"WHAT ARE THE RISKS AND OPPORTUNITIES OF BLUE CARBON AS A RESPONSE TO SEA LEVEL RISE IN THE LYTTELTON HARBOUR BASIN?"

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Table of Contents

EXECUTIVE SUMMARY

This report examines the viability of three blue carbon species (saltmarsh, seagrass and kelp) throughout the Lyttelton Harbour Basin (LHB). This was completed to understand if sea level rise (SLR) could have any positive outcomes, specifically throughout the LHB as this location is expected to be negatively impacted by SLR consequences in the coming future.

Research question:

- “What are the risks and opportunities of blue carbon as a response to sea level rise in the Lyttelton Harbour Basin?”

Methods:

- Literature reviews were completed to understand any current research on this topic. These themes included an overview and the geomorphology of the LHB, the risks of SLR and saltmarsh, seagrass and kelp as a form of blue carbon.
- Primary data collection including interviews and research.
- Secondary data collection using GIS, specifically a LiDAR 1m DEM of the Christchurch and Selwyn area.
- The Mahaanui Kurataiao Iwi Management Plan 2013 was analysed for the mana whenua perspective as COVID-19 restricted in-person consults.
- Before any interviews could take place, ethical processes were considered, and consent forms were sent to participants.

Key findings:

- Saltmarsh systems were the only viable blue carbon species for the LHB.
- SLR and GIS results were analysed to find areas ideal for blue carbon ecosystems according to the extent of inundation. Areas along the edges of the bays will be less affected by SLR due to steepness whereas other areas that are not as steep provide larger areas for blue carbon ecosystems.
- Sediments throughout the Upper Lyttelton Harbour Basin were found to consist of mainly fine and muddy sediments.
- The LHB has high turbidity, along with relatively low sediment transportation considering it is a strong zone of accumulation.

- There is no sustainable carbon sequestration option for kelp and seagrass in the LHB.
- Kelp can potentially be farmed, manufactured into biofuels or used for mahinga kai
- Seagrass would work better in different environments as it struggles in muddy sediments.

Limitations:

- Limitations on primary data included COVID-19 causing field data collection restrictions and Zoom technical difficulties along with experts declining interviews.
- Secondary data collection had limitations including GIS methods and capabilities. Specifically, the bathtub model only provided an estimate of SLR without considering many other environmental elements.
- LINZ DEM did not cover the whole peninsula, therefore excluding Allandale.

Future research:

- Whether other areas of Christchurch would be viable for blue carbon through kelp, seagrass and saltmarsh.
- Carbon donation through kelp.
- Combining vegetation maps with SLR.
- Understanding processes of restoration and establishment of saltmarsh species.
- Impacts of ocean temperature and acidification.
- Currents and the changes due to climate change.
- Storm surges
- Impacts of chemical runoff into the basin.

1. INTRODUCTION

This project researches any opportunities that blue carbon can provide through seagrass, kelp and saltmarsh as a response to sea-level rise (SLR) throughout the Lyttelton Harbour Basin (LHB). Due to rising temperatures, greenhouse gas (GHG) emissions and ocean warming, SLR manifests the need for mitigation measures. One mitigation measure may be blue carbon, which is carbon that is stored throughout ocean ecosystems, either in sediments or plant biomass. Blue carbon can open up opportunities for SLR due to increasing inundation areas. Di Lucas asked us to investigate blue carbon risks and opportunities in the LHB specifically. The research area is shown in Figure 1. Our research question is:

> "What are the risks and opportunities of blue carbon as a response to sea level rise in the Lyttelton Harbour Basin?"

The scope of the project was limited by different factors such as time and capability throughout this report. These limitations included other aspects of climate change such as ocean temperature, ocean acidification, storm surges, water quality and changes in currents due to climate change and how these will impact the LHB. Mangroves will not be considered in this report as they are only found at the top of New Zealand's North Island.

Throughout this project, five emission scenarios from the IPCC 2021 report were considered to understand climate response. These scenarios were used throughout the report to show different levels of SLR in 2100 and 2150 (IPCC, 2021). The five scenarios range from very low to very high GHG emissions and depend on socio-economic assumptions, levels of climate change mitigation and air pollution controls.

Figure 1. Case study area of the Upper Lyttelton Harbour Basin (Maxar Technologies, Terrametrics, 2020) (Google Earth).

2. LITERATURE REVIEW

2.1 Overview and Geomorphology of Lyttelton Harbour Basin

Lyttelton is an inactive shield volcano made of basaltic magma, which tends to be fast-flowing. This means that the slopes of both the Lyttelton and Akaroa volcanoes are relatively gradual (Stipp & McDougall, 1968). Figure 2 shows that the bathymetry of Upper Lyttelton Harbour Basin (ULHB) is also very gradual. The ULHB drops from 1m above sea-level to around 2-3m below sea-level. Figure 3 shows that the ULHB tends to have silty sediment, with shallower and calmer waters. The centre of the basin has sandier sediment, as does the dredging channel, while the mouth of the basin is composed of mud. Although the slope of the basin is gentle, the central and outer basin tends to have choppier and deeper waters (Hart et al., 2008).

