2 meters (Malakhov, 2019; Thomsen et al., 2016). It is predominantly intertidal in nature (Findlay & Kirk, 1988), and only the channels draining the rivers are below water at low tides (Reid et al., 2012).

H. hirtipes prefer soft waterlogged substrate in low intertidal areas whilst *H. crassa* prefer more solid mud in the higher intertidal zone (Jones, 1976; Nye, 1974). In addition to the upper reaches of the estuary, *H. crassa* has been found in the Avon and Heathcote rivers as well as nearby mudflats (Crossland et al., 1992). Mudflat burrows descend into the water table, providing a safe and water filled location that enables the crabs to survive in the exposed areas. *H. crassa* can survive in clay, while others, like *H. hirtipes* cannot due to interference with feeding mechanisms (Jones, 1976). Less studied than the other species, small numbers of *H. whitei* have been found in mud below the midtidal area.

H. crassa and *H. whitei* are euryhaline species, able to tolerate a range of salinities, including areas with lower salinities close to the estuary inputs (Jones, 1976). Low salinity areas, however, are thought to be unsuitable for *H. hirtipes* although further study is needed on this.

Prolonged submersion and higher temperatures due to climate change will likely impact the behaviour of mud crab species. *H. hirtipes* is more active when submerged and at high temperatures (Nye, 1974). *H. crassa* however is most active at low tide but can feed whilst submerged (Fielder, 1978; Jones, 1978). *H. whitei* is more active in air, and due to resistance to desiccation they can travel far from their burrows (Melrose, 1975).

Tidal movements are essential to the lifestyle of mud crabs. The tide brings in fresh organic matter for the crabs to feed on and refills their burrows with water preventing desiccation. However, water must recede again to prevent crabs from drowning (Fielder, 1978; Jones, 1978). *H. hirtipes* cannot survive underwater for longer than 4 hours and *H. crassa* for even less (Nye,1974). It is unknown how long *H. whitei* can survive underwater. The implication this holds for our research is that the mud crabs have diverse habitat and physiological requirements which will be disrupted with climate change.

Left Image: *Helice crassa* Middle Image: *Helice crassa* Right Image: *Hemiplax hirtipes*
Note: Photos by Ella Purvis and Carys Marulli de Barletta

5.1 Sediment sampling analysis and sampling methods

Sediment analysis was carried out to assess the composition of the substrate at the Avon-Heathcote estuary. Prior to sampling, a desktop study of the site was conducted, where three focus areas for sampling were identified (South New Brighton Spit, Bexley wetland and Ferrymead) (Fig.3). The length of the estuary margins was measured in Google Earth Pro to determine how many samples would be taken at each site. Systematic sampling methods were used with sampling at Bexley and Ferrymead occurring every 100m and sampling at South New Brighton Spit occurring every 200m. 10 samples were taken at each site; each sample being marked with a waypoint using a GPS to give the samples geospatial context.

Substrate analysis focussed on classifying the sediment by grain size. For sample preparation, each sample was mixed with Sodium hexametaphosphate and placed on a magnetic stirrer to become disaggregated. Once samples had been disaggregated, this solution was pipetted into the machine at the desired obscuration before being passed through a sieve to fall within the range of 0.7 µm to 2.5mm. Samples were analysed using a Micrometrics Saturn Digisizer ll 5205, which uses Fraunhofer light-scattering theory to determine particle size range. These outputs were then analysed using the Wentworth size class scale to classify sediment by grain size.

Figure 3: *Sediment sampling locations taken from the Avon-Heathcote estuary margins. These sampling locations are categorised as 'Spit' (right), 'Bexley' (top), and 'Ferrymead' (left), which includes the Charlesworth reserve.*

5.2 GIS Methods and Analysis

To fill in the gaps in our soil data set, we used open-source LiDAR data from S-Maps to create three maps that depicted soil depth, soil texture and soil order respectively. There is a relatively small area to the South of the Estuary for which data is absent despite our best efforts.

After loading the soil texture data into ArcGIS pro, we clipped it to show only our area of interest (the Avon Heathcote Estuary Margins). We then used the symbology toolset to display each feature as a unique value. Each texture value (loamy, peaty, clayey or sandy) was given a color, producing a map depicting the different soil textures surrounding the estuary. This process was then repeated for the soil depth and soil order data sets.

Next, we classified the data to show only the cells that contained suitable depth, texture and order values for *H. hirtipes*. We based suitability on the information we had on its physiology and habitat preferences. We then repeated this process for *H. crassa* but for *H. whitei* we did not include soil order in our suitability calculations as this information was not available to us.

The second part of the GIS analysis process was to create a digital elevation model (DEM), which we did using open-source LiDAR data from OpenTopography. Because OpenTopography has a download limit we had to download three different DEM's to cover the full location of interest. We then performed spatial analysis in ArcGIS pro. The Tonkin and Taylor report predicted that everything up to an elevation of 2.2 meters above sea level (MABSL) will become inundated every high tide (assuming 1m of sea level rise and an additional 1.2m of high tide). We used this information to create a map showing the new high-tide, mid-tide, and low-tide zones. We then overlayed this data with the soil texture, order and soil depth data to create suitability maps that account for the different species of crab's preference for different tidal zones.

Finally, we added a data set containing polygons of all the buildings surrounding the estuary and removed areas of habitat classified as suitable that crossed over with buildings. We were left with a map showing the suitability of habitat based off soil texture, soil depth, soil order, slope, and tidal requirements for each species.

6. Results and findings

6.1 Sediment analysis results

Sediment analysis results show the current sediment grain size of the substrate within the Avon-Heathcote Estuary. This helped inform us of the current distribution of mud crabs in the Estuary based solely on particle size (Fig.7).

Bexley consisted mainly of silt (4-60 microns). There was some variation among samples specifically samples 5 and 8 which were made up of very fine sand (63-125 microns) (Fig.4). This particle size suits *H. hirtipes* and *H. crassa* informing us that the current distribution of these two species could include Bexley.

The dominating particle size at Ferrymead was silt (4-63 microns) as well as very fine sand (63-125 microns). There was some variation among sites with sample 10 consisting mainly of fine sand (125-250 microns) (Fig.5). The variation in samples is likely due to the sampling site including the reserve opposite the estuary as well as the estuary itself. This particle size suits *H. hirtipes* and *H. crassa* informing us that their current range could extend to Ferrymead as well.

The Spit consisted of fine to very fine sand (63-250 microns). There is a small amount of course silt as well (31-63 microns). There is very little variation among the sites at the Spit (Fig.6). This particle size suits all three mud crab species, *H. whitei, H. hirtipes,* and *H. crassa.*

