Estimation of Carbon Sequestration Levels in Trees for Canterbury Plantings

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Report for Geography 309: Research Methods in Geography

October 2019

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Executive Summary

The University of Canterbury's Geography 309 research course required students to complete a geographic research project in partnership with a community-based organisation. The authors of this report were partnered with Steve Bush of Trees for Canterbury (TFC), a non-profit organisation committed to native tree planting, environmental education and social opportunity provision (Trees For Canterbury [TFC], 2019). Project research aims proposed by TFC were to quantify carbon (C) stocks and ultimately carbon dioxide (CO_2) levels sequestered by their tree plantings. Therefore, the research question of "*how many tonnes of carbon have been sequestered by trees at select Trees For Canterbury planting sites*?" was developed.

An additional aim was to generate a geospatial record of the total area of planting sites with a database of key tree attributes such as average tree height and diameter at breast height (DBH). Establishing this geospatial record was paramount in estimating the total CO_2 sequestration levels by TFC plantings.

The sites of Travis Wetland Reserve, Styx Mill Reserve, Charlesworth Reserve and Otukaikino Reserve were selected for sampling. Field research methods entailed locating predetermined sample areas using GPS coordinates and establishing a 10m x 10m sample plot within each stand. All trees within the plot greater than 1.4m high were measured and all trees with a DBH of >3cm were recorded. DBH and tree height were recorded as key parameters to estimate C content and CO_2 sequestration levels. Data collected was used as part of an allometric equation to determine C content levels, and using atomic mass ratios, was converted into CO_2 sequestration levels for each site. Site areas were determined using aerial imagery in ArcMap then applied to C output data to calculate total CO_2 sequestration levels.

A GIS was then used to display average DBH and tree height within planted areas at the different sample sites. Google Earth was used to display interactive data which TFC can continue to use and develop over time. Results show TFC plantings have sequestered 270.27 tonnes (t) of C across 18.19 ha of planted land. This equates to 54.62 t of CO_2 sequestered per ha by TFC plantings, and a total of 993.56 t of CO_2 sequestered.

Key research limitations were: access issues to predetermined sample areas leading to less representative data, a lack of data from below ground biomass (BGB) C content, and the lack of forestry professionals conducting data collection. Results may therefore underestimate C stocks and CO_2 levels. To improve accuracy, future researchers can collect more C content data and conduct chemical analysis on felled trees using more advanced equipment and techniques. Additional TFC planting sites can also be measured to provide a more complete estimation of C stocks and CO_2 levels.

1. Introduction

International concerns over anthropogenically induced climate change have made CO_2 sequestration a global focus. New Zealand is one of several nations worldwide that has made commitments to international climate treaties such as The Paris Agreement and The Kyoto Protocol to move towards C neutrality (Ministry for Primary Industries [MPI], 2015). Offsetting CO_2 emissions with reforestation and afforestation initiatives such as the "One Billion Trees Program" is the New Zealand Government's primary strategy in reaching greenhouse gas reduction goals (MPI, 2015; Te Uru Rakau, 2018). As demand for trees in New Zealand is increasing, tree nurseries are providing vital services on a national scale (Te Uru Rakau, 2018). To assess the impact trees are having on offsetting emissions, it is becoming increasingly important to be able to quantify the CO_2 sequestration capacity of trees.

Trees for Canterbury (TFC) is an eco-conscious and charitable native plant nursery founded in Christchurch in 1990 (TFC, 2019). TFC supplies trees to the One Billion Trees Program and to date, estimate their total number of plants either sold, donated and/or directly planted, has exceeded one million (S. Bush, personal communication, July 25, 2019).

The community partners operating on behalf of TFC are Steve Bush and Richard Earl, who proposed a research project for Geography 309 students at the University of Canterbury. They requested a geospatial record of their total planted area throughout Canterbury be generated, complete with a tree attribute database containing tree species variety, diameter and height. Quantitative tree attribute data was to be collected to ultimately estimate how many t of CO_2 TFC plantings had sequestered.

From these requests, a group research question of "how many tonnes of carbon have been sequestered at select Trees for Canterbury planting sites?" was developed; this underlined the methodological framework and data collection methods used for this report.