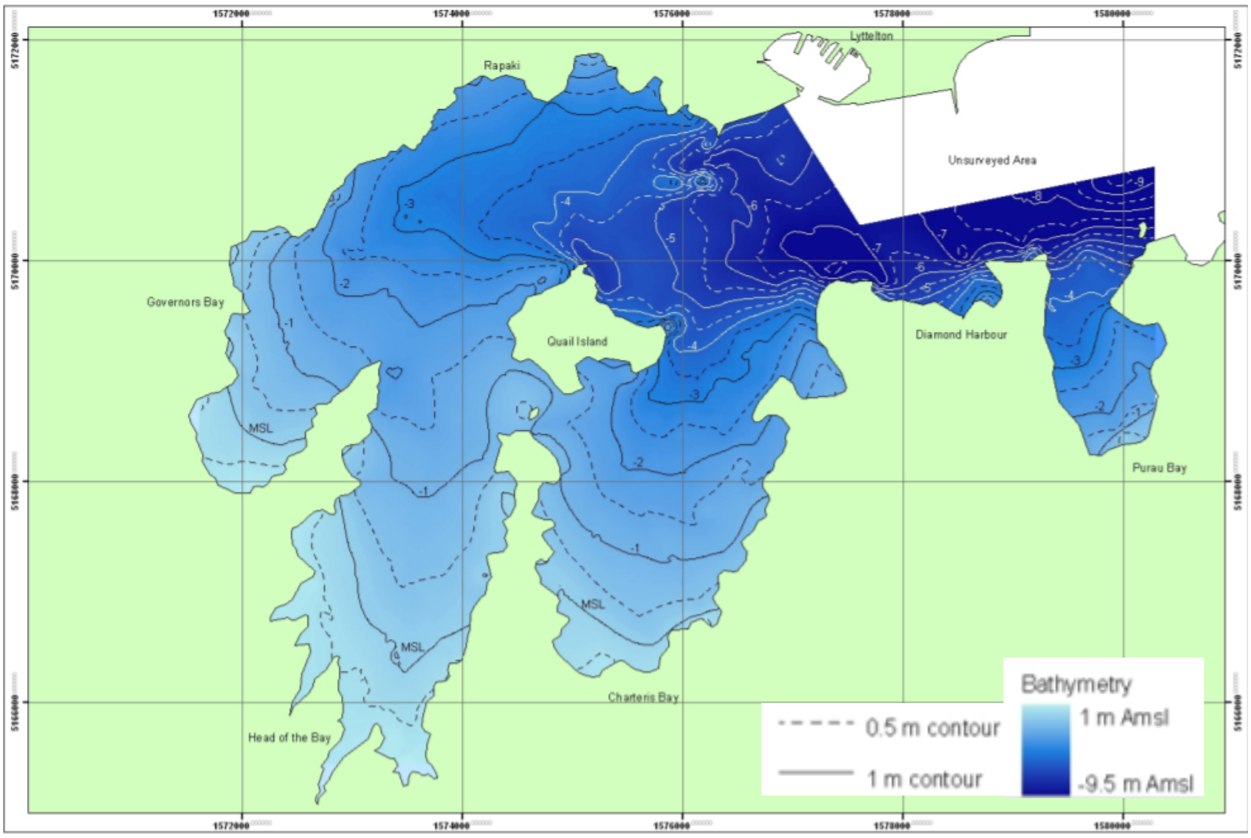

Figure 2. Bathymetry of Lyttelton Harbour Basin (Hart et al., 2008)

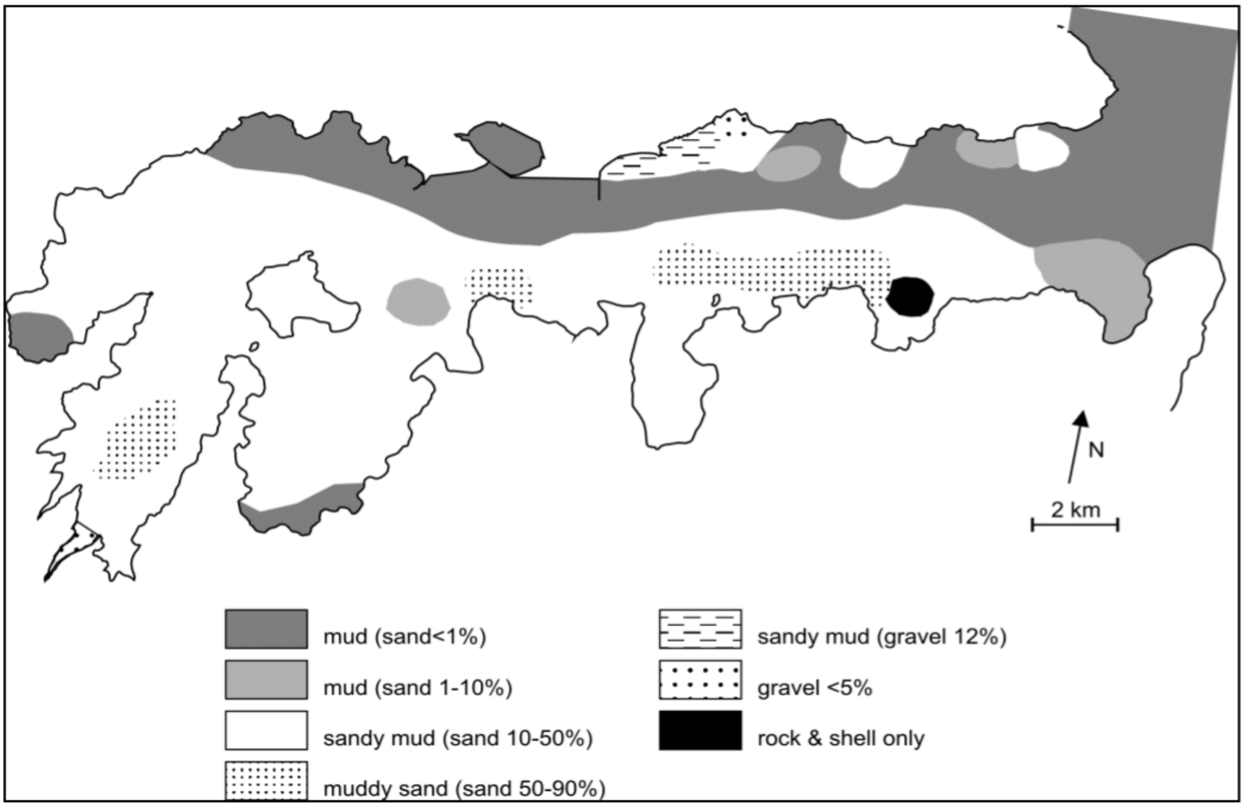

Figure 3. Sediment Types of Lyttelton Harbour Basin (Hart et al., 2008)

2.2 Sea Level Rise and Risks in Lyttelton Harbour

Allandale, Teddington, Charteris Bay and Purau are susceptible to SLR due to these areas having sandy, low lying shores (Tonkin+Taylor, 2017). SLR projections, such as the IPCC report, are important in terms of measuring estimations of future implications of SLR (Nauels et al., 2017). The IPCC projections are categorised by very low, low, intermediate and very high as seen in Table 1 (IPCC, 2021). The global mean SLR above the likely range is 2m by 2100, and 5m by 2150, however, this is low confidence as there is significant uncertainty around ice sheet processes (IPCC, 2021). These will also help to understand the benefits of adaptation and the protection of our environment.

Table 1. *IPCC Scenarios of Sea Level Rise for the Years 2100 and 2150 (adapted from IPCC, 2021)*			
Scenarios	**Categorisation of GHG emissions**	**Global Mean Sea-Level Rise by 2100**	**Global Mean Sea-Level Rise by 2150**
SSP1-1.9	Very low	0.28-0.55m	0.37-0.86m
SSP1-2.6	Low	0.32-0.62m	0.46-0.99m
SSP2-4.5	Intermediate	0.44-0.76m	0.66-1.33m
SSP3-7.0	-	-	-
SSP5-8.5	Very high	0.63-1.01m	0.98-1.88m
	Extreme/Low Confidence	2m	5m

2.3 Saltmarsh as a Form of Blue Carbon

Saltmarsh tends to grow between the mean high-water neap and spring tides (McOwen et al., 2017). They are usually restricted to sheltered locations and made up of salt tolerant herbs, grasses and low shrubs adapted to regular or occasional emergence (McOwen et al., 2017). They are unique highly dynamic systems which connect saline and freshwater ecosystems (McOwen et al., 2017). Saltmarsh are globally significant for carbon storage and represent an ongoing sink (Burden et al., 2019). They sequester carbon through high primary productivity and flow attenuation in which suspended sediments are deposited in peat layers (Coverdale et al., 2014). This process stores carbon in both their biomass and underlying soils (McLeod et al., 2011). Unlike terrestrial forests saltmarsh systems do not become saturated with carbon so the rate of carbon sequestration and the size of the sediment sink can increase over time (McLeod et al., 2011). Below ground accumulation in saltmarsh ecosystems is reported to be around 244g/m^2/yr (Orchard et al., 2020). Carbon burial rates are affected by hydroperiod, salinity, nutrient status and suspended sediment supply (Kelleway et al., 2016; McLeod et al., 2011). They are considered some of the most valuable but vulnerable ecosystems and are being lost at critical rates (Kirwan et al., 2016).