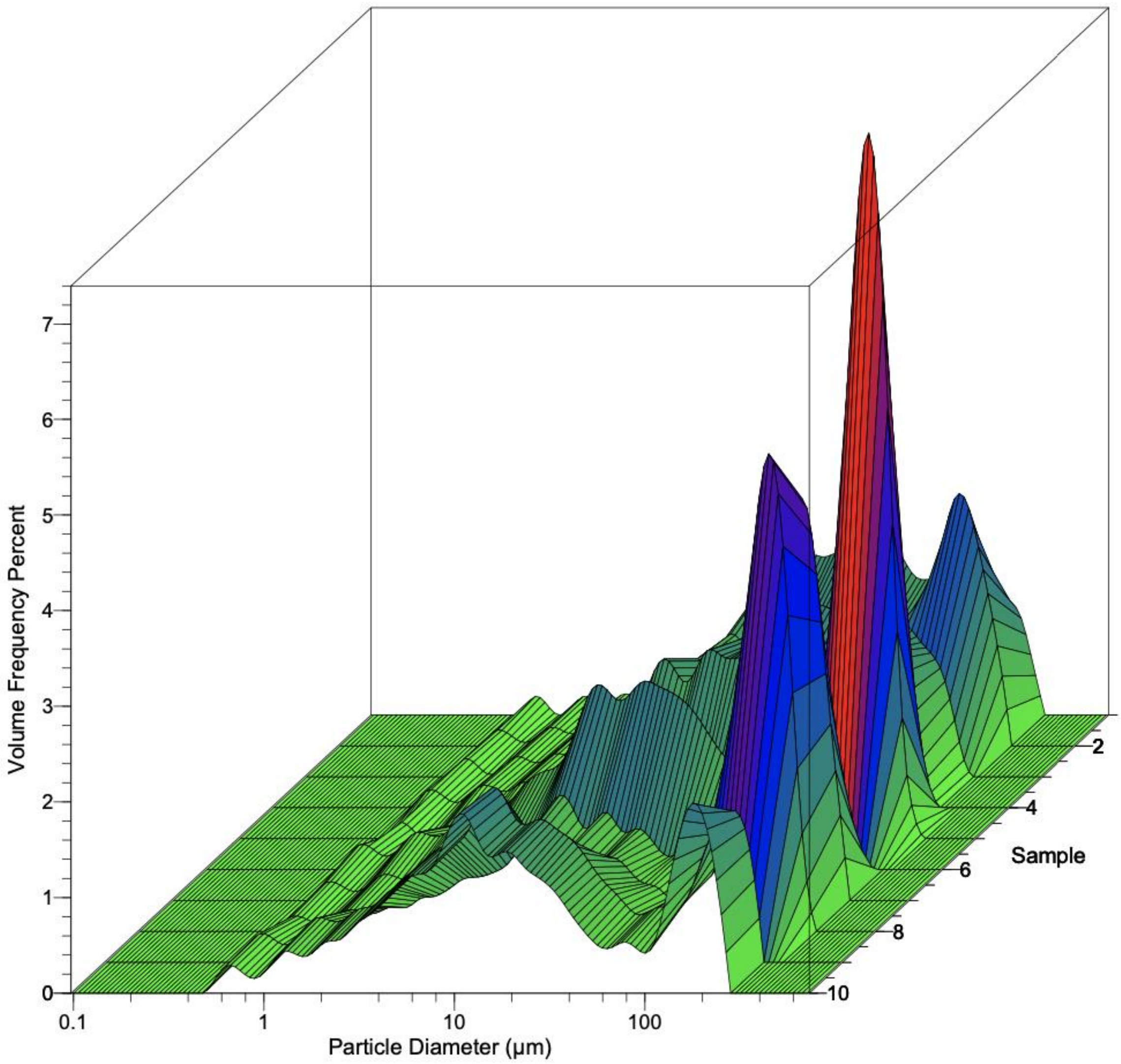

Figure 4: *Graph showing the predominant sediment particle size at Bexley*

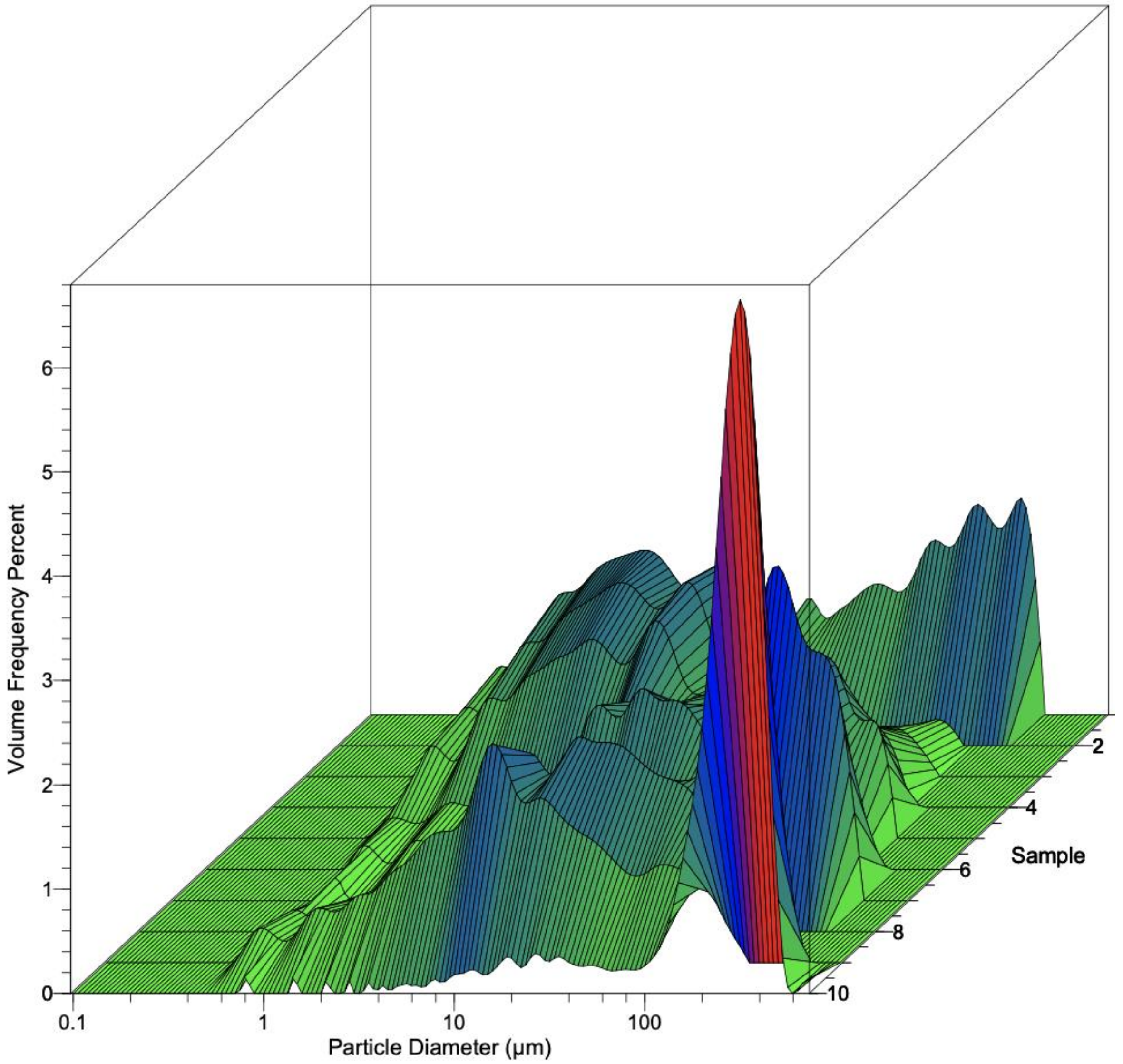

Figure 5: *Graph showing the predominant sediment particle size at Ferrymead and Charlesworth reserve*

