THE CARBON SEQUESTRATION POTENTIAL FOR THE ŌTĀKARO AVON RIVER CORRIDOR

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Executive Summary

- After the earthquakes of 2010/2011 rendered 602ha of urban Christchurch land unsuitable for residential housing (Residential Red Zone), a 'green spine' was formed along the Ōtākaro Avon River from the city centre along to the sea. Finding a use for this land had been debated for almost a decade and many options for vegetation restoration have been put forward.
- This research report was conducted with the guidance of the Ōtākaro Living Laboratory Trust to assess the current and future potential of the Ōtākaro Avon River Corridor and residential red zone to sequester carbon through ecosystem regeneration.
- Using available existing literature, many aspects of carbon sequestration were investigated, including the regeneration of wetlands and forests. Assessments of national and international projects were conducted to give insight into what is already being done internationally.
- Using S-Map, we found Christchurch is made up of various soil types, each of which is suitable for different vegetation types. Using ecosystem maps, the tolerances of various plant species were assessed, and it was found sedge species, such as *Carex spp.*, would be most appropriate in the Bexley area due to waterlogged conditions. In drier areas, like Avonside, it was found shrub and tree-type vegetation would be more appropriate, for example, *Sophora microphylla* (Kōwhai), *Leptospermum scoparium* (Mānuka), and *Cordyline australis* (cabbage tree).
- Due to time constraints and a lack of existing research on native New Zealand plants, it was not possible to quantify the potential to sequester carbon.
- Further research would need to be conducted to better understand New Zealand's unique species and their growth patterns.

Introduction

The Ōtākaro Avon River Corridor is a stretch of land encompassing the Avon River. It includes the Christchurch red zone, which is a former residential area that was evacuated due to the 2010/2011 earthquakes. The Corridor is approximately 602 hectares and is mostly comprised of vacant lots where houses once stood (Department of the Prime Minister and Cabinet (DPMC), 2021). The land was purchased by The Crown between 2011 and 2019 and restoration plans have been developed in recent years.

The overarching question for this report, "How can the red zone contribute to carbon neutrality?", was brought to light by the Ōtākaro Living Laboratory Trust. It was decided to focus mainly on the red zone's ability to sequester carbon through ecosystem regeneration, therefore, adjusting the research question to "What is the current and future potential of the Ōtākaro Avon River Corridor and red zone to sequester carbon through ecosystem regeneration".

This report will look at research that has been done in the field of quantification of carbon sequestration and assess the current and proposed projects in the red zone. By using past literature, we hope to create a map of the appropriate vegetation and restoration sites that could be used to contribute to carbon neutrality.

The importance of researching the land's potential to sequester carbon means Christchurch has the chance to experience first-hand how a coastal city can adapt to become resilient to changing climates. Currently, a large proportion of the red zone isn't being used, meaning there are many opportunities for regeneration and restoration of the natural environment.

Literature Review

Carbon sequestration is the storage of atmospheric carbon (CO_2) in biomass and soils through photosynthetic processes (Anjali et al., 2020).

Our subthemes for the following literature reviews are as follows:

1. Proposed development and current projects to sequester carbon within the Avon River Corridor
2. How natural and assisted ecosystems regeneration and creation (wetlands) can contribute to sequestering carbon and what the implications are
3. How natural and assisted ecosystems regeneration and creation (forests and vegetation) can contribute to sequestering carbon and what the implications are
4. Proposed development and current projects to sequester carbon internationally

1. Current and Proposed Projects in the Ōtākaro Avon River Corridor

1.1 Ōtākaro Avon River Corridor Regeneration Plan

The Ōtākaro Avon River Corridor Regeneration plan consists of the basic plans and future development potential within the area. This plan was created by Regenerate Christchurch and was approved in 2019 by the Minister for Greater Christchurch Regeneration (DPMC, 2021). Regenerate Christchurch (2019) has described the themes behind the regeneration plan to be an emphasis on aspects such as restoring the natural environment, building a connection between the people, the river, and the land, and making the corridor a place for everyone. While the plan does not investigate the potential for carbon sequestration, there are many opportunities in the area to do so.

1.2 What has currently been suggested for the area

Within the Ōtākaro Avon Corridor Regeneration Plan, Regenerate Christchurch (2019) have considered social, recreational, environmental, and economic aspects. The main concepts include practising Mahinga kai, regenerating nature, connecting and involving the community, creating prosperity, making it a destination for all, living with water, and the living laboratory (Regenerate Christchurch, 2019).