The initial brief for this research project was to conduct measurements at nine major TFC planting locations in Christchurch city and the greater Canterbury region. However, this scale was deemed infeasible for the scope of this project and consequently, just four planted sites in the Christchurch area were chosen for sampling. An appropriate allometric equation was requested for application toward C estimations at additional TFC planted sites, which may be sampled in future research.

2. Literature Review

Foundational knowledge on best forestry sampling practices to develop project methods was derived from several peer-reviewed sources. Ostberg, Delshammar, Wistrom, & Nielsen (2013) highlight the importance of defining key tree attributes to record and measure according to the research objectives. Luoma et al., (2017) outline the accuracy that can be achieved by employing traditional forestry measurement techniques for data extrapolation; this involved using a diameter tape to measure tree diameter at breast height (DBH) and a handheld digital device and transponder to calculate tree height using an in-built trigonometric function. Quantifying forest biomass is fundamental in determining tree C stock and CO_2 sequestration levels (Gil, Blanco, Carballo, & Calvo, 2010). Accurately estimating tree carbon content (TCC) and CO_2 sequestration levels typically involves analysis of both above ground biomass (AGB) and below ground biomass (BGB) (Makinde, Womiloiu, & Ogundeko, 2017; Schwendenmann & Mitchell, 2014; Wulder et al., 2008). However, with tree DBH and height measurements from sample plots, an allometric equation can be used to determine TCC from the AGB (Beets et al., 2012; Schwendenmann & Mitchell, 2014; Wulder et al., 2008). An allometric equation enables the relationship between a tree's physical attributes to be quantified (Schwendenmann & Mitchell, 2014). There are a range of allometric equations with predefined exponents that can be used to estimate TCC from a variety of parameters (Beets et al., 2012; Schwendenmann & Mitchell, 2014). A general mixed species allometric equation uses predefined exponents for AGB and relatively easily measurable parameters of tree DBH and height to output TCC (Beets et al., 2012). To minimise bias, sample areas must be defined using a consistent selection method prior to commencing field-work; this can be done using a GIS and remotely sensed aerial imagery to establish systematic grid sample areas (Rice, 2010; Kohl, Magnussen, & Marchetti, 2006).

3. Methodological Framework and Methods

The research focus for this project was on collecting quantitative primary data from in-situ measurements and existing methodologies from secondary data sources. Of the nine major sites requested for sampling, four were chosen using the non-probability convenience sampling method as this is an efficient approach when there are time and resource constraints (Macmillon, n.d.; Rice, 2010). Those four sites were: Styx Mill Reserve, Charlesworth Reserve, Travis Wetland Reserve and Otukaikino Reserve. Probability-based simple random sampling was used to select sample areas from each tree stand at each of the four sites. This was done using a New Zealand Imagery Basemap in Esri ArcMap. Polygon grids 200m x 90m were overlaid on each stand at each of the four selected TFC planting sites. Each grid was evenly divided into 9 sub-grids (Figure 1). A random number generator was used to determine the grid location of each sample plot. Only grids appearing to harbour representative tree samples were selected (Figure 2). Latitude and longitude coordinates from each grid corner were recorded for later GPS alignment in the field. This process was done for each stand of trees at each of the four sample sites. Advice was sought from industry professionals from the University of Canterbury's Forestry Department on appropriate forestry measurement tools. Department staff provided forestry measurement equipment and a tutorial on how to use the following:

- A diameter tape, which is pre-calibrated to give a diameter reading from measuring the circumference of the tree (in cm)
- A transponder and handheld Haglöf Vertex Hypsometer digital device which sends a signal to the transponder then to the top of the tree and uses an inbuilt trigonometric function to output a tree height measurement (in m)