2.4 Seagrass as a Form of Blue Carbon

Seagrasses are a group of 60 flowering marine species that form seagrass meadows in large groups (Alongi, 2018). These species grow in the intertidal and shallow subtidal zones of coastlines, predominantly in soft sediments (Alongi, 2018). New Zealand only has one native seagrass species, New Zealand eelgrass (*Zostera muelleri*) (Dos Santos & Matheson, 2017). This species is under-studied with no papers analysing the role it may have in blue carbon sequestration. Currently, there is no data found on significant populations in the LHB. One suggested carbon sequestration rate for seagrass was $610g/m^2/yr$ (Duarte et al., 2013). However, carbon sequestration effectiveness varies significantly between species and can often be conditional upon certain environmental conditions (Mazarassa et al., 2018). Factors relating to a common European species include canopy complexity, trophic webs, turbidity, sediments, water depth and salinity (Mazarassa et al., 2018; Röhr, 2018). The only relevant knowledge from the literature was that New Zealand eelgrass has a flowering biomass 1.7-3.9 times higher in the upper intertidal zone than other areas (Dos Santos & Matheson, 2017).

2.5 Kelp as a Form of Blue Carbon

Kelp grows on hard surfaces such as rocky substrates and absorbs nutrients from the surrounding water column which allows it to grow without a root system (Alongi, 2018). The way kelp grows and, subsequently, the lack of sediment storage for carbon creates a range of opinions on whether kelp forests can be considered as contributors to blue carbon. Howard et al. (2017) concluded that due to the relatively short lifespan of kelp and the lack of sediment to provide long term carbon storage, kelp forests cannot effectively contribute to blue carbon sequestration. However, Filbee-Dexter and Wernberg (2020), Ikawa and Oechel (2015) and Chung et al. (2013) concluded that kelp forests do contribute to blue carbon sequestration. Chung et al. (2013) concluded that kelp forests contribute to roughly 16-19% of the total blue carbon sink. Hill et al. (2015) indicates that kelp is not viable as a long-term carbon sink. However, due to its short-term ability to sequester carbon, kelp can still contribute to blue carbon by donating carbon to other ecosystems.

3. METHODOLOGY

3.1 Primary Data Collection

Primary research was conducted through interviews with experts in the fields of coastal science and marine biology. These experts were from either Environment Canterbury, the University of Canterbury or Whaka-ora Healthy Harbour and were lecturers at the University or were recommended by other experts. Once the interviews were scheduled, a series of questions were drawn up. Experts in similar fields were asked the same questions in order to get a range of opinions. For example, the coastal science experts were asked: "Are rising sea levels likely to have an impact on currents and sediments within the harbour?" Marine biologists were asked questions like: "Should exotic or native species be used for restoration?" The full list of questions can be found in Appendix A. Once the interviews were complete, the responses to similar questions were grouped together to be analysed.

3.2 Secondary Data And GIS

Secondary data in the form of a LiDAR 1m digital elevation model (DEM) of the Christchurch and Selwyn area was retrieved from Land Information New Zealand (LINZ) and used to create a model of SLR in ArcGIS. The DEM provided a base for the analysis. A hillshade tool was then used to create a greyscale representation of the DEM surface in 3D. The upper limit of the five IPCC scenarios (Table 1) were used to model the different levels of SLR expected (IPCC, 2021). The bathtub model was used as a simple method to approximate SLR (Williams & Lück-Vogel, 2020). The bathtub model treats the ocean like a bathtub filling up with water (Williams & Lück-Vogel, 2020). To create the bathtub model, the DEM was reclassified into areas above and below a given scenario of SLR. Using the reclassification tool, the DEM elevation was split into three categories: elevations below zero, elevations between zero and a given scenario of SLR, and everything above the given scenario. Respectively, these show the intertidal zone, areas of inundation and areas not affected by SLR. The five scenarios for the years were layered on top of each other to illustrate the different levels for the years 2100 and 2150.

3.3 Mana Whenua Perspective

The Lyttelton Harbour/Whakaraupō takiwa is a part of the hapu of Ngāti Wheke and the iwi of Ngāi Tahu (Mahaanui Kurataiao, 2019). Due to the COVID-19 lockdown, we were unable to properly consult with these groups. However, the Mahaanui Kurataiao Iwi Management Plan 2013 provides a general indication of the mana whenua perspective. The objectives relating to

Whakaraupō include the restoration of the cultural health of the Harbour and the restoration of indigenous biodiversity values (Jolly & Ngā Papatipu Rūnanga Working Group, 2013). More specifically, policy WH5.1 focuses on "the sustainability of the resources and its environment with the local community, hoping it will help return the bay to its former healthy state." (Jolly & Ngā Papatipu Rūnanga Working Group, 2013). Part of the work towards this has been manifested by the recent introduction of the Mātaitai Reserve bylaws (Fisheries (Lyttelton Harbour/Whakaraupō Mātaitai Reserve Bylaws), 2020). Bylaw 8 prohibits the taking of any seaweed with the exception of karengo and wakame from the reserve area which covers most of the Harbour.

3.4 Ethics Process

Ethics needed to be considered for interviews. Consent forms were drawn up and then approved by the project supervisor, Jillian Frater, under the blanket ethics approval for the GEOG309 class (Appendix B). The consent form outlined the project, what was required of each expert, recording and storage of the interview audio, the contact information of the project supervisor and the agreement to participate. Using a consent form was essential in order to ethically conduct the research project, without it there would be a lack of trust from the interviewees and the integrity of the research would be compromised (Gomez & Jones, 2010; Israel & Hay, 2006).

4. RESULTS

4.1 Sea Level Rise And GIS

Figure 4 shows the bathtub model using the five scenarios for 2100. The lowest SLR scenario being 0.55m and the extreme being 2m. Figure 5 shows the 2150 map which has a larger amount of inundation from the five scenarios, with the minimum scenario being SLR of 0.86m and the extreme being 5m. The grey area in the bays are areas that are currently intertidal but with SLR these zones will reduce. The areas of the coast that are not ideal for blue carbon ecosystems can be seen along the edges of the bays with minimal effects of SLR as they are steep. Table 2 highlights the views of the coastal science experts on future SLR, how SLR will affect the tides and currents within the LHB and historical SLR in the area.