1.3 Current uses of the area

The area is currently being used for community initiatives, for example, the Barkery, planting projects, community gardens, and recreational purposes. The Barkery aims to find homes for dogs and is being operated from the red zone in hopes of regenerating a sense of community within the area (The Barkery, n.d.). Planting is done by multiple groups and organisations, for example, the Eco-Action Nursery which has planted 11,000 plants around Christchurch (Eco-Action Nursery Trust, 2022). There are currently two community gardens located within Richmond and New Brighton. A study by Kulack and Vasquez (2012) showed urban agricultural soils have the potential to sequester carbon. For precise quantification, more research is required in this area. Recreational purposes include frisbee golf and multi-modal transport. Multi-modal transport allows people the freedom to choose how they travel, and the area is currently popular for walking, running, and biking. Locals have the option to use existing roads and pathways left behind after the earthquakes or to use informal paths that have been made over time. Within Regenerate Christchurch's (2019) plan, the intention to incorporate pedestrian and cycle paths has been stated. A study by Ballantyne & Pickering (2015) suggested having clearly defined formal paths had less impact on surrounding vegetation and had less chance of path-widening which would impact surface soil conditions.

1.4 Key points from the research

By investigating current plans for the area, it has been found there are many initiatives in the Corridor which indicate great potential for carbon sequestration, although with some plans there is a chance that the potential for carbon sequestration will become less over time. There is future research needed within the Corridor when considering its potential to sequestrate carbon.

2. Carbon Sequestration Potential of Wetlands

Since the Bexley area in the red zone was historically swampland, it has the potential to contribute to carbon neutrality through wetland restoration. Wetland carbon storage is a critical part of the global carbon cycle and is important for mitigating climate change (Deng et al., 2022). 35% of terrestrial carbon and 40% of global soil organic carbon is estimated to be stored in wetlands, yet they only account for 6-9% of the earth's surface (Mitsch & Gosselink, 2000, Deng et al., 2022).

2.1 Carbon sequestration of disturbed and undisturbed wetlands

Two of the papers (Howe et al., 2009, Nahlik & Fennessy, 2016) examined how carbon sequestration differs between disturbed and undisturbed wetlands. Howe et al. (2009) investigated two sites, one of which was disturbed (Site 1), and the other undisturbed (Site 2).

2.2 Carbon sequestration at different types of wetland sites

Chen et al. (2017) focused on the carbon storage of restored wetlands at Illinois' Emiquon Preserve. They compared two different wetland types (marsh and sedge meadow). There were two sites of each wetland type. Similarly, Nahlik & Fennessy (2016) also looked at the difference between soil carbon in seagrasses and mangroves. Howe et al. (2009) also looked at the carbon stored at their two sites which consisted of mangroves, salt marshes and tidal pools.

2.3 Long-term wetland carbon sequestration at specific locations

Morris et al. (2013) focused on carbon storage within the Doñana Wetlands in Southwestern Spain and collected water samples at 11 different sites. Deng et al. (2022) also looked at carbon storage in the wetlands in the Guangdong-Hong-Kong-Macau Greater Bay Area in China, but they looked at it over 25 years from 1995 to 2020.

Key findings

2.4 Carbon sequestration of disturbed and undisturbed wetlands

Howe et al. (2009) found at site 1 (rehabilitated site) the carbon concentration ranged from 1.4% to 7.4%. At site 2 (natural site) there was only carbon data from 2008 which means it's not as reliable as the data from site 1. The total carbon concentration ranged from 8% to 11.6%. This shows the total carbon data is significantly different between the two sites. Site 2 stores approximately 50% more carbon than Site 1.

Nahlik & Fennessy's (2016) findings were similar to Howe et al. (2009) in that the degraded wetlands had less Soil Organic Carbon (SOC). The undisturbed wetlands had significant carbon densities of 407 ± 51 tC ha^{-1} whereas the disturbed sites had carbon densities of 236 ± 47 tC ha^{-1} which is a significant difference.

Both studies (Howe et al., 2009, Nahlik & Fennessy, 2016) came to the same conclusion that undisturbed wetland sites store more carbon than disturbed and stressed wetland sites (or rehabilitated).