- A handheld digital GPS device, model Garmin GPSMap 60CSX

3.1 Field Methods

Pre-recorded GPS coordinates from the simple random sampling grid were used to locate sample areas, however, once onsite at Otukaikino Reserve, accessibility issues to randomly selected sample areas became apparent. This led to the adoption of accessibility sampling which is a form of convenience sampling (Rice, 2010). Similar issues also required accessibility sampling to be applied at Styx Mill Reserve. Forestry sample plots are commonly 20m x 20m (Makinde et al., 2017), however, due to time and resource constraints 10m x 10m sample plots were established at each sample site. A measuring tape was used to establish the 10m x 10m plots with a white ribbon positioned at each corner of the plot. A Garmin GPS device was then used to georeference each of the plot corners. Employing the methods of Schwendenmann, & Mitchell (2014), any tree with 50% or more of their stem within the plot boundaries were measured for key parameters of DBH and height. In New Zealand, breast height (BH) is standardized at 1.4m up from the base of the tree stem (Beets et al., 2012). For each DBH measurement, a 1.4m long measuring stick was used to determine BH. A diameter tape was then used to output the DBH of each tree. According to Perez-Quezada et al. (2015), a base minimum DBH must be established so as not to skew results. Perez-Quezada et al.'s (2015) base minimum of 3cm DBH was applied, excluding any trees with a DBH of <3cm from the data collected. Trees with a DBH >3cm were measured for height using a Haglöf Vertex Hypsometer. The transponder was attached to each tree at BH and the handheld digital device was held by a user positioned a minimum distance of the tree's height away. A signal was then sent from the Haglöf Vertex Hypsometer to the transponder. A signal was then recorded of the top of the tree and trigonometric relationships were detected to digitally output tree height. The variety of tree species within each plot was also recorded using the help of native tree identification books "Knowing Your New Zealand Trees" by Lawrie Metcalf and "Native Trees of New Zealand 2" by J.T. Salmon. These steps were repeated at each stand at each sample site.

3.2 GIS Methods

Following field data collection, two GIS software programs were used to visualise the numerical data. GPS coordinates of each of the 10m x 10m sample plots were loaded onto a New Zealand Imagery Basemap in ArcMap. These were formatted as geographic coordinates in degrees, minutes and seconds (DMS), using the New Zealand Transverse Mercator 2000 (NZTM2000) projection. Each set of coordinates was put through the Absolute X, Y option, digitising the four corners of the plot polygons (Figure 3).

Figure 1. *GIS rendered map of 200m x 90m polygon grid, overlaid on the Styx Mill Road planting area. 66m x 30m subgrids are labelled accordingly from 1-9 for random plot area selection*

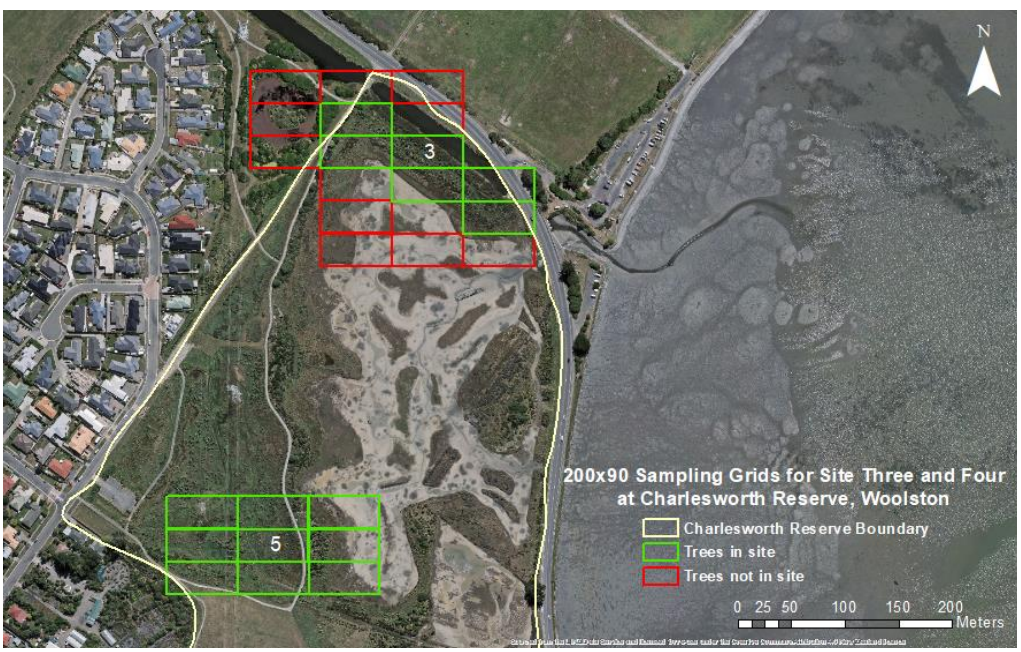

Figure 2. *GIS rendered map of systematic grids overlaid in Charlesworth Reserve, with grids 3 and 5 being randomly selecting for sampling.*

Figure 3. *Polygons in Charlesworth Reserve (in red) were created in ArcMap from GPS coordinates collected in-field. Each polygon represents the exact locations of the 10m x 10m sample plots.*

These polygons were exported as shapefiles and imported into Google Earth which is KML file compatible and openly accessible. Google Earth was then used to produce interactive maps with 3D polygons which were set to the average tree height in each planting area. The total area planted was also outlined for each sample location and polygons were created for each TFC planting area (Figure 4). The estimated total planting area of each sample site was output as a number in the "properties and attribute tables" in Google Earth and ArcMap.