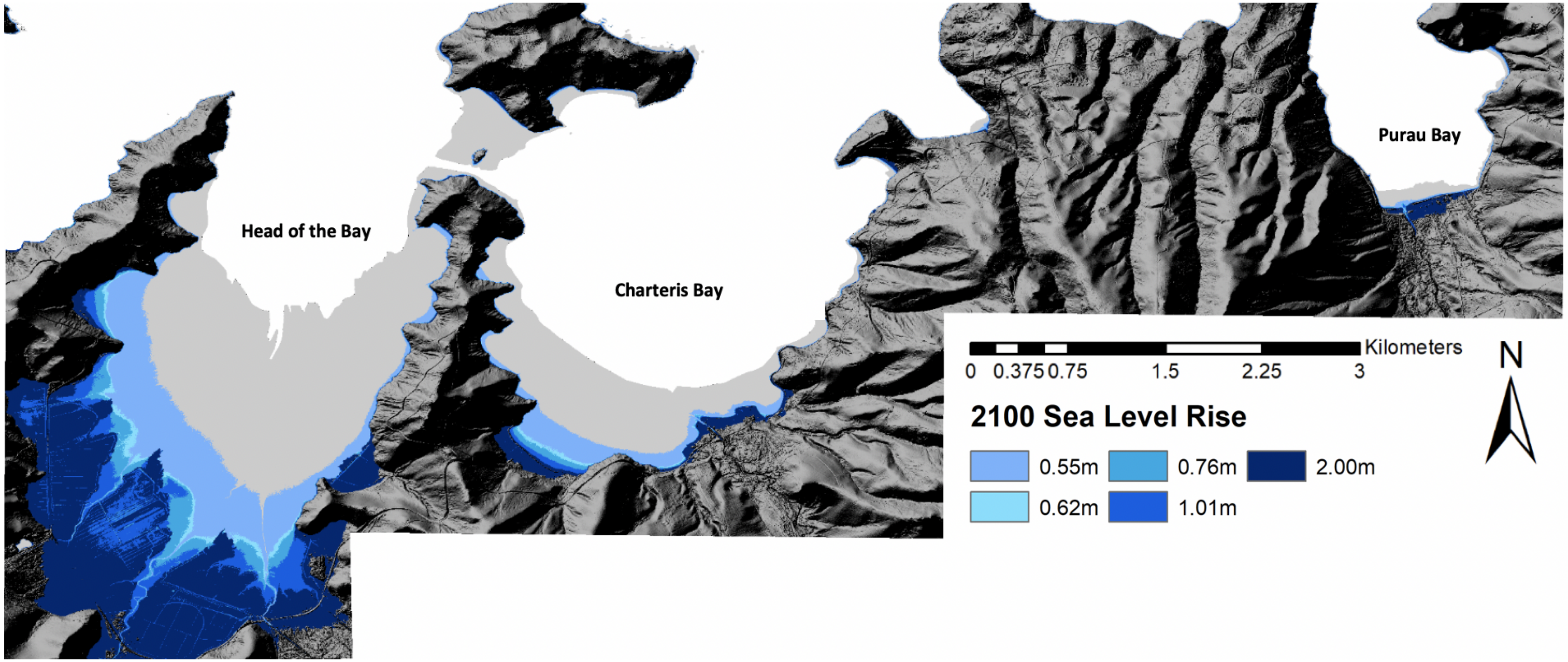

Figure 4. Sea level inundation scenarios for the Upper Lyttelton Harbour Basin for the year 2100. Modelling done in ArcGIS with data retrieved from LINZ (2017).

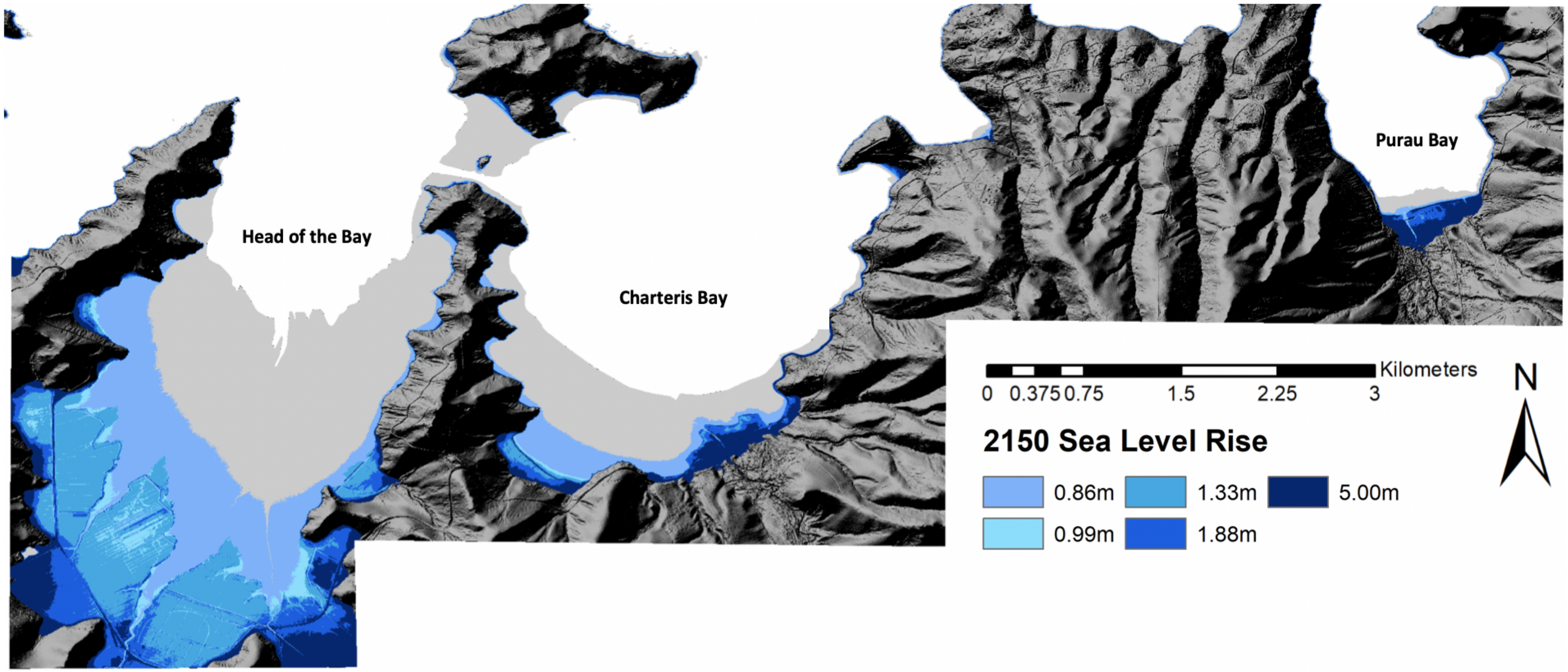

Figure 5. Sea level inundation scenarios for the Upper Lyttelton Harbour Basin for the year 2150. Modelling done in ArcGIS with data retrieved from LINZ (2017).