2.5 Carbon sequestration at different types of wetland sites

As shown in Table 1, Chen et al. (2017) found the sedge meadow wetland stored significantly more carbon than the marsh wetland. The sedge meadow stored three times more organic carbon than the marsh wetland.

Table 1

Carbon concentrations for a sedge meadow wetland and a marsh wetland at Illinois' Emiquon Preserve

	Sedge Meadow Wetland	Marsh Wetland
Aboveground Plant Organic Carbon	4.07 Mg C ha^{-1}	1.64 Mg C ha^{-1}
Average Soil Organic Carbon	131.81 Mg C ha^{-1}	50.06 Mg C ha^{-1}
Ecosystem Storage of Organic Carbon	136.63 Mg C ha^{-1}	52.04 Mg C ha^{-1}

Note: Adapted from Chen, H., Popovich, S., McEuen, A., & Briddell, B. (2017). Carbon and nitrogen storage of a restored wetland at Illinois' Emiquon Preserve: potential for carbon sequestration. *Hydrobiologia, 804*(1), 139-150. https://doi.org/10.1007/s10750-017-3218-z

Howe et al. (2009) found the carbon density of salt marshes was approximately 65% higher than that of mangroves for both sites 1 and 2. The salt marsh habitats had the highest soil carbon, then the mangroves followed by the permanent tidal pools. Nahlik & Fennessy (2016) found the average soil carbon in seagrasses (140 tC ha^{-1}) is much lower than the mangroves (471 tC ha^{-1}) and saltmarshes (340 tC ha^{-1}). This shows a contrast between the two studies as Howe et al. (2009) found carbon densities were greater for saltmarshes than mangroves whereas for Nahlik & Fennessy (2016) it was the other way around. This could be because Nahlik & Fennessy (2016) were only looking at soil carbon whereas Howe et al. (2009) were looking at total carbon density. These studies were also conducted in two completely different climates (Australia and America) which could contribute to the difference.

2.6 Long-term wetland carbon sequestration at specific locations

Morris et al. (2013) found the dissolved carbon dioxide particle pressure ranged between 5 and 10980 µatm and varied significantly across the 11 different sites. The median dissolved carbon dioxide particle pressure was the highest in the temporal wetland area. The four sites with semi-permanent water bodies had low values in spring and high values in summer, showing there is a seasonal effect on the amount of carbon sequestered. Deng et al. (2022) found carbon storage within the area fell from 33.38 Tg C in 1995 to 16.64 Tg C in 2020. Specifically, carbon storage significantly decreased in the paddy fields after 2000. This shows the long-term trend is the wetlands are sequestering less carbon over time.

Conclusion

Reviewing this literature has provided key lessons for the research design and methods. Research and results are much more reliable if there are multiple sample points, especially when looking at a single site like the Avon River Corridor. Howe et al. (2009) and Nahlik & Fennessy (2016) showed undisturbed wetlands with little to no stressors perform much better at sequestering carbon than disturbed or rehabilitated wetlands. Therefore, it will be important to look at ways to reduce disturbance to the Bexley wetland in our research. By looking at Chen et al.'s (2017) research, it is evident that sedge meadows are more effective than marsh wetlands at sequestering carbon. We will investigate the possibility of sedge meadows being planted throughout the wetlands to improve carbon sequestration.

3. Carbon Sequestration Potential of Forests

The third literature review focuses on the ability of forest and vegetation rehabilitation to sequester carbon. The main aim of this review is to assess the global research that has been done regarding urban carbon sequestration and to surmise how this could be useful for the regeneration of the Ōtākaro Avon River Corridor in Ōtautahi Christchurch.

3.1 Quantifying carbon sequestration in soil organic carbon

Many factors contribute to the storage of organic carbon in soil, including environmental factors, soil texture, biomass production, land use, and microbial abundance (Albaladejo et al., 2012). The source of Soil Organic Carbon (SOC) can be split into two main parts: above ground and below ground. Above ground, leaf litter decomposes to leave organic carbon behind and below-ground root systems exudate organic compounds (Ji et al., 2020).

Batjes (1996) theorised the best way to approximate the organic carbon content of soil would involve looking at a defined area, at a specified depth, with information about the different soil types and bulk density.