Figure 4*. 3D polygons and outlines of sites 1-3 in Charlesworth Reserve. The red outlines are snapped above ground level for visibility, with the green interior highlighting the entire planting area. The 10m x 10m sample plots are symbolised by the 3D red blocks, set at the height of the average tree height of each location.*

Choropleth maps were created in ArcMap showing average tree height and DBH of each stand at each sample site. To overcome the limitations of remotely sensed aerial imagery as identified by Sprague et al. (2019), TFC planted areas were "ground truthed" by touring each stand within each of the four sample sites. This was done with the aid of aerial maps provided by TFC community partners or reserve site managers.

3.3 Carbon and Carbon Dioxide Calculation Methods

There are several different equations to estimate tree carbon content (TCC) using different parameters such as volume, wood density and/or tree basal area (Beets et al., 2012; Schwendenmann & Mitchell, 2014). The "Beets general mixed-species" allometric equation (Equation 1) best suited this research as it uses relatively easily collectable DBH and height measurements (Beets et al., 2012; Schwendenmann & Mitchell, 2014).

$$\text{TCC (kgC)} = 0.0162\ (\text{DBH}^2 \times \text{H})^{0.943} + 0.0175\ \text{DBH}^{2.20} + 0.0171\ \text{DBH}^{1.75} \tag{1}$$

Individual tree DBH and height values were implemented into the equation and summed to estimate the C content of each sample plot. Sample plot total C was then extrapolated to the entire planted area at each site. This was done based on the area ratio between the sample plot and planting area. Sample plot C estimations were then multiplied by the area ratio to produce the overall C for the different planting sites at the three locations. Total C from each sample site was summed to estimate total C across the three sample sites. C is a fraction of CO_2 as determined by a ratio of their individual atomic masses (Romm, 2008). C has an atomic weight of 12, and CO_2 has an atomic weight of 44, therefore to convert C to CO_2, the ratio of 44/12 was used, or 3.67 t of CO_2 for every 1 t of C (Romm, 2008). The total C tonnage estimation from each site was then multiplied by 3.67 to output CO_2 sequestration estimations.

4. Results

Accessibility issues lead to incomplete data collection at Otukaikino Reserve and Styx Mill Reserve sample site two, leaving that data to be excluded from the results.

4.1 Tree Species Identified

Native tree species identified across the three sample sites included: Cabbage Trees, Manuka, Mapau, Kanuka, Pittosporum varieties, Kowhai, Totara, Lancewood, Lemonwood, Tawa, Long Leaved-Lacebark, Kahikatea, Monatau, Ribbonwood, Akeake, Narrow Leaved-Lacebark and Houhere.

4.2 Tree Measurements

Table 1 shows DBH and height range and average at Styx Mill Reserve.

Table 1. *The range in tree measurements taken from Styx Mill Reserve (SMR)*

Sample plot	**Min DBH (cm)**	**Max DBH (cm)**	**Average DBH (cm)**	**Min Height (m)**	**Max Height (m)**	**Average Height (m)**	**Number measured**
SMR One	14.00	28.10	22.28	2.80	5.50	4.02	5
SMR Three	4.00	36.00	14.74	1.90	5.80	4.31	7
SMR Four	3.10	5.50	4.43	2.8	4.2	3.34	8

Table 2 shows DBH and height range and average at Charlesworth Reserve.

Table 2. *The range in tree measurements taken from Charlesworth Reserve (ChR)*

Sample plot	**Min DBH (cm)**	**Max DBH (cm)**	**Average DBH (cm)**	**Min Height (m)**	**Max Height (m)**	**Average Height (m)**	**Number measured**
ChR One	10.90	11.40	11.12	1.90	2.40	2.03	10
ChR Two	10.50	15.30	11.08	2.80	4.80	3.42	18
ChR Three	3.80	18.10	11.08	2.20	4.10	2.82	4
ChR Four	3.40	11.40	5.93	2.20	4.90	3.35	10

Table 3 shows DBH and height range and average at Travis Wetland Reserve.