Table 2. *The Views on Sea Level Rise of the Coastal Scientists Interviewed*			
	Future SLR in LHB	**Tides and currents**	**Historical SLR**
Jamie Shulmeister	• Gradual rise in sea level inevitable	• Volume/shape of estuary • Larger exchange between bay and open sea = greater current in bay	• LHB flooded and reflooded often throughout recent geological history
Deirdre Hart	• SLR will occur for potentially 100s of years, both naturally occurring and due to human activity	• Deepening the harbour over these timescales could allow more circulation and energy as waves are currently depth limited	-
Justin Cope & Lesley Bolton – Ritchie	-	• SLR in of itself is not going to alter any of the tides • Do not think it will affect current velocity • Deeping on dredged channel may have effect on waves- not so much up the head of the harbour	-

4.2 Sediments in the Harbour Basin

Figure 3 shows that most of the ULHB consists of fine and muddy sediment. There is very little hard substrate, with only a few negligible patches. This results in high turbidity. There is also low sediment transportation. This is consistent with the information provided by Deirdre Hart, that the area is a strong zone of accumulation, with some flushing of sediment. The 2004 Healthy Harbour report states that catchment erosion results in 44300 T/pa of sediment input in ULHB. Jamie Shulmeister, Justin Cope and Lesley Bolton-Ritchie all agree that this amount is considered to be between moderate to high levels of sediment input. Many of the experts mentioned that most of the sediment is historic, caused by natural erosion as well as the devegetation of the catchment areas by the early settlers and subsequent residential development.

4.3 Blue Carbon Viability

The viability of kelp as a blue carbon species was clear after interviewing the marine biologist experts. Both Shane Orchard and Mads Thomsen agreed that there was not an option for kelp to contribute to blue carbon sequestration in the LHB. Table 3 shows the opinions of Mads Thomsen and Shane Orchard on the viability of kelp. Both Shane and Mads, alongside Karen Banwell did also offer alternative options for kelp that could be considered.

The results from the interviews on seagrass were consistent that seagrass is not a viable option for carbon sequestration in the LHB. Table 4 shows how this is due to environmental deficiencies in the LHB that would prevent seagrass from effectively sequestering carbon. Shane Orchard, Mads Thomsen, Lesley Bolton-Ritchie and Justin Cope all agreed on the critical points although there was some minor deviation on non-critical points.

There is currently a small region of saltmarsh in the Head of the Bay by Teddington. Environmental conditions in the harbour, high suspended sediment levels and turbidity, are the most conducive to saltmarsh ecosystems. Shane Orchard and Mads Thomsen both agree that there is the most potential for saltmarsh restoration in Lyttelton Harbour (Table 5). They, and Lesley Bolton-Richie, all acknowledge that there is very little flat land as it is a volcanic basin so there is only so much space for saltmarsh to grow (Table 5). Karen Banwell and Lesley Bolton-Ritchie outlined the risks of coastal squeeze on a migrating saltmarsh population due to the road in Teddington (Table 5).

Table 3. *The Views on Kelp Viability of the Marine Biologists Interviewed*

Experts	**Blue carbon**	**Kelp alternatives**
Shane Orchard	• Does not have any kind of burial • Lyttelton harbour is not the best zone for seaweed	• Grow kelp on rafts in deep water, dropping to the seafloor to be buried • Farming
Mads Thomsen	• They decompose very rapidly • Enormous amount of space required to grow kelp	• Sink kelp into the deep ocean, 1000m • Sinking kelp has the potential to create environmental problems
Karen Banwell	-	• High potential for Mahinga Kai, harvested and utilised

Table 4. *Results from Interview Experts for Seagrass*		
Experts	**Opportunities**	**Risks**
Shane Orchard	• Atypical seagrass population found in Kaikoura growing on small ledges of rocks where soft substrate accumulates • However, the Kaikoura example is unlikely to work in the LHB as it is a sensitive system and the seabed is different • Rate of carbon burial is important - includes trapping sediments and burying own dead material • Use of native seagrass brings wider biodiversity benefits	• Few areas of soft substrate that also get sufficient light
Mads Thomsen	• Some seagrass growing in the outer parts of the LHB • Need large shallow areas • Using native seagrass is preferred as exotic species can have unknown negative flow-on effects	• Seagrass struggles in the LHB due to high turbidity • High turbidity = low light penetration to the seagrass leaves • Substrates are also not suitable • No seagrass meadows and up to 20m^2 growing in the LHB in total
Karen Banwell	• Using native seagrass is preferable but the more important goal is the re-introduction of seagrass • Seagrass is a nursery ground for fish	• Seagrass was last found in the LHB in the 1980s
Lesley Bolton-Ritchie and Justin Cope	• Seagrass is intertidal and subtidal	• No seagrass in the upper LHB, a little in Purau • Seagrass is a rooted plant which means that it will struggle with the muddy sediments • Light is a significant factor but the high turbidity of the LHB limits growth

Table 5. *Results for Interview Experts for Saltmarsh*

Experts	Potential	Risks	Suggestions
Shane Orchard	• At Teddington	• However as volcanic basin there is not much flat land, limit to where saltmarsh can grow • Loss of saltmarsh system may cause loss of its stored carbon	• Let saltmarsh grow where they want • Restoration probably only viable for saltmarsh
Mads Thomsen	• Can do it	• Lyttelton not the best place as there is not a lot of room, steep coastlines	-
Karen Banwell	• Healthy Harbour has plan to restore saltmarsh in Teddington	• Road will have an impact on restoration due to coastal squeeze.	-
Lesley Bolton-Richie	• Yes, in the Head of the Bay • Current work into increasing saltmarsh at head of the bay. • Co-benefits of creating an ecosystem and protection from storm waves, carbon sequestration	• Saltmarsh have very specific requirements, if immersed too long they die, need to have somewhere for saltmarsh to migrate with SLR • Not many places you can go with salt marsh vegetation. Requires gently sloped area for vegetation to go, not much flat area in Lyttelton leading to coastal squeeze	• Can establish pipes under roading to allow migration of saltmarsh past road which would otherwise lead to coastal squeeze.

5. DISCUSSION

5.1 Sea Level Rise

Combining the information received from the experts with the GIS modelling of SLR, it was determined that the effects of inundation would be seen in Head of the Bay, Charteris Bay and Purau Bay. The other areas of the ULHB are too steep to see any major effects of SLR. The SLR model is consistent with work done by Tonkin+Taylor (2017), where inundation was modelled under similar scenarios and timescales. The results of the inundation for Teddington (Figures 6 & 7) by Tonkin+Taylor (2017) compares well to the model created for this research. Tonkin+Taylor (2017) used a similar bathtub model, where they extrapolated inundation levels over a DEM based on four emission scenarios from the IPCC.

Considering timescales is also important when modelling SLR, a point considered was the timescales used. Deirdre Hart acknowledged the importance of including both short-term (2100) and long-term (2150 and beyond) timescales. It is also important to consider longer term scenarios despite these having less confidence as, by this point, human behaviour and responses may have changed.