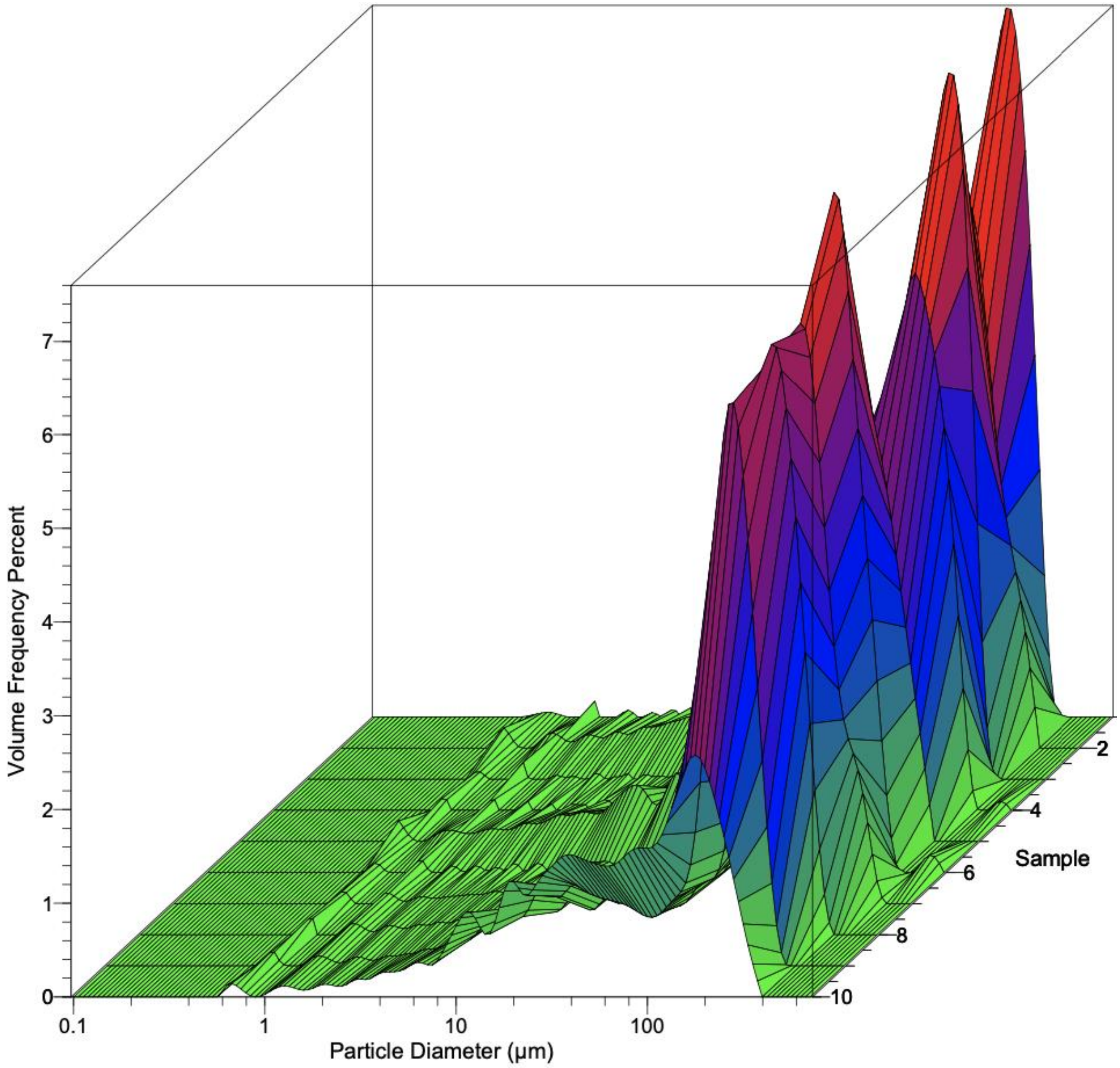

Figure 6: *Graph showing the predominant sediment particle size at the South New Brighton Spit*

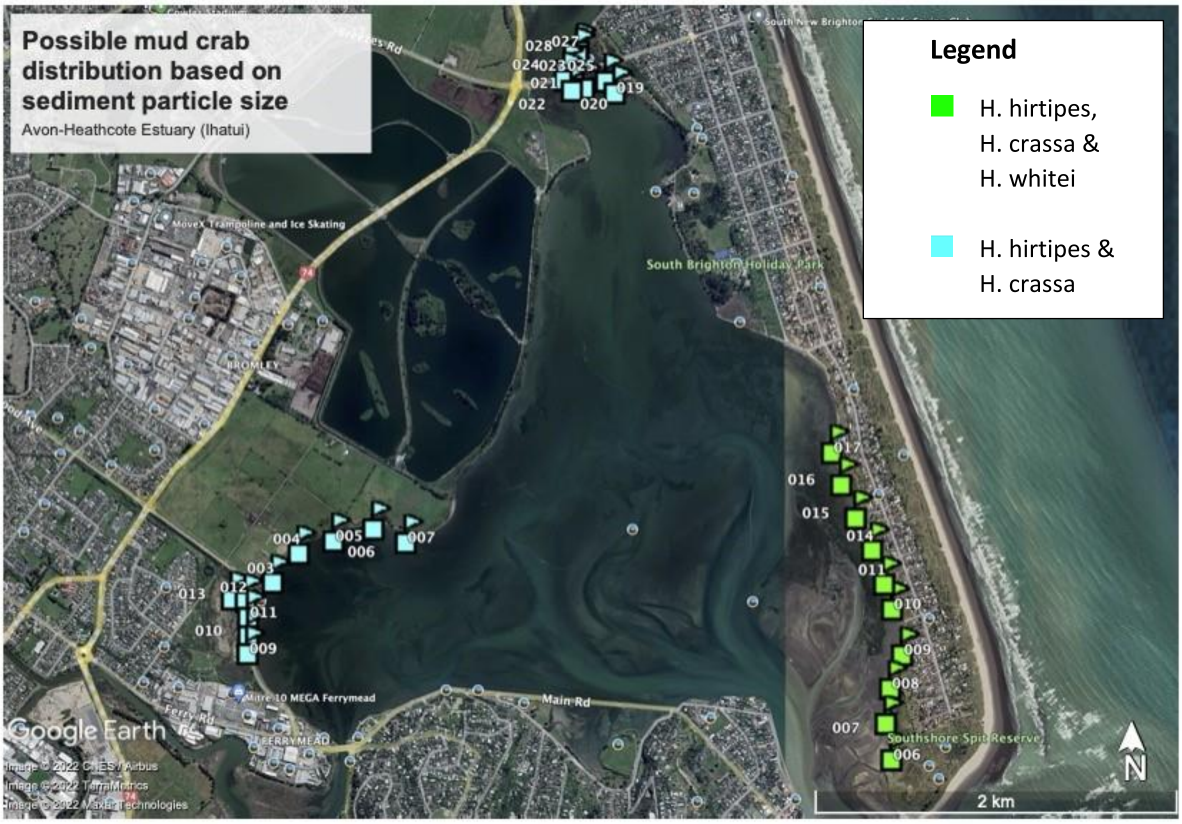

Figure 7: *Possible mud crab distribution in the Avon-Heathcote estuary based on sediment particle size analysis. This shows that H. crassa and H. hirtipes can inhabit all estuary margins. However, H. whitei can only inhabit the Spit.*

6.2 GIS results

According to our results, sections of the Avon-Heathcote estuarine margins are suitable habitats for mud crabs. One disadvantage of LiDAR data is that it can reflect off water surfaces, creating inaccuracies. This makes the Avon and Heathcote riverbeds appear suitable for *H. hirtipes* in some of our maps, but this is incorrect (Fig.12). Our analysis of soil depth found that nearly all sections of the margin have a suitable soil depth for mud crabs, except for the ridges of Mount Pleasant to the south of the estuary, which regardless are inaccessible for mud crabs. Different species of mud crabs require different types of soils depending on their physiology. Our analysis of soil texture and order produced three maps that show the location of suitable soil for three study species (Fig.8, Fig.9, & Fig.10). Neither soil texture nor order limit habitat availability for *H. hirtipes* (Fig.8) but *H. crassa* was excluded from water logged soils such as gley (Fig.9) however, a large portion of the estuary still contained soil suitable for *H. crassa* . *H. whitei* was limited to areas that contained soil texture of no less than fine sand mostly towards the North of the Estuary and along the spit (Fig.10).

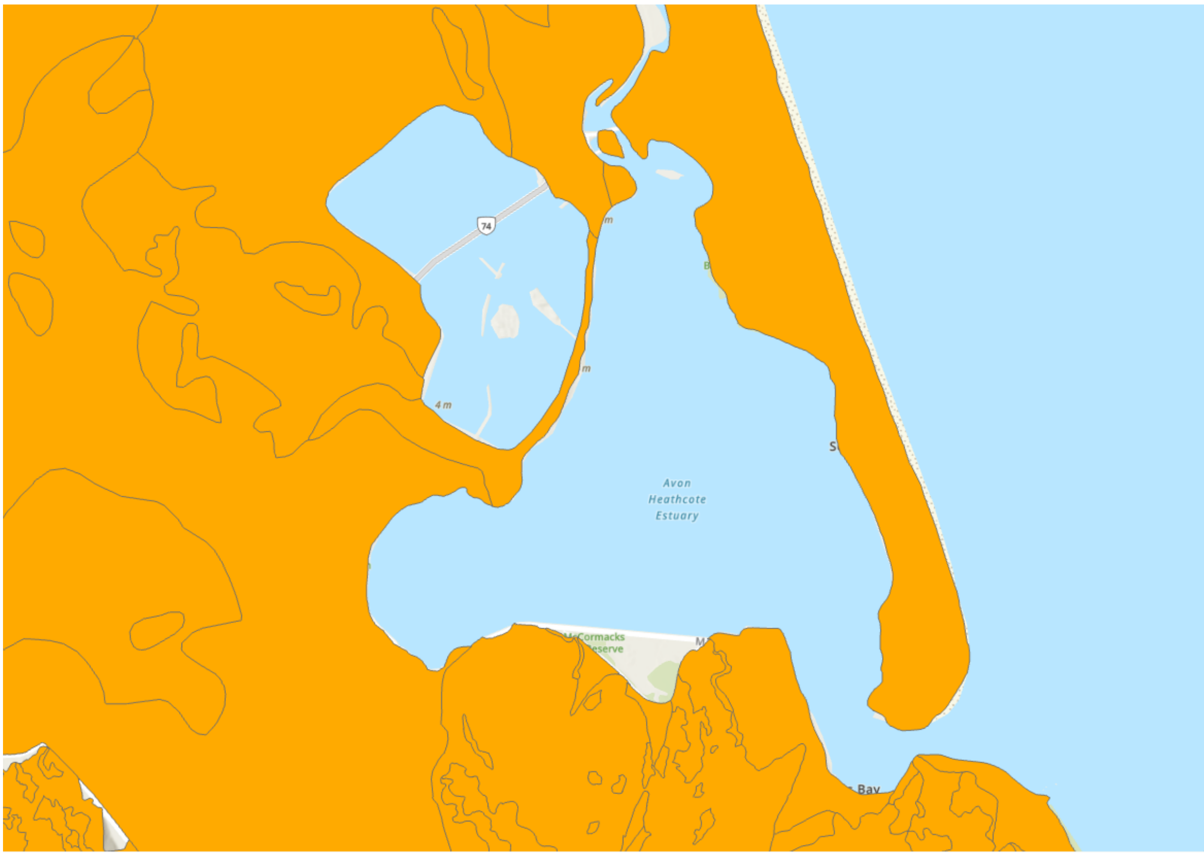

Figure 8: *Suitable Sediment for Hemiplax hirtipes based off its preference for soft, muddy, and waterlogged soil*