Table 3. *The range of tree measurements taken from Travis Wetland Reserve (TWR)*

Sample plot	**Min DBH (cm)**	**Max DBH (cm)**	**Average DBH (cm)**	**Min Height (m)**	**Max Height (m)**	**Average Height (m)**	**Number measured**
TWR One	3.60	19.30	9.10	2.40	5.90	4.20	22
TWR Two	5.40	16.40	10.32	6.70	11.60	8.30	9
TWR Three	3.50	13.90	8.99	2.40	7.30	5.20	9
TWR Four	3.00	5.40	4.20	2.20	4.60	3.40	2

4.3 Carbon Dioxide Sequestration

Table 4 shows the estimated C and CO_2 sequestration from Styx Mill Reserve.

Table 4. *C and* CO_2 *sequestration at Styx Mill Reserve (SMR)*

Site	SMR One	SMR Three	SMR Four	Total
Planting area (ha)	1.98	0.48	3.32	4.78
Sample plot C (t)	0.23	0.23	0.01	0.47
Total planted area C (t)	39.34	35.77	8.22	83.33
Total Planted area CO_2 (t)	144.37	131.29	30.16	305.82

Table 5 shows the estimated C and CO_2 sequestration from Charlesworth Reserve.

Table 5. *C and* CO_2 *sequestration at Charlesworth Reserve (ChR)*

Site	ChR One	ChR Two	ChR Three	ChR Four	Total
Planting area (ha)	0.19	0.33	0.31	0.74	1.57
Sample plot C (t)	0.08	0.18	0.05	0.03	0.34
Total planted area C (t)	1.53	5.13	1.55	2.45	10.67
Total Planted area CO_2 (t)	5.60	18.84	5.69	9.01	39.14

Table 6 shows the estimated C and CO_2 sequestration from Travis Wetland Reserve.

Table 6. *C and* CO_2 *sequestration at Travis Wetland Reserve (TWR)*

Site	TWR One	TWR Two	TWR Three	TWR Four	Total
Planting area (ha)	3.24	6.81	0.90	0.89	11.84
Sample plot C (t)	0.19	0.13	0.09	0.003	0.413
Total planted area C (t)	52.65	116.66	7.12	0.30	176.73
Total Planted area CO_2 (t)	193.23	428.12	26.13	1.11	648.60

4.4 GIS Outputs

Using ArcMap, field data was rendered into 2D and 3D maps with tree height and DBH ranges shown for each planting area. Figures 5 and 6 show average tree height and DBH, respectively for Styx Mill Reserve. Figures 7 and 8 show average tree height and DBH, respectively for Travis Wetland Reserve. Figures 9 and 10 show average tree height and DBH, respectively for Charlesworth Reserve. Plots labelled “No Data” were found to be inaccessible for data collection (Figures 5 and 6).

Figure 5. *Choropleth map distinguishing the average height of trees across TFC several planting areas in Styx Mill Conservation Reserve.*

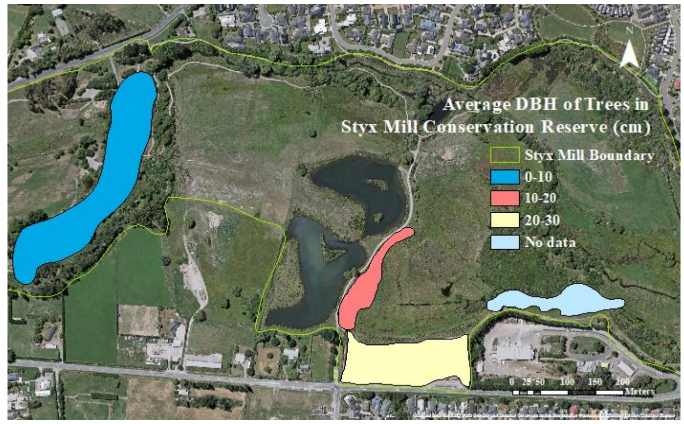

Figure 6. *Choropleth map distinguishing the average DBH of trees across several TFC planting areas in Styx Mill Conservation Reserve.*