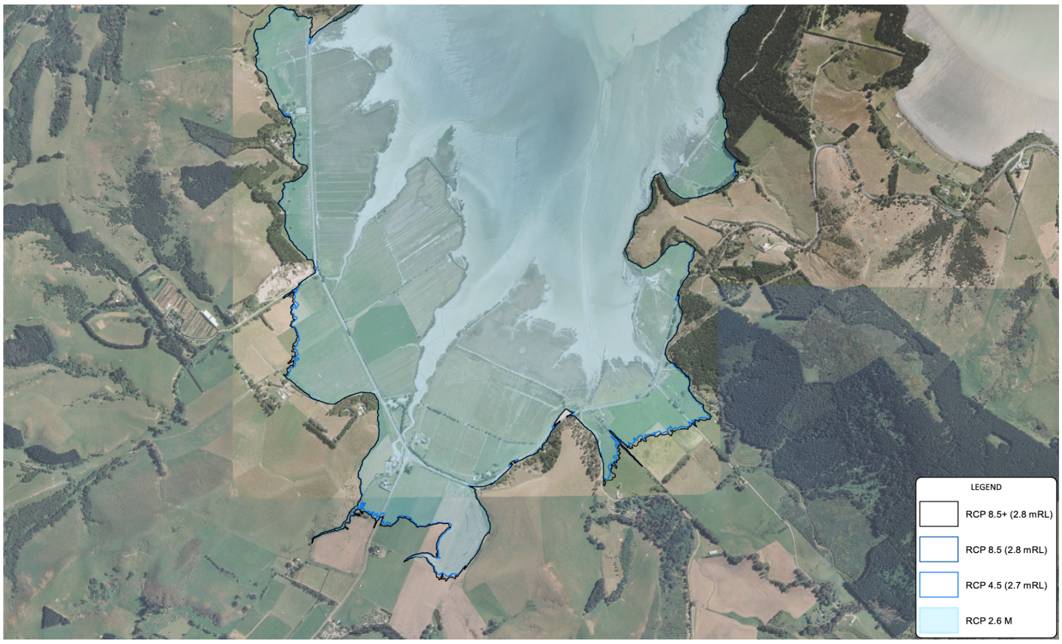

Figure 6. Inundation in Teddington for the year 2065. Created by Tonkin+Taylor (2017) for the Christchurch City Council Coastal Hazard Assessment. RCP (Representative Concentration Pathway) are alternative emission scenarios used by the IPCC. Date retrieved 18/10/2021.

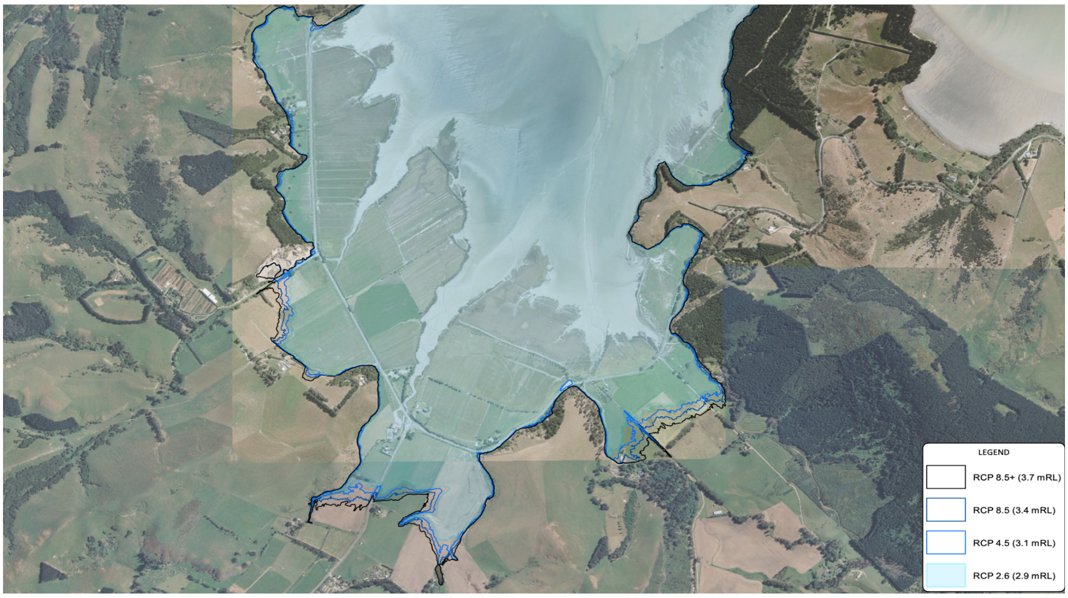

Figure 7. Inundation in Teddington for the year 2120. Created by Tonkin+Taylor (2017) for the Christchurch City Council Coastal Hazard Assessment. RCP (Representative Concentration Pathway) are alternative emission scenarios used by the IPCC. Date retrieved 18/10/2021.

5.2 Viability of Kelp

The results of the interviews concluded that kelp would not be a viable form of blue carbon sequestration for the purpose of this project. This is due to the uncertainty around carbon donation and the area of the LHB being too small for the growth of a significant amount of kelp. This conclusion is consistent with the mixed opinions found when reviewing the literature in section 2.5. Both Shane Orchard and Mads Thomsen offered alternatives for kelp, such as growing kelp on rafts in deep water and sinking it as a form of sequestering carbon for the long term. There is also the opportunity to farm kelp to make biofuels, which, while not sequestering carbon for the long term, would help make the move away from fossil fuels. Howard et al. (2017), Chung et al. (2013) and Sondak et al (2017), also discussed the merits of harvesting kelp and using it to manufacture more sustainable products and biofuels. Additionally, kelp is a form of mahinga kai. Karen Banwell explained that kelp is often harvested as a source of food. The issue is that any sequestered carbon in the kelp will be returned to the atmosphere through respiration (Sondak et al., 2017).

5.3 Viability of Seagrass

Seagrass may have potential as a blue carbon species but it is not viable for the LHB environment for three reasons. This can be seen in the very low reported current populations. First, the GIS analysis revealed that a large intertidal area would become subtidal as a result of sea level rise as shown by the grey areas on Figure 8. Overall, it is expected that the intertidal area will decrease in size. A synthesis of the limited literature and results from the interviews (Table 4) show that the intertidal zone is the preferred zone for New Zealand eelgrass (Dos Santos & Matheson, 2017).

Second, the substrate of the LHB is not suitable for New Zealand eelgrass because it is muddy. Lesley Bolton-Ritchie explained that New Zealand eelgrass is a rooted plant that prefers fine, soft sediments to muddy sediments. This repeats the conclusions of Röhr et al. (2018) that sediment density and sorting is a key factor.

Third, turbidity is a significant factor. Mads Thomsen explained that this was because the suspended sediments in turbid waters block sunlight from reaching the leaves of seagrass. However, Shane Orchard noted that much of the carbon sequestering ability of seagrass occurs through the capture of suspended sediments. Therefore, increased turbidity levels may increase carbon sequestration where the turbidity does not limit growth. These conflicting factors are not unusual in the study of seagrass as a blue carbon species. For example, Mazarassa et al. (2018) and Lavery et al. (2013) concluded differently on water depth and light exposure.