There are approximations to calculate the density of soil organic carbon (SOC) in topsoil (t/ha), which involves determining the SOC content (g/kg), the bulk density (ϒ, g/cm^3), the recorded thickness (H, cm) and the fraction of >2mm fragments in the soil (δ, %) (Song et al., 2005).

$$Doc = SOC \times \gamma \times H \times \left(1 - \frac{\delta 2mm}{100}\right) \times 10^{-1} \quad \textbf{(1)}$$

The total SOC pool (Poc) can be estimated by:

$$Poc(tC) = \sum_{i=1}^{n} Si \times \sum_{j=1}^{n} SOCj \times \gamma j \times Hj \times 10^{-1} \quad \textbf{(2)}$$

Where *j* is the sublayer number of topsoil and S*i* is the area (ha) of given soil types (Song et al., 2005).

An easier way to calculate terrestrial biomass is via aerial surveys and Geographic Information Systems (GIS) in urban areas (Anjali et al., 2020). This is an effective method economically and less intrusive than direct methods including tree felling, which may be more accurate but is very destructive. By creating a database of urban tree density, those who are planning projects would be able to create estimates for the carbon sequestration potential of their project. This of course would rely upon more research being conducted on New Zealand native plant species and their carbon sequestration potential.

Similarly, Grace et al., (2012), show how forest growth within different climates can be calculated via 3PG modelling. This generates a response to the climatic inputs and site characteristics, resulting in a simulated growth rate for specific species. This method is uncomplicated and can be easily replicated if suitable data is available.

3.2 Restoration of ecosystems

In a study by Ji et al. (2020) on a wetland area in China, it was found out of reed, lake-sedge, poplar, and willow species that the large trees resulted in an increase of SOC storage compared to that of shrub-like species. It has been seen in other studies that afforestation of agricultural land results in increased total soil C in the first few decades, but little is known about afforestation of urban lands (Ji et al., 2020).

3.3 Problems with quantification

It is difficult to determine the global amount of carbon and nitrogen pools due to many factors including limited knowledge of the extent of different kinds of soil, the lack of reliable data on soils, some soils that are similar but different and have not been classified as such and the complex effects that climate, parent material, vegetation, and land use cause (Batjes, 1996).

Each plant species has its own potential to sequester carbon, but little is known about New Zealand native plants. Factors such as wood density and growth patterns impact carbon sequestration potential, but it is roughly estimated the average sequestration rate per tree is about 11kg having a crown area of 50m^2 (Anjali et al., 2020).

3.4 Gaps in knowledge

Terrestrial carbon sequestration is dependent on many factors, such as precipitation, temperature, soil characteristics, microbial abundance, and biomass production. However, little is known about how each of these factors specifically impacts the storage of SOC (Albaladejo et al., 2012). Much of the previous research done on SOC content has focussed on the surface soil horizon rather than the total soil profile, even though more than 50% of the total SOC is stored below 20cm depth (Albaladejo et al., 2012). There has been some evidence that subsurface soil is much more sensitive to factors such as temperature or changes in nutrients than topsoil (Albaladejo et al., 2012).

For the restoration of the Ōtākaro Avon River Corridor project, appropriate native vegetation would have to be selected to maximise the carbon sequestration potential although there is little known about native New Zealand species' specific ability to store SOC. With the input of appropriate mana whenua, the vegetation selected would likely be robust, culturally, or economically important, and tolerant to fluctuating water levels (Gutiérrez-Ginés et al., 2017). It has been found native tree species such as *Cordyline, Sophora,* and *Carex* could be suitable to restore native vegetation in urban areas, although there is little known about native New Zealand trees in cities due to introduced species being preferred (Jang & Woo, 2022).

4. Current and Proposed International Projects

The purpose of this literature review is to focus on how proposed development and current projects internationally sequester carbon and how this may apply to the regeneration of the Ōtākaro Avon River Corridor in Ōtautahi Christchurch.

4.1. Literature

Trees are recognised as carbon sinks and therefore are a valid means to offset carbon emissions (Grace et al., 2012). The basis of the study conducted by Grace was implemented in North-Eastern Australia and targeted to offset greenhouse gas (GHG) emissions of 1000t CO_2, and the land area required to do so (Grace et al., 2012).

Blue carbon is defined as the sequestering and storing of carbon from the atmosphere within marine and coastal ecosystems (Conservation international, 2019). A second study demonstrated blue carbon is typically conceptualised as storing carbon in shallow coastal ecosystems, typically using salt marshes or mangroves (Kuwae et al., 2022). Japan has implemented three blue carbon projects through seagrass meadows, microalgal beds and macroalgal farming. This study illustrates the characteristics these projects have portrayed within carbon offset.