Figure 7. *Choropleth map distinguishing the average height of trees across several TFC planting areas in Travis Wetland.*

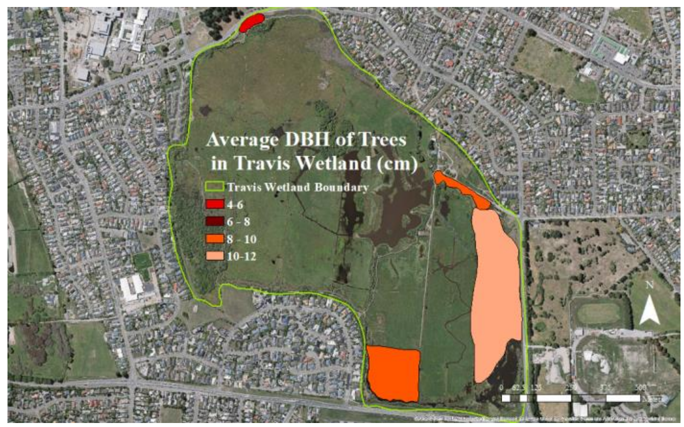

Figure 8. *Choropleth map distinguishing the average DBH of trees across several TFC planting areas in Travis Wetland.*

Figure 9*. Choropleth map distinguishing the average height of trees across several TFC planting areas in Charlesworth Reserve.*

Figure 10. *Choropleth map distinguishing the average DBH of trees across several TFC planting areas in Charlesworth Reserve.*

5. Discussion

The results showed considerable variation in C sequestration across three separate TFC planted sites. Travis Wetland sequestered the most C at 176.73 t compared to Styx Mill which sequestered 83.33 t and Charlesworth which sequestered 39.14 t. GIS area estimations showed Travis Wetland had 11.84 ha of TFC plantings compared to Styx Mill with 4.78 ha and Charlesworth with 1.57 ha. Due to the range TFC of planting areas, variation in C sequestration levels can be expected. Tree age and stocking density would also be major components of C content variations, however they were not addressed within the scope of this report.

The combined total C content of Travis Wetland, Styx Mill and Charlesworth was estimated to be 270.60 t which equates to 993.56 t of CO_2. The total TFC planting area across the three sites was estimated to be 18.19 ha. These results suggest that 14.88 t of C and 54.60 t of CO_2 are sequestered per ha of TFC plantings. For context, research completed on native trees within an Auckland park showed 45.9 t of C stored in the AGB and BGB (Schwendenmann & Mitchell, 2014). The results of this report were lower than those of Schwendenmann and Mitchell (2014) which can be attributed to several factors including inabilities to: fell trees, measure BGB, process entire tree mass to study chemical composition, assess stocking density, measure all nine TFC planted sites and so on.

Calculating BGB C stocks requires extracting tree roots and studying tree litter and soil minerals (Beets et al., 2012). Lack of this data for inclusion in calculations suggests that C and CO_2 sequestration levels estimated for TFC plantings may be lower than the true amount. According to Coomes et al., (2002), natural South Island forests contain 60% of their C stock within their living biomass, with 10% stored in dead biomass. The findings of Coome et al., (2002) would suggest that 30% of C stocks then are stored in the BGB and soil. Applying this to the TFC plantings suggests that the 270.60 t C and 993.56 t of CO_2 represents only 60% of TFC C content across three sites. This suggests that TFC tree C content may be in excess of 450 t and CO_2 sequestrated may be at levels of 1655 t.

Efforts to address global warming are focused on offsetting CO_2 emissions on a local and worldwide scale. In New Zealand, the average distance travelled annually by car is 10,000km; with one standard petrol vehicle estimated to add 1.92 t of CO_2 to the atmosphere per year (Carbon Footprint, n.d.; Ministry of Transport, 2014). From the results of this report, the CO_2 sequestered by TFC plantings across the three sites would offset the emissions of 518 cars each year. Using these results, an aspect of TFC's positive environmental impact can be assessed.

Results highlight the significance of tree planting to offset New Zealand's CO_2 emissions. TFC plantings will continue to grow their impact in offsetting emissions as they contribute more trees to the government sanctioned "One Billion Trees Program" (Te Uru Rakau, 2018).