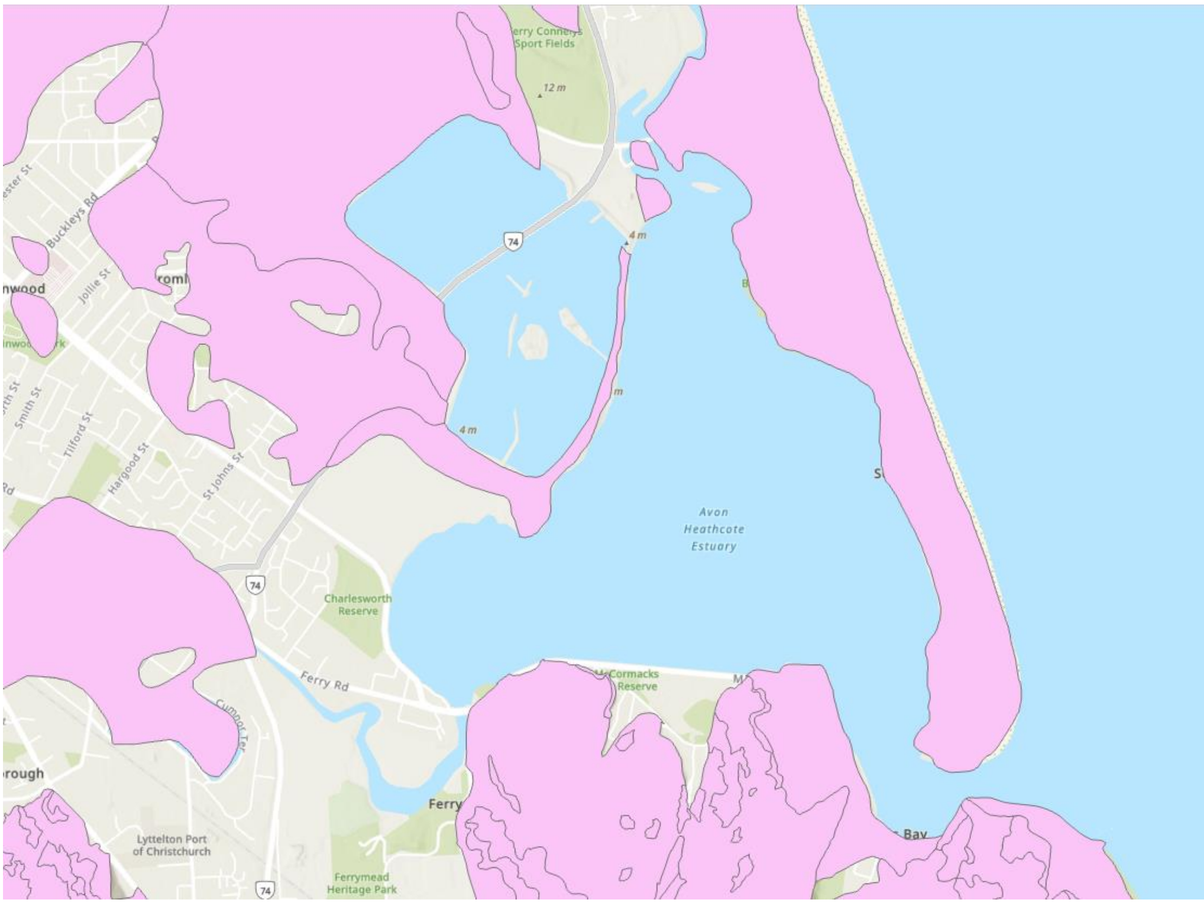

Figure 9: *Suitable Sediment for Helice crassa based off its preference for solid sediments.*

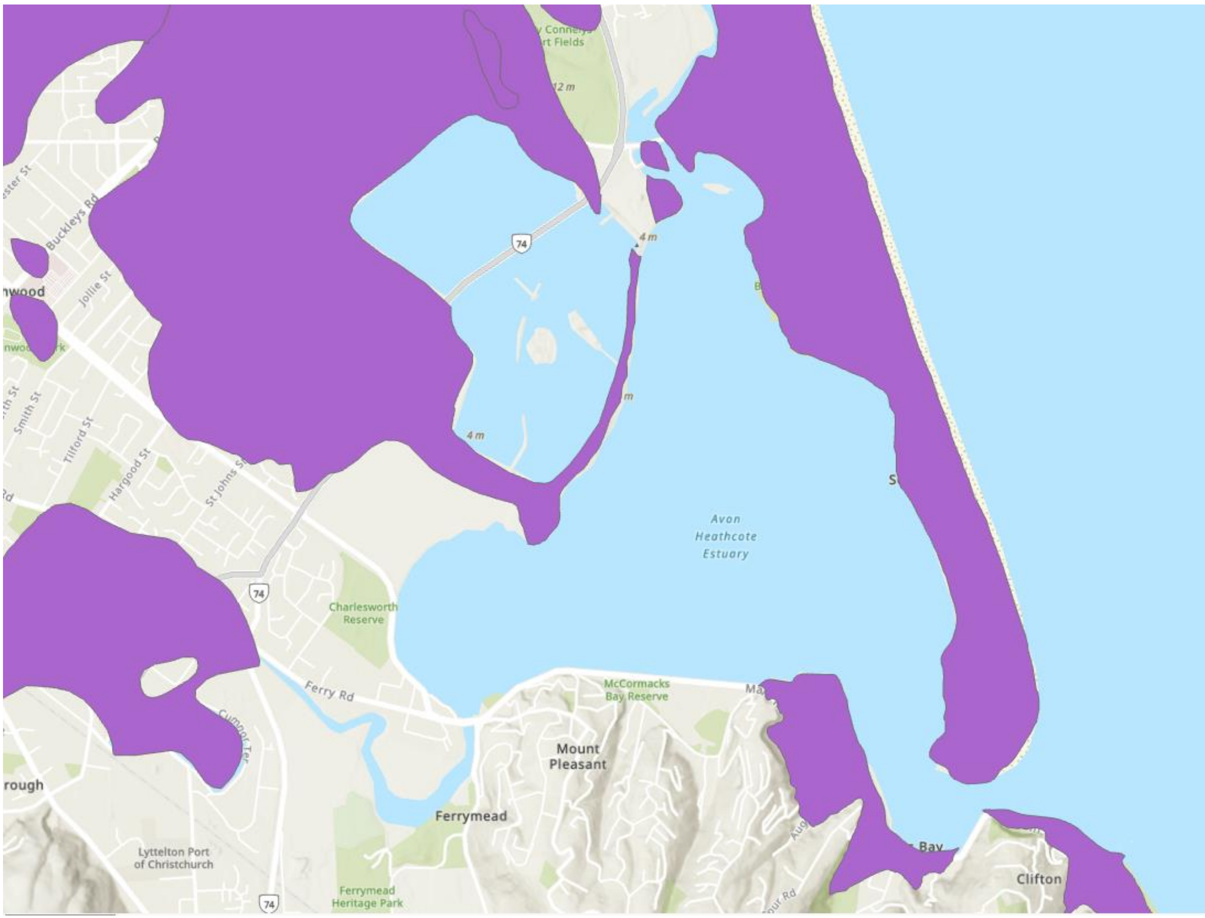

Figure 10: *Suitable Sediment for Halicarcinus whitei based off its preference for soil textures no less than fine sand.*

However, as estuary crabs, the tide is crucial to their lifestyles. The results of the spatial analysis (Fig.11) show that the new tidal limits will extend well into the Christchurch suburbs of Ferrymead, Bromley, Woolston, and New Brighton. This further limits the available habitat for mud crabs as buildings create obstructions. Roads have not been included as barriers to dispersal or areas that crabs cannot inhabit in this analysis due to time constraints on geoprocessing. After including the preferences of each of the crabs for different tidal zones, *H. hirtipes* for the low tide zone, *H. whitei* for the mid-tide zone, and *H. crassa* for the high tide zone, the suitable habitat becomes increasingly limited (Fig.12, Fig.13, & Fig.14)