4.2 Methods

The Yokohama blue carbon project within Japan comparatively uses the idea of carbon offset but also utilises blue carbon resources within the community. Methodologies used implemented carbon credits and measured carbon offset capacity via equation 3 to calculate the carbon offset of seagrass meadows (Kuwae et al., 2022). The calculations allowed for the reduction of CO_2 to be implemented within the city in long-term and short-term aspects. In the Hakata Bay project, eelgrass beds (seagrass meadows) carbon sink capacities were accredited as 42.1 tCO_2/year in an area of 15.6 ha (Kuwae et al., 2022). Ultimately the eelgrass beds were eligible for carbon offset due to their manageability and carbon sequestration abilities.

$$Annual\ capacity = Active\ data(ha) \times Removal\ coefficient(tCO2\ /\ ha\ /year) \quad \textbf{(3)}$$

4.3 Key results

Carbon sequestration sink rates can be estimated via biological processes such as stem biomass (Grace et al., 2012). The key findings were the higher productivity soils, in comparison to the low productivity soils, saw a faster sequestration rate occurring within 10 years after planting and that growth data can estimate carbon sequestration (Grace et al., 2012).

Carbon credit offset schemes implemented in Japan using seagrass meadows and micro/macroalgae farming shows a large potential for carbon sequestration. GHG emissions were to be reduced by 7% by 2021 and ultimately target to reach 30% by 2030 (Kuwae et al., 2022). Implementing seagrass resources within the Avon River Corridor may be a viable option since it is indicative of having large CO_2 sequestration potential as demonstrated by the Japan blue carbon projects.

Methods

To find out what can be done to sequester carbon in the red zone and Ōtākaro Avon River Corridor, we reviewed existing research and literature. Our method for this project was a large literature review. This is known as the method of existing data research (Babbie, 2016). Snyder (2019) emphasised that literature reviews are a promising method of research when done right and are a great way to collect existing research. We then reviewed and used the information we gathered from this large literature review and applied it to our project. We also conducted a three-hour site visit on the 12th of September with Holly Johnstone (our community partner) and Georgie Rule (our tutor). We went to the Bexley, Burwood, and Richmond red zones. We also drove through the Avondale, Dallington, and Avonside red zones. The purpose of the site visit was to get an idea of what currently grows in the red zone and where there might be scope for more planting. The site visit and review of literature helped us choose plants and vegetation that are effective at sequestering carbon and where the optimal locations are along the red zone and Avon River Corridor to plant them. We looked at an ecosystem map and S-Map to see what the soil was like and where it would be best for each type of plant. We then used a map from Canterbury Maps which highlighted the red zone and annotated it with our vegetation and location recommendations from our research. This was requested by our community partner and is an effective way to portray and communicate our ideas to the public. It is a powerful way to visualise our recommendations and spatial geographic information (Gomez & Jones, 2010).

Results and Discussion

To decide where the most appropriate locations were to plant the different types of vegetation, the type of soil in each area was investigated. Looking at the soil type of the area was an important first step so we could know what types of vegetation would grow in certain areas. Four areas of planting were chosen for this research as it allowed for further research and deeper analysis. If more than four areas were chosen, there was a risk of creating generalised suggestions for future planting within the area that wasn't specific.

Figure 1 shows the locations of different soils around Christchurch. In the Bexley Wetland area, the soil is very poorly drained. This is also the case in the surrounding area of the Horseshoe Lake Reserve. The only part of the red zone and Avon River Corridor that has well-drained soil is the Avonside red zone. Overall, much of the red zone has either poorly drained or very poorly drained soil. Figure 2 is an ecosystem map of Christchurch which was also used to determine planting locations as it shows historic indigenous vegetation.