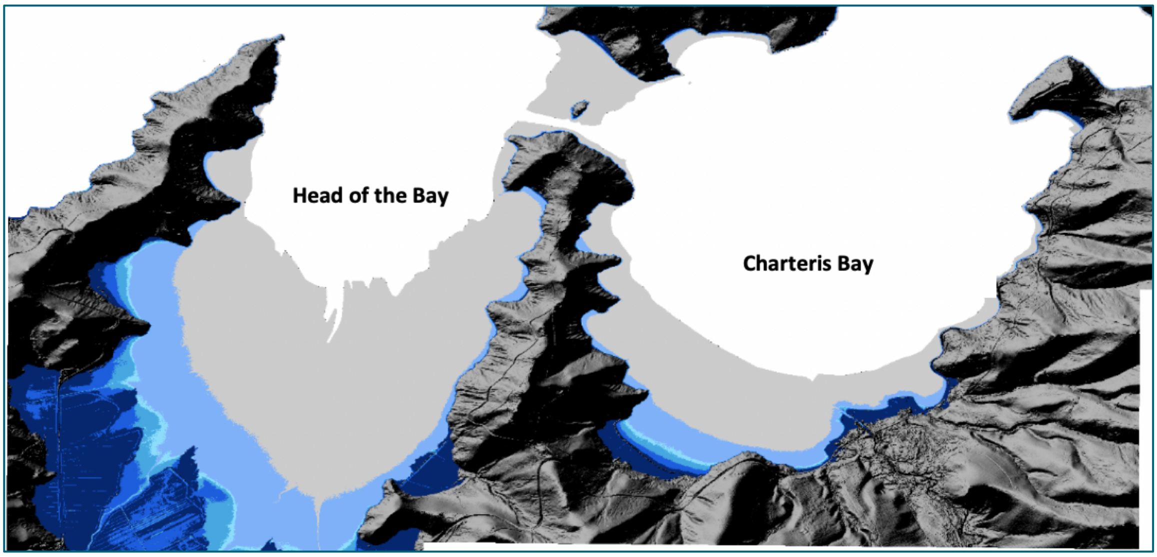

Figure 8. Magnified map of the upper LHB highlighting the current intertidal zones. The grey area represents the current zone. Taken from figure 4, data from LINZ (2017).

5.4 Viability of Saltmarsh

Saltmarsh are the most viable of the three blue carbon systems considered for the LHB. This is due to the environmental conditions in the harbour being most suited to saltmarsh species with high levels of suspended sediments and turbidity (Kelleway et al., 2016; McLeod et al., 2011). The existence of a saltmarsh system at the Head of the Bay is indicative of the suitable conditions for saltmarsh restoration.

The Head of the Bay (Figure 1) provides the most suitable area for restoration as there is a current population and it will see the most inundation with SLR (Figures 4 & 5). Lesley Bolton-Richie (Table 5) also suggested the potential for saltmarsh establishment in Purau. Figures 4 and 5 show that SLR will likely open up space for saltmarsh and if the conditions are suitable provide a potential area of establishment.

While there are opportunities for saltmarsh and their restoration or establishment in LHB in response to SLR, there are also risks. There is a high level of uncertainty in how saltmarsh will respond to SLR (Orchard et al., 2020). With rising sea levels, saltmarsh requires space to migrate. Any barriers to this migration such as roads can lead to coastal squeeze (Table 5; Orchard et al., 2020). Saltmarsh may also die if submerged for too long. Lesley Bolton-Richie, Justin Cope and Jamie Shulmeister suggested pipes could be installed under roads to connect saltmarsh systems on either side of the road allowing more space. There are additional issues with flow, circulation and nutrient levels associated with culverts that would also need to be considered (McMurtrie, 2010).

Shane Orchard suggested that saltmarsh do have some potential to resist SLR due to accretion. Slow rates of SLR may lead to trapping of more carbon-filled sediments and giving saltmarsh systems the potential to grow at a similar rate or even exceeding that of SLR (Kirwan et al., 2016). However, this will only occur until a critical rate of SLR at which saltmarsh vegetation will drown and the systems will stop accumulating carbon (Mudd et al., 2009 from Mcleod et al., 2011). The loss of saltmarsh systems risks the loss of buried carbon.

Saltmarsh systems require a period in which to establish before they begin accumulating carbon at a constant rate. Research by Burden et al. (2019) suggested that carbon accumulation after saltmarsh was more rapid in the first 20 years before slowing to a steady rate. They suggested that it would take around 100 years for restored saltmarsh to have similar carbon stock as natural systems (Burden et al., 2019). However, this was European based research so New Zealand saltmarsh may respond differently due to different environmental conditions and species.

6. LIMITATIONS

6.1 Limitations of Primary Data

Due to COVID-19 restrictions, field data was unable to be collected. This meant that the overall understanding of the LHB was slightly hindered and reliant on expert interviews and outdated secondary data. Interviews were conducted via Zoom, which often led to technical difficulties, including unreliable internet and audio. This often resulted in delays and stilted interviews. In particular, one interview was conducted in the Central Library Tūranga, where the study rooms were unavailable due to COVID-19 restrictions, so the interview proceeded in a public area in the presence of library staff and the public. Other issues that occurred while conducting interviews were that some experts declined an interview or did not reply at all. This meant that there may be some key information that was not considered in the analysis of this project. To combat this, similar questions were asked of each group of experts, so that key information would not be missed.

6.2 Limitations of Secondary Data

There were also limitations to our chosen GIS methods. The bathtub model used, assumes the inundation to be even across a set elevation. This is not accurate and while the bathtub model is useful for its simplicity, there are many limitations that are associated with the primitiveness of it. The model provides nothing more than a rough estimate of SLR and does not consider differing elevations, friction, wind, atmospheric pressure, waves and tide; all of which can have an impact on the susceptibility of a certain area to inundation (Khojasteh et al., 2021; Williams & Lück-Vogel, 2020). The bathtub model also highlights low-lying areas as being flooded even if they are not connected to the coast (Williams & Lück-Vogel, 2020). Additionally, the LiDAR DEM did not cover all of the ULHB missing out areas such as Allandale, meaning SLR could not be modelled for every bay. Also, the group had limited GIS experience, so only basic modelling could be achieved.

7. FUTURE RESEARCH

Limitations to time and capability for this project provided areas for further research. This further research could include looking if other areas of Christchurch would be viable for blue carbon through kelp, seagrass and saltmarsh. Seagrass is known to work better in estuaries and the Avon-Heathcote Estuary/Ihutai currently has saltmarsh. Future research could also look into carbon donation from kelp, along with combining vegetation maps with SLR to understand the impacts of SLR on different ecosystems. Understanding the processes of restoration and establishment of saltmarsh species is an important area of future research to allow for successful restoration.

The other aspects of climate change impacts not considered in this report that were highlighted in section 1 also need to be considered for future research. All of these factors mentioned would allow for a deeper understanding of the impact of climate change on blue carbon ecosystems.

8. RECOMMENDATIONS

The primary recommendation from this project is to restore saltmarsh systems in the Head of the Bay and to explore establishment options in other locations such as Purau. Saltmarsh restoration is likely to be more successful if a culvert is constructed under Governors Bay-Teddington Road to allow saltmarsh to migrate landwards and reduce coastal squeeze.