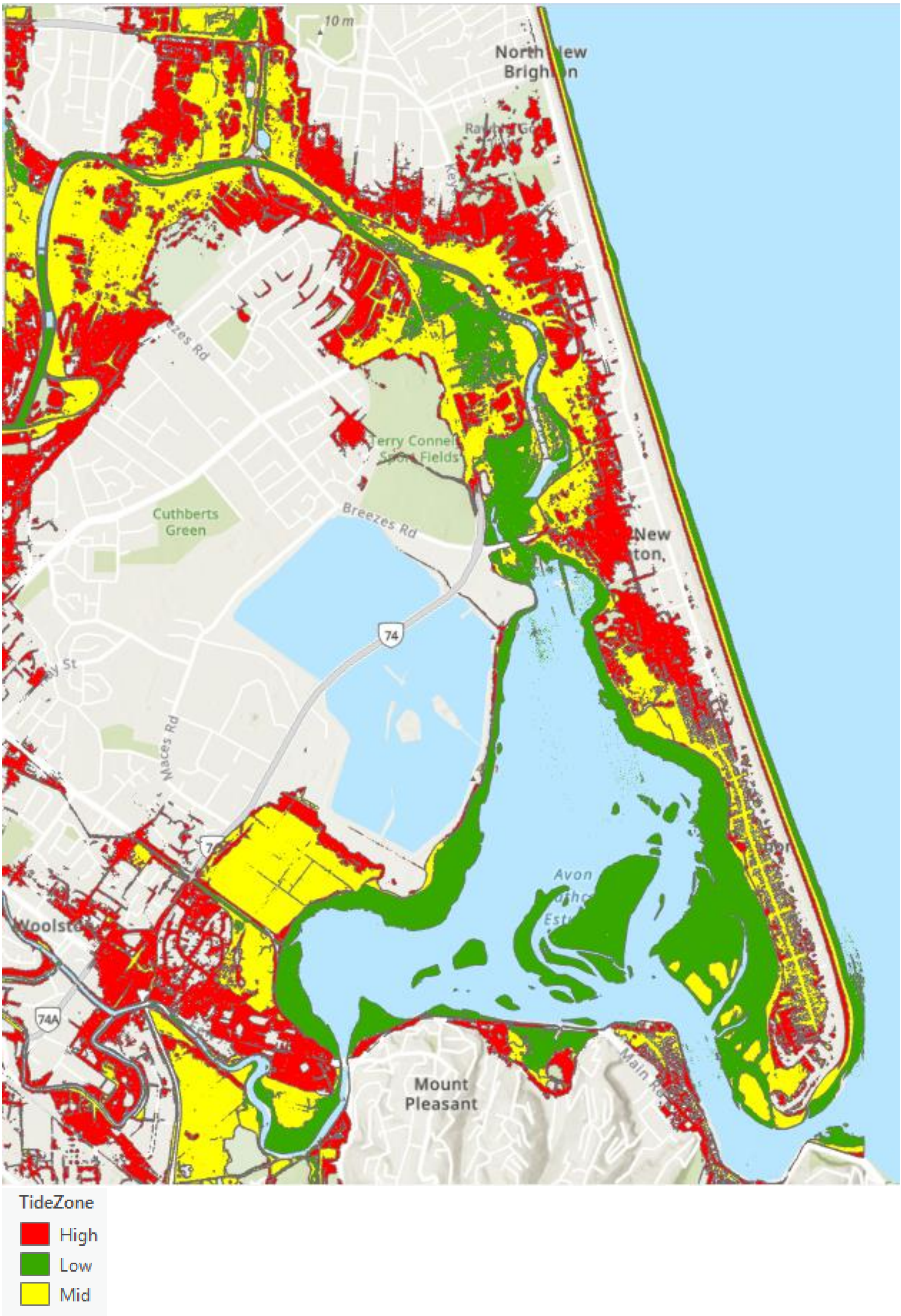

Figure 11: *New Tidal Limits based on 1m sea level rise predictions*

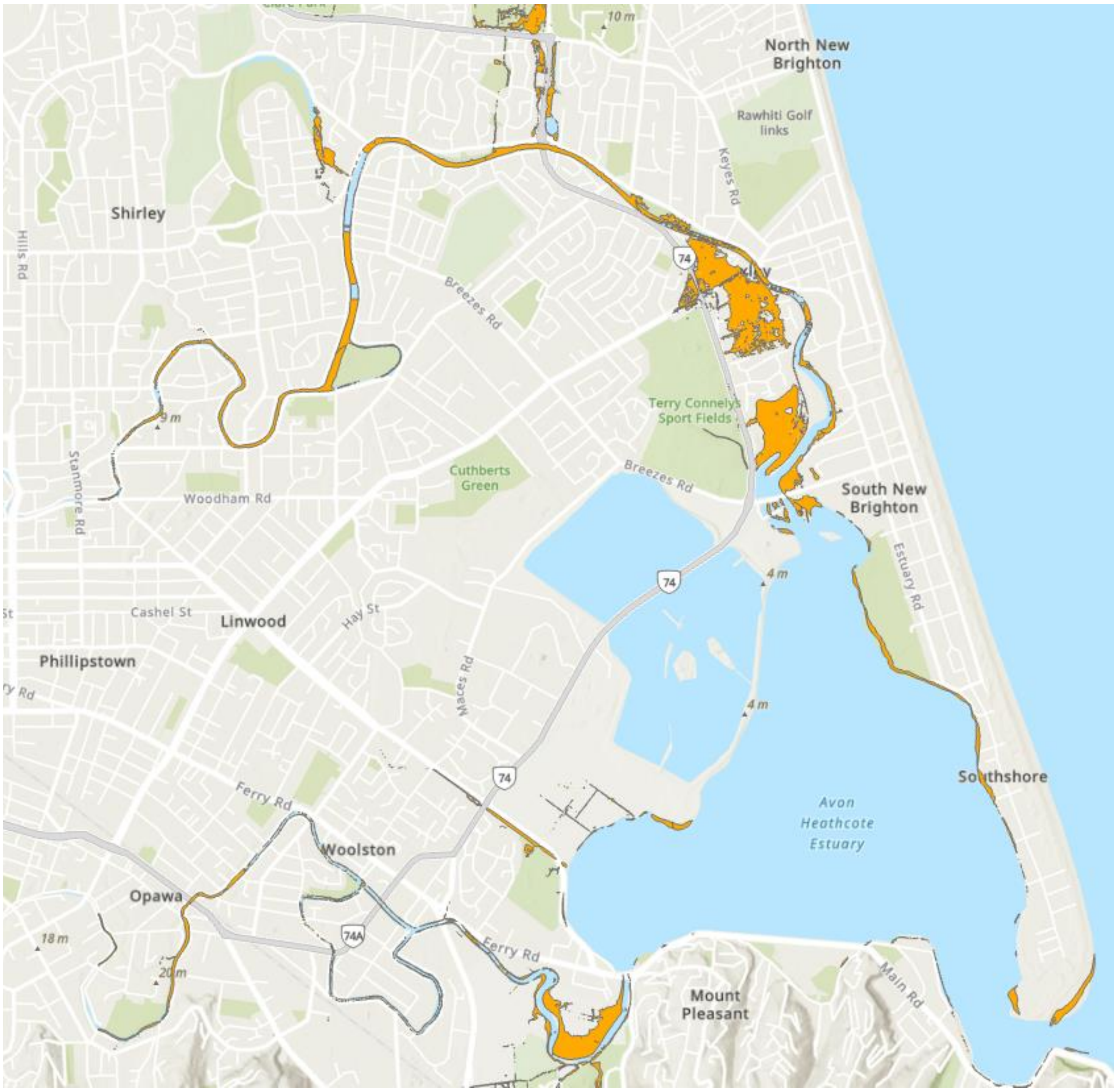

Figure 12*: Suitable Habitat for Hemiplax hirtipes. This suitable habitat was determined using H. hirtipes preferences for waterlogged sediment in the lower intertidal zone with a depth of at least 6 cm, excluding all clay sediments that clog its feeding mechanisms.*

NB: The rivers are not suitable habitat; this is a fault of the LiDAR data.