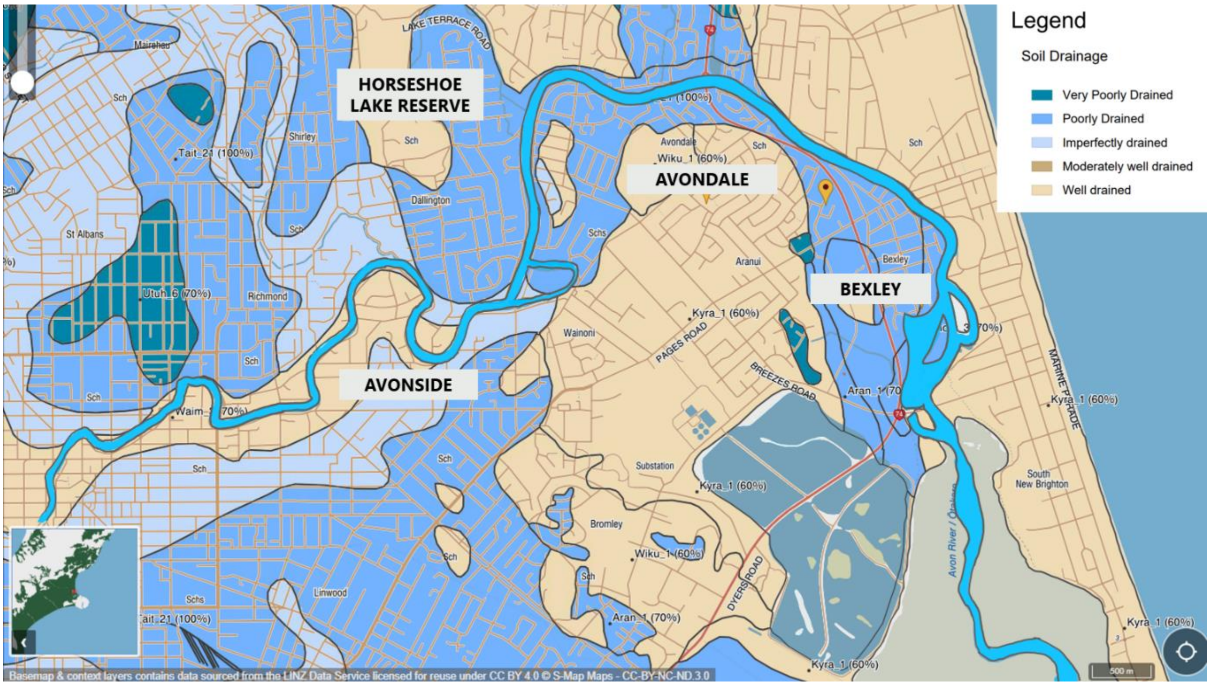

Figure 1

Map of the soil types in Christchurch. Areas of interest are labelled. Note: adapted from S-Map Online. (2022). *Landcare Research NZ (Manaaki Whenua).* https://smap.landcareresearch.co.nz/maps-and-tools/app/