In maintaining estimations of CO_2 sequestration levels, the geospatial database generated from this research can be routinely updated. Working with a GIS also enables visualisation of explicit spatiotemporal patterns, which can be applied to maximising efficiency in afforestation and reforestation initiatives. Future CO_2 management can be forecasted by visualising current and future land-use, and by creating scenarios for best land-use practices. The generated geodatabase can provide an avenue for future research to evaluate and map C and CO_2 on a wider scale.

5.1 Assumptions

The primary assumption of this research was that sample sites and sample plots were representative of the entire area of TFC plantings. It was also assumed that the biomass exponents of the mixed species allometric equation were representative of the branch and leaf biomass of the trees measured. It was also assumed that stocking density was consistent across stands and planted sites as well as that all trees within these areas were living at the time of this research.

5.2 Limitations

Out of TFC's nine major planting areas throughout Canterbury, four were selected for sampling based on size and proximity to Christchurch. Selecting sample sites based on proximity is a non-probability convenience sampling method may yield bias (Rice, 2010). Accessibility sampling may yield the same bias and according to Rice (2010) "cannot be used to make statistical inferences about the population from which they are drawn." Inherent limitations of the project were accepted and research results were not statistically analysed. The accuracy of the results, therefore, cannot be concluded with any statistical confidence (Rice, 2010).

Another key limitation to the accuracy of the results is the exclusion of plant and shrub species and trees with a DBH of <3cm from calculations. This again implies resulting C estimates may be lower than the actual C and CO_2 sequestration levels of TFC plantings.

The research results are based on data from a relatively small sample size relative to the population of TFC plantings throughout Canterbury. As well, there are variations in C sequestration across native New Zealand trees species (Beets et al., 2012), which was not accounted for in this research. To improve accuracy, a species specific equation could have been implemented such as is listed in Beets et al. (2012). The species specific equation was not used as the parameter data collection it would require exceeded available time and resources for the scope of this report. The general mixed species equation used in calculations may underestimate C stocks by 0.07 t compared to a species specific equation (Schwendenmann & Mitchell, 2014).

At select sample sites, inaccessibility was a health and safety concern and inhibited us from collecting data at Otukaikino Reserve and the second sample site at Styx Mill Reserve.

Incomplete field data resulted in less sample representation on the GIS rendered 2D maps, where TFC planted areas were highlighted with polygons and labelled "No Data" (Figures 5 and 6). A NZTM2000 projection map was supplied by TFC with digitally highlighted TFC planted areas at each of the selected field sites, however it did not contain georeferenced data. Future research can improve accuracy by surveying and georeferencing each TFC planted site. Further studies may wish to utilise immersive geospatial solutions such as using ArcScene to create 3D sample plots for a more realistic visualisation.

5.3 Future Research

More in depth research can be done with TFC to estimate the total area of their plantings throughout Canterbury and their C stocks and CO_2 sequestration levels. This can be done by assessing BGB and soil C content to give a more accurate representation of TFC's total contribution in offsetting New Zealand's CO_2 emissions.

6. Conclusion

This study researched select TFC planting sites across Christchurch. The research aims of this project included calculating the total amount of C and CO_2 sequestered by trees at Travis Wetland, Styx Mill and Charlesworth Reserves as well as creating a geospatial record of the results. After in-field data collection, GIS output generation, C and CO_2 calculations, varying results were noted across the three TFC planted sites. Travis Wetland Reserve sequestered 176.73 t C which was the largest amount of C sequestered across the three sites. Overall, there was 270.60 t of C accrued and 993.56 t of CO_2 sequestered across the three sites which equates to 14.88 t of C and 54.60 t of CO_2 sequestered per ha of TFC tree plantings. Research aims and objectives were achieved with the provision of both geospatial solutions, C and CO_2 calculations. Further research should account for BGB and soil components to further calculate C and CO_2 sequestration. A remaining question is "how much C and CO_2 have been sequestered by other TFC planted sites?" This research has outlined a methodology that may be built upon for future Geography 309 projects to examine additional TFC planting sites in more depth, utilising different methods.

Acknowledgements

We would like to thank Steve Bush for his wealth of knowledge, passion and expertise throughout this research. Without Steve's help and communication this project would not have run as smoothly. We would also like to thank Richard Earl for combining with Steve and providing us with an interesting and thoroughly enjoyable research topic. Finally we would like to thank the staff at the University of Canterbury within the Geography and Forestry department who shared their knowledge and tools with us to complete this project.

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