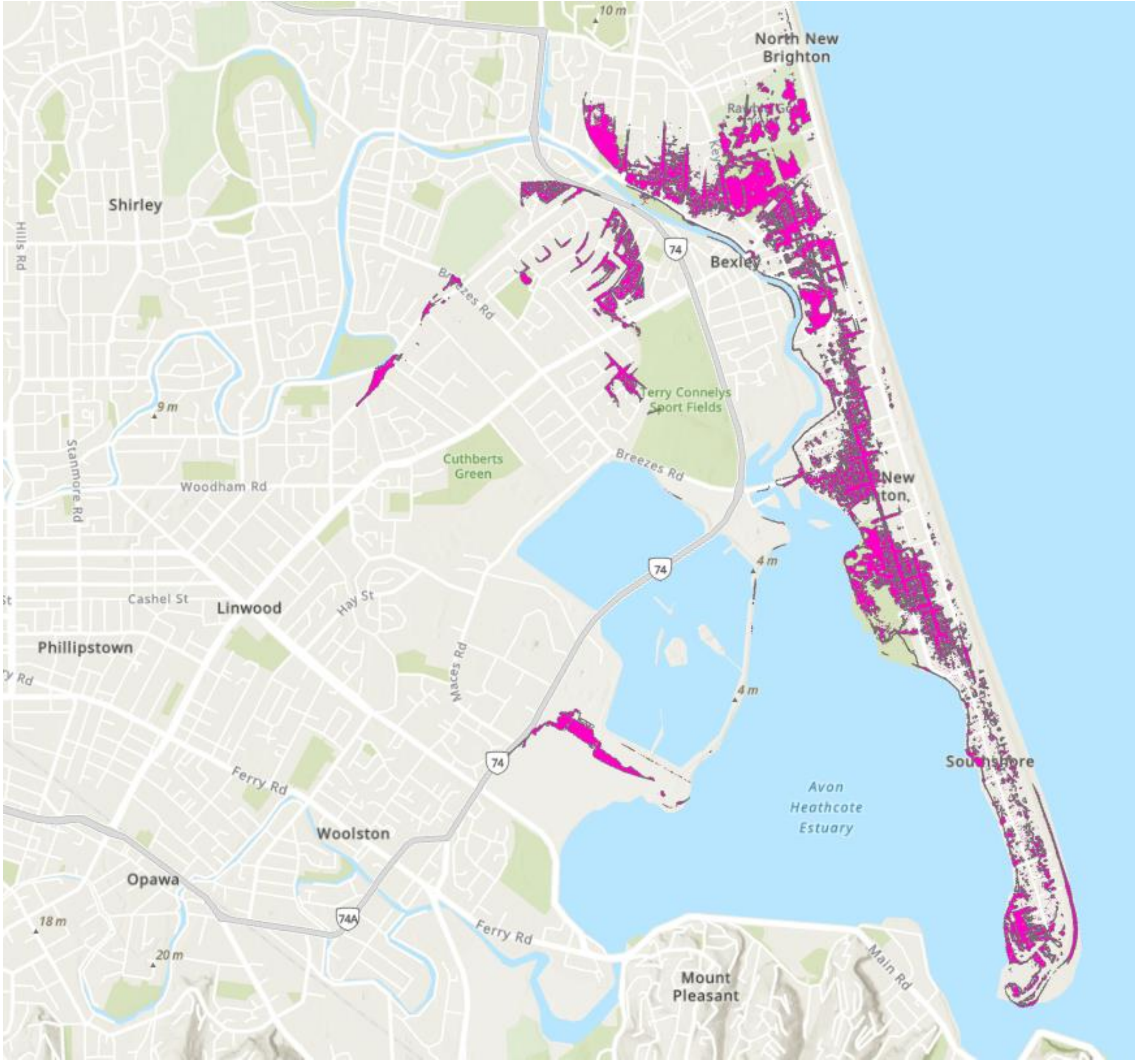

Figure 13: *Suitable habitat for Helice crassa. Suitability was determined using H. crassa's preference for soild mud in the high tide zone with a depth of at least 7 cm.*

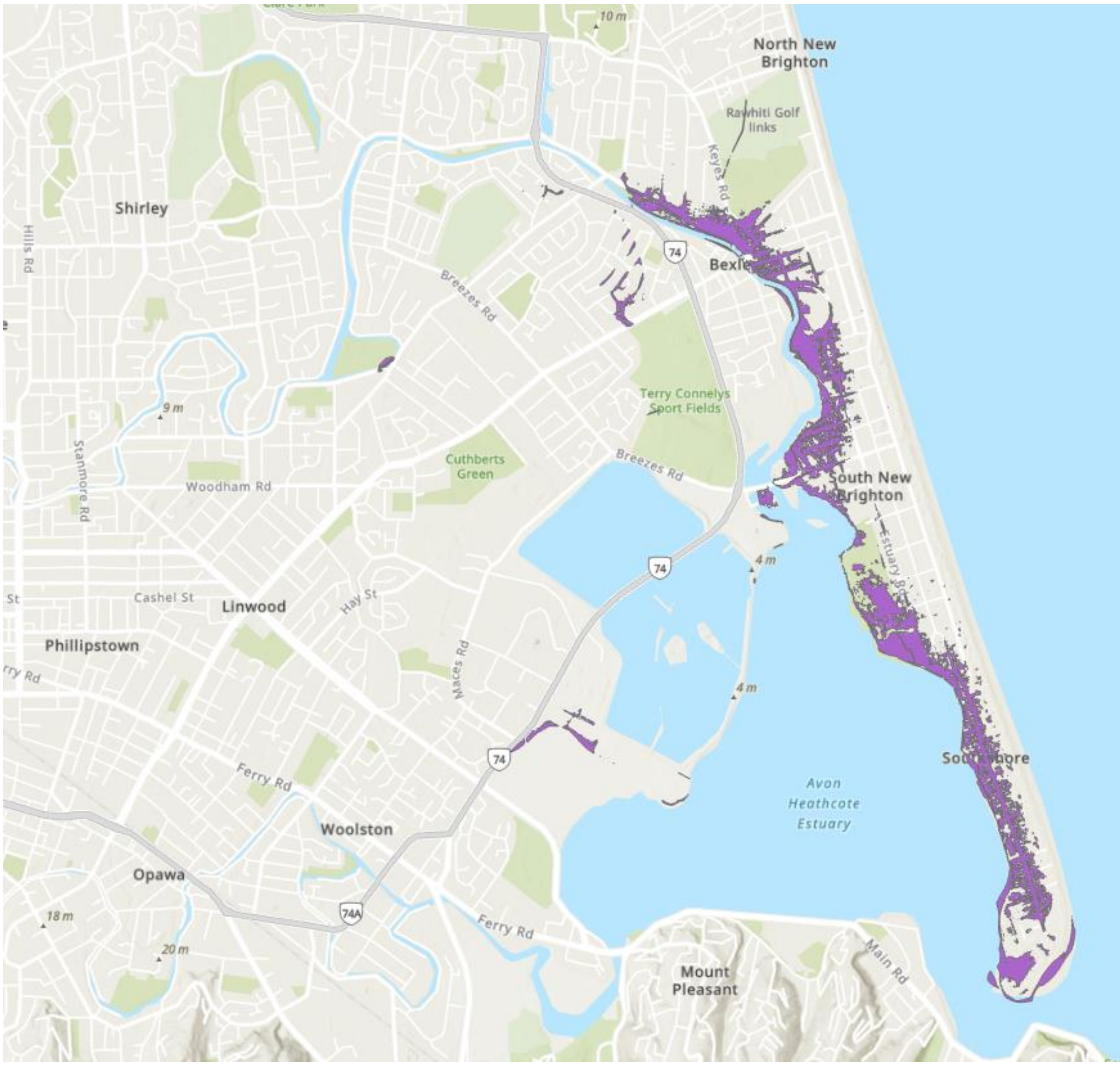

Figure 14: *Suitable habitat for Helicarcinus whitei. Suitability was based on H. whitei's requirement to have soil texture no less than fine sand with a depth of at least 6 cm and its preference for the mid tidal zone.*

7. Discussion

7.1 Findings

Our results from the sediment analysis suggest that based on particle size *H. hirtipes* and *H. crassa* could be found at all locations that we sampled (Fig.7). It also revealed that based on particle size, *H. whitei* could only be found at the South New Brighton Spit (Fig.7). All analysis of particle size was only conducted within the estuary and did not include the margins.

Building on our results from the sediment analysis, Our GIS findings suggest that the Ihutai Avon-Heathcote Estuary margins have habitat suitable for mud crabs. We determined that substrate is not a factor limiting suitable habitat, but that infrastructure and tides could be. We have also considered options for movement of mud crabs to suitable habitat.