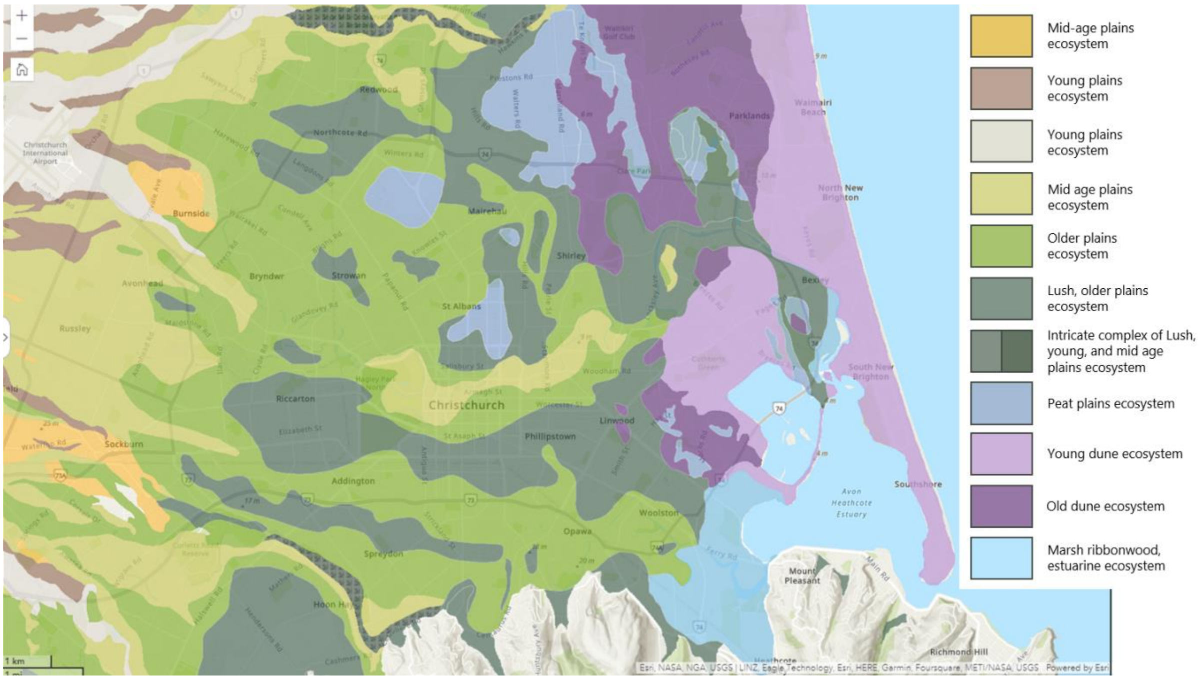

Figure 2

Ecosystem map defining the different ecosystem types in Christchurch and supplied plant species lists for each ecosystem type. Note: Adapted from Christchurch City Council. (n.d.). *Ecosystem map.* https://ccc.govt.nz/environment/land/ecosystem-map

Using information gathered from S-Map, the Ecosystem map and our literature reviews we produced an annotated map shown in Figure 3. This map shows the different locations along the Avon River Corridor and red zone where we would plant the vegetation.

It was decided to plant sedge grasses (see Appendix A for more specific species) in the Bexley Wetland and Horseshoe Lake Reserve. This is because sedge grasses thrive in wetland environments where there is poorly drained soil which was the case in both locations. We recommend planting Kōwhai, Mānuka, and cabbage trees in the Avonside red zone as this was the only location with well-drained soils which is what these plants require to thrive. The community gardens should be planted by Anzac Drive because this is an area where there aren't already community initiatives, and currently the land is not being used at all. It is also an ideal spot for a community garden because there are houses and communities nearby to help maintain the area. Within Christchurch there is currently a guideline for having a community garden produced by the Christchurch City Council (2016), the first step of the process is to create a management group and therefore it must have a community to support it. Another reason behind our decision to include another community garden is they have a large potential to store carbon (Kulack & Vasquez, 2012), as well as contribute other valuable resources for the community. A summary of our recommendations in the annotated map can be found in Table 2.

Figure 3

Annotated map showing recommended locations for future vegetation and community garden to effectively sequester carbon in the Christchurch red zone and Avon River Corridor. Note: Adapted from Canterbury Maps. (2021, October 1). *Red Zone.* https://opendata.canterburymaps.govt.nz/datasets/894ed05bbc3745c0bc2dbed6382b9b58/about

Table 2

Summary of recommendations

Location	Soil Type	Recommendations
Bexley Wetland	Very Poorly Drained	Sedge Grasses (Carex)
Horseshoe Lake Reserve	Very Poorly Drained	Sedge Grasses (Carex)
Avonside red zone	Well Drained	Cabbage Tree, Kōwhai Plant and Mānuka Tree
Hulverstone Drive, Avondale	Very Poorly Drained	Community Garden

Sedge grasses were chosen because they are very effective at sequestering carbon as discovered in the literature reviews (Chen et al., 2017). We decided to focus mostly on using native plants, so we recommended six different native species of sedge grasses to create sedge meadows that should hopefully sequester a significant amount of carbon in the red zone. It was also found that Kōwhai, Mānuka, and cabbage trees, amongst many others, are very effective at sequestering carbon. We decided to use these three because they are native plants that have cultural significance. Mānuka, in particular, is very beneficial due to the bonus of helping sustain bees.

Blue Carbon was a proposed strategy we could use within the Ōtākaro Avon River Corridor in Ōtautahi Christchurch. It was noted that blue carbon initiatives are best suited for saline environments, where mangrove, seagrass and marsh ecosystems are typically used (Conservation International, 2019). Seagrasses are considered the most viable option within the Avon River Corridor plan as demonstrated by our wetland restoration initiatives as well as literature. Kuwae et al., (2022) state seagrasses and macroalgae as having high potential sequestration rates. Blue carbon plans could be implemented by further planting seagrasses in the Avon River within the Corridor. An important note from the findings is although these systems can sequester carbon, if degradation or destruction occurs to the ecosystems, the stored/captured carbon can be re-emitted into the atmosphere (Conservation International, 2019). Considering these factors, it is unlikely a blue carbon scheme will be implemented within the area. The environment is not suited for the plants and growth is unlikely to occur as they are not in a coastal ecosystem, therefore it is not feasible (Reynolds, n.d.). If a blue carbon credit scheme were to be put in place the overall footprint of the corridor will need to increase (see Figure 3 for original footprint), extending to the estuarine and marine environment.