For the other blue carbon species, it is recommended that seagrass planting in other locations such as estuaries and river mouths be considered. Kelp planting may also be effective through farming or rafting kelp and sinking it in deep water.

9. CONCLUSION

In conclusion, SLR does open up opportunities for blue carbon ecosystems on tidal flat areas in the LHB. Saltmarshes were found to be the only ecosystem that would provide effective long-term outcomes for blue carbon in LHB due to the most suited environmental conditions. The turbidity is too high for seagrass and a lack of sediment storage for kelp would limit growth throughout the LHB. Along with opportunities of SLR for saltmarsh, there are also risks around the viability of them relating to flooding and coastal squeeze.

Time, capability, COVID-19 restrictions, GIS methods and difficulties with zoom interviews were all limitations experienced throughout this report, however this did not limit our findings significantly. Overall, the ULHB does have an area for a saltmarsh that can contribute to blue carbon sequestration due to SLR, however, this could be more viable in other areas of New Zealand.

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Appendix A

Interview Questions

Marine Biology Questions

- Is there a potential for kelp as carbon sequestration or donors?
- In our research, we found that in order to be a carbon donor, there are three requirements - high biomass, effective transfer/ transport and successful burial at receiver habitats. Using these requirements would you class kelp as a carbon donor?
- Is there currently or potential for seaweed/ kelp or seagrass and saltmarsh systems in the LHB?
- What are the existing seagrass areas in the LHB?
- Can seagrass/kelp/saltmarsh restoration work in LHB? If it is applicable in LHB what would be challenges associated?
- What environmental factors are important for sequestering blue carbon in these species?
- Should exotic or native species be used for restoration? What if the exotic species are more efficient and more likely to be successful?
- How long/how much have to be there to make a notable impact?
- Would a "restoring" or "farming" approach be more beneficial? (restoring as planting the seagrass and leaving it there versus farming it).
- Our project is aiming to look at both the opportunity and the risks associated with blue carbon and SLR. Would you consider there to be risks associated with the establishment of these ecosystems in the basin to processes such as sedimentation, currents etc. in the harbour? What do you consider the important aspects which we should consider as risks of these ecosystems to the dynamics of the harbour system?

Lyttelton Expert Questions

- The Healthy Harbour plan is focussing on the ecological and cultural health of the bay, has blue carbon been considered in any of the planning for the basin?
- Is there a record of blue carbon species: seagrass and kelp systems existing in Lyttelton in the past?
- What SLR plans or adjustments have currently been made within the Healthy Harbour plan?
- What effects would blue carbon ecosystems have on Mahinga Kai? Mahinga Kai Seaweeds?
- In the Healthy Harbour plan it mentions the restoration of wetlands and saltmarshes, is there any restoration plans for other blue carbon species?
- The plan mentions the restoration of saltmarsh at the Head of the Bay/ Teddington area, is there consideration into effects of coastal squeeze on these due to SLR?
- Should exotic or native species be used for restoration? What if the exotic species are more efficient and more likely to be successful?
- Water quality data in LHB: Do you have data on this, or could you recommend someone who does?

- Gaps mentions in 2013 report - has there been further research: There is less evidence regarding how changes in harbour bathymetry and structures resulting from port activities has affected the harbour sediment system in general and, in particular, upper harbour mudflat growth and seabed textures. Has the sediment accumulation investigations recommended been done?
- In relation to the whole harbour system gap, this review noted that, despite detailed surveys in discrete areas, the bathymetry of the harbour as a whole has rarely been updated in one source. Has the GIS mapping of sediment texture that was recommended actually been done?
- Curtis (1985a) comprises the only publically documented whole-harbour study that attempts to understand the harbour from a systems perspective. Has the "full-harbour system" research been undertaken or are we still lacking information from a full-harbour perspective?
- If you were conducting research similar to this, what specific things would you be mapping? Would you have a particular approach to it all?
- Areas to put more focus on?

Coastal Science Questions

- Is it reasonable to extrapolate SLR in singular bays from the Tonkin+Taylor report to the whole harbour basin?
- We know that the Council has decided to work on SLR plans for the Lyttelton locations first, do you know of any plans for SLR protections or mitigations anywhere in the harbour basin?
- Are rising sea levels likely to have an impact on currents and sediments within the harbour?
- In the Healthy Harbour report (2004) it mentions how deepening of the dredged area of the basin reduced wave and current energies, would increase sea levels impact energies in the upper basin (ignoring increased storm events due to climate change)
- Types and availability of sediments in the LHB?
- In the report for Healthy Harbour on sediments (2004), it says that the upper basin has 44300t/a input from catchment erosion. Is this considered a lot of sediment input?
- As it also states fluvial inputs are small (Heath 1976 from the same report). Are you aware of this general amount changing? Perhaps with the earthquake?
- Are there certain areas in the harbour which are more or less likely to retain sediments?
- The report mentions no lateral sediment flow but there is movement up and down the harbour. Does this mean there is little exchange of sediments between the northern bays in the harbour?
- The figures indicating the sediment budget of the basin indicate erosion input to Head of the Bay and Charteris Bay, does Governors Bay have any input of sediments?
- Is the input similar between these two bays or is one gaining more than the other?
- Is there a likely impact of large sediment input of inundation due to increasing sea level?

- There has been an increased sediment input to the harbour since European settlement and sequential land-use change, are reforestation efforts around the harbour catchment likely to have an impact on sediment inputs?
- Some of our research into overseas studies seems to show that SLR reduces the intertidal zone. Is there any way to predict a change in tidal zone using the SLR data that we have for the Lyttelton basin?
- When it comes to future effects of sea-level rise, how far ahead would you suggest we consider? How far ahead do we have data for and would extrapolation be appropriate?
- Our project is aiming to look at both the opportunity and the risks associated with blue carbon and SLR. Would you consider there to be risks associated with establishment of these ecosystems in the basin to processes such as sedimentation, currents etc. in the harbour?
- What do you consider the important aspects which we should consider as risks of these ecosystems to the dynamics of the harbour system?

Appendix B

Consent Form

School of Earth and Environment
Phone: *+64 3 3692026 Ext 92026*
Email: hll42@uclive.ac.nz
06/09/2021

What are the risks and opportunities of blue carbon as a response to sea-level rise in the Lyttelton Harbour Basin?
Consent Form for Participants

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without consequences. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain possible.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password-protected electronic form. I understand the data will be destroyed after five years.
- ☐ I agree to being audio recorded. I understand how this recording will be stored and used.
- ☐ I would like to approve any quotes being used before the submission of this report and reserve the right to modify them if required.
- ☐ I understand that I can contact the researcher Hanna Lyford and the group or supervisor (Jillian Frater, jillian.frater@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Research Ethics Committee, Private Bag 4800, Christchurch, (email: human-ethics@canterbury.ac.nz).
- ☐ I would like a summary of the results of the project.
- ☐ I consent to my contact information being kept and used by researchers to contact me about future, related research opportunities.
- ☐ By signing below, I agree to participate in this research project.

Name:___________________________Signed:_________________________Date: ________________________________

Email address *(for report of findings, if applicable)*: ____