Tonkin&Taylor Ltd (2013) investigated inundation of the Avon-Heathcote Estuary. They modelled rising sea levels and extreme flooding events. Their results show that much current mud crab habitat will be subject to an increase in inundation frequency, with many areas becoming permanently inundated. The aim of our project was to determine whether the margins of the Ihutai Avon-Heathcote estuary were suitable for mud crab retreat in the face of climate change and 1m sea level rise. We reviewed literature to determine habitat preferences and physiological requirements of three different study species and used this information as a basis on which to build our recommendations of suitable locations for mud crab retreat. We then undertook our own research, analysing the substrate of the estuary and using GIS analysis to build a picture of the geomorphological and spatial characteristics of the estuary. By combining these two aspects we have determined that sections of the estuary margins are suitable for mud crab retreat.

We have identified areas (Fig.12, Fig.13, & Fig.14) that based on slope, tidal zone, sediment, and lack of buildings are suitable for mud crab habitation in the event of a 1m sea level rise. Noticeably absent from our calculations are salinity measurements, which we have chosen to exclude. Both *H. crassa* and *H. whitei* are euryhaline which means they can tolerate a wide range of salinities (Jones, 1976). Some studies suggest *H. hirtipes* has an affinity for the high salinities (Simons and Jones, 1981) towards which the estuary is trending in the face of sea level rise (Vineis et al, 2011). However, others suggest *H. hirtipes* is in fact limited by high salinities (Marsden, 1997). Salinity preferences of *H. hirtipes* therefore require more investigation before they can be used to make habitat suitability predictions. As previously stated, roads were also not included on our suitability maps due to geoprocessing time constraints. We also acknowledge that our research accounts only for sea level rise and not for one in hundred-year extreme inundation events. Extreme inundation events pose a huge problem for mud crabs because moving species further up the shoreline to avoid these events means they will not be close enough to the tides that their lifestyle is based around.

For all three of our study species, after taking into account factors other than sediment, the area in which they can inhabit decreased dramatically. This leads us to the conclusion that it is tidal zones and infrastructure, not substrate requirements that will limit the availability of mud crab habitat.

The goal of the Avon-Heathcote Estuary Ihutai trust is to preserve the natural and historic resources of the estuary. Our research comes under goal 3 of The Estuary Management plan 2020-2030 which involves adapting species to climate change by protecting and restoring habitat (Avon-Heathcote Estuary Ihutai Trust, 2020). They have identified that mud crabs are an important species for conservation due to their key role as bioturbators. When Mud Crabs burrow, they aerate the soft sediments of the estuary and increase nutrients (Shull, 2009) which is important because it improves primary productivity and microbial activity. Our maps and findings will allow the Estuary Trust to protect and prioritize areas of the estuary for restoration that contain suitable mud crab habitat.

Spidalieri (2020) suggests management options for the conservation of coastal ecosystems include the restoration/enhancement of existing coastal communities or the facilitation of their landward retreat. We recommend Bexley as an area for consideration as it is one of the larger areas of suitable habitat and caters to all species-specific requirements.

We acknowledge that getting to the suitable habitat we have indicated is another challenge for mud crabs entirely. Options for this include translocation or building a corridor to allow mud crabs to migrate naturally. Borchert et al. (2018) indicates that the establishment of migration corridors are essential to facilitate the landward migration of estuarine species, particularly if the surrounding estuarine margins are highly urbanised.

Tonkin&Taylor Ltd (2013) suggests that landward migration potential for coastal communities depends on the availability of surrounding land. Our results show that the availability of suitable mud crab habitat is limited but present. This makes the sustainability of mud crabs in the face of climate change promising.

Photo: *Hemiplax hirtipes* by Ella Purvis and Carys Marulli de Barletta

7.2 Limitations

Inaccessibility constrained our data collection as some areas we had initially planned on sampling during our desktop study were blocked off by roadworks when we arrived at the estuary. These areas included the far side of Bexley and toward the Ferrymead bridge.

Due to time constraints, we only consider slope, soil texture, order and depth, tidal zones, and buildings to determine suitability of the landscape for mud crabs. This ignored other factors affecting habitat suitability such as salinity, organic matter, phosphorus and nitrogen, and metal contaminants. Further research investigating these factors in the estuary is necessary to understand their current distribution in the Avon-Heathcote Estuary.

A limitation of our recommendations for where the mud crabs could go is that we did not include roads in this analysis, and it is likely these would further restrict where mud crabs could retreat to.

While our project focused on the suitability of surrounding areas mud crabs can migrate to, the method by which the crabs may move to these locations is beyond the scope of our research.

7.3 Recommendations

Studies that could be carried forward from this report may include establishing how the mud crabs will migrate to their new habitat. We suggested Bexley as a suitable location, however the migratory route to get there is unknown. The mud crabs may be able to naturally extend their range, however, this may not be possible due to roads creating barriers, therefore it is important to consider other methods of migration. One such method is translocation. Conservation translocations are defined as the movement of individuals from one environment to another, and is driven by humans (IUCN, 2013).

Conservation translocations are high risk and should be treated as a last resort. A key parameter of conservation translocations is that they must be ecosystem focussed, whether that is replacing another species to fulfil a missing ecosystem function, or to buffer declining numbers in a population. Our marine environment has become increasingly degraded due to climate change (Swan et al., 2016). This pressure could force more marine species to be on the brink of extinction, whereby conservation translocation may be the only option to secure their survival.

There are two types of conservation translocations, these are population restoration and conservation introduction, each with their own criteria to follow. Population restoration occurs in the species home range, whereby individuals can be introduced to reinforce an already existing population or re-established into an area they once inhabited but have disappeared from. In the case of the mud crabs from the Avon-Heathcote Estuary, it may be possible to translocate them to another beach, to a population of conspecifics. If this is the case, it would be considered conservation reinforcement according to the IUCN guidelines.

8. Concluding remarks

Estuarine mud crabs are critically important to the interdependent Avon-Heathcote estuary food web as they provide resources to co-existing estuarine species, thus, their presence is indicative of a thriving ecosystem.

With predicted sea level rise and flooding scenarios modelled by (Tokin & Taylor, 2013), where inundation extends over the Avon-Heathcote estuary for several days, mud crabs will be unable to feed in the intertidal zone. The landward migration of mud crabs will be crucial for their survival and support the diversity of other estuarine species at the Avon-Heathcote for the continuation of a productive ecosystem that provides essential services.

While the habitat we have found to be suitable is limited, each mud crab species has options that make their sustainability under climate change promising. We suggest Bexley is likely the most suitable area for the retreat of mud crabs, based on our sediment and GIS analysis considering slope, soil depth, substrate suitability, buildings, and new tidal zones.

This research contributes to environmental and community resilience in the face of climate change. It should be taken into consideration for urban development planning and coastal adaptation strategies to prevent the local extinction of mud crabs at the Avon-Heathcote estuary. We recognise that further research is required to determine the facilitation of the managed retreat of mud crabs, whether this will occur through natural processes or aided by human intervention.

9. Acknowledgements

A special acknowledgment to our community partner Ann Kennedy representing the Avon-Heathcote Ihutai trust and tutor Jillian Frater. Additionally, thanks to Justin Harrison, Chris Grimshaw, Sarah McSweeney, Giles Ostermeijer, & Mads Thomsen for help and guidance within various stages of this report.

We would like to acknowledge that the GIS data is obtained from open data sources provided by the Christchurch City Council. Due to this, figures can be used in a commercial context provided approval from the Avon-Heathcote Estuary Ihutai Trust alongside acknowledgement that the data is open-sourced.

10. References

Avon-Heathcote Estuary Ihutai Trust. (2020, August). Estuary Management Plan 2020-2030. ISBN: 978-0-473-55693-8. http://www.estuary.org.nz/f/6ca2816ff22a4bb2.pdf

Borchert, S. M., Osland, M. J., Enwright, N. M., Griffith, K. T., & Rohr, J. (2018). Coastal wetland adaptation to sea level rise: Quantifying potential for landward migration and coastal squeeze. *The Journal of applied ecology*, *55*(6), 2876-2887. https://doi.org/10.1111/1365-2664.13169

Castilla J.C., Manríquez P.H., & Camaño, A. (2010, November 18). Effects of rocky shore coseismic uplift and the 2010 Chilean mega-earthquake on intertidal biomarker species. *Mar Ecol Prog Ser*, 418, 17-23. https://doi.org/10.3354/meps08830

Chua, V. P., & Xu, M. (2014). Impacts of sea-level rise on estuarine circulation: An idealized estuary and San Francisco Bay. *Journal of Marine Systems, 139*, 58-67.