Limitations

Quantifying the carbon sequestration for the Corridor is difficult due to a lack of research/information on native New Zealand plant species. Most existing literature on the quantification of the carbon sequestration potential of plant species is limited to non-native New Zealand species. What would be useful is an index of New Zealand species and their potential over time to estimate the sequestration potential of any plantings or restoration done.

Another limitation of our project and research is we were limited by time. Due to the lack of time, our main method for collecting data was reviewing literature. However, if we had no time constraints, we would have collected quantitative data out in the field by recording the carbon dioxide levels within the red zone and Avon River Corridor before and after the changes were implemented. Therefore, we would be collecting data and it would be over a long-time period meaning they would be accurate. We would also be able to see if the environmental/vegetation changes are effective in decreasing carbon in the surrounding atmosphere and soil. However, this could not be executed due to the time limit and was not feasible.

Conclusion

The potential for the Ōtākaro Avon River Corridor and red zone to sequester carbon through ecosystem regeneration is not insignificant. Research obtained via literature reviews indicated wetland, forest and vegetation rehabilitation were the main options for carbon sequestration rather than a blue carbon scheme. A map could then be generated indicating the best-suited plants for rehabilitation/regeneration processes within the area. It was recommended to plant sedge grasses to create a sedge meadow in the Bexley Wetland and Horseshoe Lake Reserve because of the waterlogged soil. Kōwhai plants, mānuka and cabbage trees should be planted in the well-drained soil in Avonside red zone. Due to the proximity of communities, a community garden should be established by Anzac Drive so it can be maintained. Future research is needed within the area regarding the feasibility of native plant types and their carbon sequestration abilities as the research was limited by this. The ability to gather qualitative or quantitative data is also recommended as research was restricted by the methods available to use. The reliability of the conclusions is appropriate as literature reviews are noted to be an effective method (Snyder, 2019). Places, where conclusions may be less appropriate, are those regarding website references as opposed to peer-reviewed articles. However, due to the types of methods used, peer-reviewed articles and journals were of primary use, frequently backing up what web page articles displayed.

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Appendices

Appendix A. *a table of plant species suitable for the red zone ecosystems according to what their needs/tolerances are.*

	DRY	*WET*	*SHADE*	*SUN*
Tall Trees:		*Dacrycarpus dacrydioides* *Prumnopitys taxifolia (SUN/WET)*		*Cordyline australis* *Sophora microphylla*
Small Trees and Shrubs:	*Coprosma repens* *Griselinia littoralis* *Hoheria angustifolia (DRY/SUN)* *Pittosporum tenuifolium*	*Coprosma areolate (WET SHADE)* *Coprosma robusta* *Coprosma rotundifolia (WET/SHADE)* *Hedycarya arborea (WET/SHADE)* *Pennantia corymbose (WET/SHADE)*	*Lophomyrtus obcordate* *Melicytus ramiflorus* *Myrsine australis*	*Leptospermum scoparium* *Plagianthus divaricatus*
Climbers and Vines:	*Parsonsia capsularis* *Parsonsia heterophylla*			
Shrubs and Scramblers:		*Myrsine divaricata* *Olearia bullata*	*Melicope simplex*	*Coprosma propinqua* *Coprosma rubra*
Groundcover Herbs and 'Grasses':		*Astelia fragrans* *Astelia grandis* *Carex cockayneana* *Carex forsteri* *Carex lambertiana* *Carex virgata* *Carex solandri* *Carex conoidea*	*Nertera depressa*	*Pratia angulate* *Apodasmia similis* *Austroderia richardii* *Cyperus ustulatus* *Hydrocotyle sulcate* *Isolepis basilaris* *Juncus australis* *Juncus pallidus* *Phormium tenax* *Carex coriacea* *Carex litorosa*
Ground and Tree Ferns:	*Austroblechnum penna-marina*		*Hypolepis ambigua* *Hypolepis rufobarbata*	