Crossland, A., Deely, J., Harris, R., & Owen, S. J. (1992). *The Estuary Where Our Rivers Meet the Sea Christchurch's Avon-Heathcote Estuary and Brooklands Lagoon* (1st ed.). Christchurch City Council.

Du, J., Shen, J., Zhang, Y. J., Ye, F., Liu, Z., Wang, Z., Wang, Y. P., Yu, X., Sisson, M., & Wang, H. V. (2018). Tidal response to sea-level rise in different types of estuaries: The Importance of Length, Bathymetry, and Geometry. *Geophysical Research Letters, 45*(1), 227-235.

Environment Canterbury. (n.d.). Avon-Heathcote Estuary/Ihutai. *Land Air Water Aotearoa*. https://www.lawa.org.nz/explore-data/canterbury-region/estuaries/avon-heathcote-estuaryihutai/

Fielder, D. R., & Jones, M. B. (1978). Observations of feeding behaviour in two New Zealand mud crabs (Helice crassa and Macrophthalmus hirtipes).

Findlay, R. H., & Kirk, R. M. (1988). Post-1847 changes in the Avon-Heathcote Estuary, Christchurch: A study of the effect of urban development around a tidal estuary. *New Zealand Journal of Marine and Freshwater Research, 22*(1), 101-127. https://doi.org/10.1080/00288330.1988.9516283

GeoNet. (2016, November 21). *Coastal Uplift: How has the Kaikoura Coastline Changed.* *https://www.geonet.org.nz/news/3kTum4hHVCEI2YwMoUWmEm#:~:text=Coastal%20uplift%20is%20when%20the,land%20to%20be%20pushed%20up*

Hunter, E. C., de Vine, R., Pantos, O., Clunies-Ross, P., Doake, F., Masterton, H., & Briers, R. A. (2022). Quantification and Characterisation of Pre-Production Pellet Pollution in the Avon-Heathcote Estuary/Ihutai, Aotearoa-New Zealand. *Microplastics, 1*(1), 67-84. https://www.mdpi.com/2673-8929/1/1/5

IUCN/SSC (2013). Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp

Jaramillo, E., Dugan, J.E., Hubbard, D.M., Melnick, D., Manzano, M., Duarte, C., Campos, C., & Sanchez, R. (2012, May 2). Ecological Implications of Extreme Events: Footprints of the 2010 Earthquake along the Chilean Coast. *PLoS ONE, 7*(5), e35348. https://doi.org/10.1371/journal.pone.0035348

Jones, M. B. (1976). Limiting factors in the distribution of intertidal crabs (crustacea: Decapoda) in the Avon Heathcote estuary, Christchurch. New Zealand Journal of Marine and Freshwater Research, 10(4), 577- 587. https://doi.org/10.1080/00288330.1976.9515641

Malakhov, Y. (2019). *Intertidal microphytobenthos of Te Ihutai/Avon-Heathcote Estuary (areas adjacent to the oxidation ponds)*. https://doi.org/10.13140/RG.2.2.34139.18728

Marsden, I. D. (1997). (rep.). *Macroinvertebrates of the Avon-Heathcote Estuary* . Christchurch , Canterbury : Canterbury Regional Council.

Melrose, M. J., & New Zealand. Department of Scientific and Industrial Research. (1975). The marine fauna of new zealand: Family hymenosomatidae (crustacea, decapoda, brachyura). New Zealand Department of Scientific and Industrial Research

Nye, P. A. (1974). Burrowing and burying by the crab macrophthalmus hirtipes. New Zealand Journal of Marine and Freshwater Research, 8(2), 243- 254. https://doi.org/10.1080/00288330.1974.9515502

Osland, M. J., Chivoiu, B., Enwright, N. M., Thorne, K. M., Guntenspergen, G. R., Grace, J. B., Dale, L. L., Brooks, W., Herold, N., Day, J. W., Sklar, F. H., & Swarzenzki, C. M. (2022). Migration and transformation of coastal wetlands in response to rising seas. *Science advances*, *8*(26), eabo5174-eabo5174. https://doi.org/10.1126/sciadv.abo5174

Reid, C. M., Thompson, N. K., Irvine, J. R. M., & Laird, T. E. (2012). Sand volcanoes in the Avon–Heathcote Estuary produced by the 2010–2011 Christchurch Earthquakes: implications for geological preservation and expression. *New Zealand Journal of Geology and Geophysics, 55*(3), 249-254. https://doi.org/10.1080/00288306.2012.674051

Ross, A. C., Najjar, R. G., Li, M., Mann, M. E., Ford, S. E., & Katz, B. (2015). Sea-level rise and other influences on decadal-scale salinity variability in a coastal plain estuary. *Estuarine, Coastal and Shelf Science, 157*, 79-92.

Rullens, V., Mangan, S., Stephenson, F., Clark, D.E., Bulmer, R.H., Berthelsen, A., Crawshaw, J., Gladstone-Gallagher, R.V., Thomas, S., Ellis, J.I., & Pilditch, C.A. (2022). Understanding the consequences of sea level rise: the ecological implications of losing intertidal habitat. *New Zealand Journal of Marine and Freshwater Research, 56*:3, 353-370, DOI: 10.1080/00288330.2022.2086587

Schiel D.R., Gerrity, S., Orchard, S., Alestra, T., Dunmore, R.A., Falconer, T., Thomsen, M.S., & Tait, L.W. (2021). Cataclysmic Disturbances to an Intertidal Ecosystem: Loss of Ecological Infrastructure Slows Recovery of Biogenic Habitats and Diversity. *Front. Ecol*. Evol, *9*. doi: 10.3389/fevo.2021.767548

Schwarz, K. (1994, May 1). Chapter 5: Most Tolerant of Desiccation. *The University of Florida Book of Insect Records*.

https://entnemdept.ufl.edu/walker/ufbir/chapters/chapter_05.shtml#:~:text=Organisms%20have%20a%20variety%20of,hottest%20part%20of%20the%20day

Shull, D. H. (2009). Bioturbation. *Encyclopedia of Ocean Sciences*, 395–400. https://doi.org/10.1016/b978-012374473-9.00656-1

Simons, M. J., & Jones, M. B. (1981). Population and reproductive biology of the mud crab, Macrophthalmus hirtipes (Jacquinot, 1853) (Ocypodidae), from marine and estuarine habitats. *Journal of Natural History, 15*(6), 981-994. https://doi.org/10.1080/00222938100770731

Spidalieri, K. (2020). Where the Wetlands Are—And Where They Are Going: Legal and Policy Tools for Facilitating Coastal Ecosystem Migration in Response to Sea-Level Rise. *Wetlands (Wilmington, N.C.)*, *40*(6), 1765-1776. https://doi.org/10.1007/s13157-020-01280-x

Swan, K. D., McPherson, J. M., Seddon, P. J., & Moehrenschlager, A. (2016). Managing marine biodiversity: the rising diversity and prevalence of marine conservation translocations. *Conservation Letters, 9*(4), 239-251.

Thomsen, M. S., Hildebrand, T., South, P. M., Foster, T., Siciliano, A., Oldach, E., & Schiel, D. R. (2016). A sixth-level habitat cascade increases biodiversity in an intertidal estuary. *Ecology and Evolution, 6*(22), 8291-8303. https://doi.org/https://doi.org/10.1002/ece3.2499

Thomsen, M. S., Mondardini, L., Thoral, F., Gerber, D., Montie, S., South, P. M., Tait, L., Orchard, S., Alestra, T., & Schiel, D. R. (2021). Cascading impacts of earthquakes and extreme heatwaves have destroyed populations of an iconic marine foundation species. *Diversity and Distributions*, ***27***(12), 2369–2383. https://www.jstor.org/stable/48632834

Tonkin & Taylor Ltd (2013, November). Effects of Sea Level Rise for Christchurch City. *Christchurch City Council*. T&T Ref: 61707

Vineis, P., Chan, Q., & Khan, A. (2011). Climate change impacts on water salinity and health. *Journal of Epidemiology and Global Health*, *1*(1), 5. https://doi.org/10.1016/j.jegh.2011.09.001

Wasson, K., Woolfolk, A., & Fresquez, C. (2013). Ecotones as Indicators of Changing Environmental Conditions: Rapid Migration of Salt Marsh–Upland Boundaries. *Estuaries and Coasts*, *36*(3), 654-664. https://doi.org/10.1007/s12237-013-9601-8