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Student Research Report

COMPARING THE LEVEL OF ABOVE-GROUND CARBON SEQUESTRATION AND RESPECTIVE ECOSYSTEM SERVICES BETWEEN NATIVE AND CULTIVATED TREES

Prepared by: Tsz Him LAU

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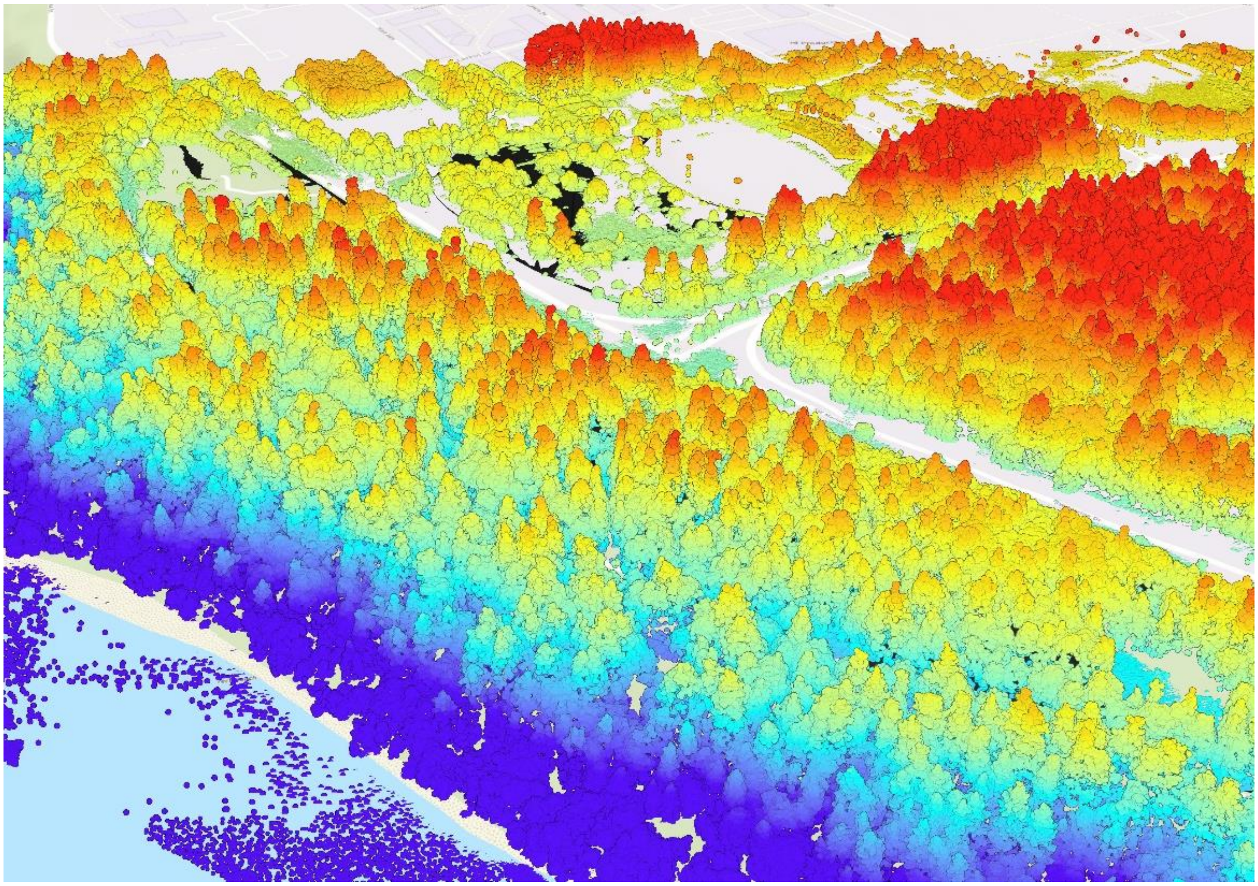

COMPARING THE LEVEL OF ABOVE-GROUND CARBON SEQUESTRATION AND RESPECTIVE ECOSYSTEM SERVICES BETWEEN NATIVE AND CULTIVATED TREES IN UBC BOTANICAL GARDEN

Name: Tsz Him LAU

Current Degree: BSSc (Hons) in Geography and Resource Management

Topical Mentor: Tara Moreau

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Final Report

Abstract

Urban trees play an essential role in alleviating the local effects of global warming by sequestering atmospheric carbon dioxide, regulating temperature and reducing air pollution in urban areas. There have been studies estimating carbon sequestration of urban trees using Light Detection and Ranging (LiDAR). Yet, neither of the studies made comparison between species nor extended the discussion towards ecosystem services. Therefore, this study compared the attributes between native and cultivated trees in the Asian Garden of UBC Botanical Garden, estimated their level of above-ground carbon sequestration, and thus examined respective implications in terms of ecosystem services. A canopy height model was first generated from LiDAR point cloud data for individual tree segmentation based on Dalponte algorithm. There were 803 derived trees matched successfully with the field-measured trees in ArcGIS with an accuracy of 69.5%. The level of above-ground carbon sequestration of each tree was estimated from tree height and canopy area using a non-linear regression model. Results showed that the average carbon sequestration level of native trees was higher than cultivated trees by 1102 kg (p = 3.045 x 10^{-7}), which facilitated more effective soil formation. The average canopy areas of both trees were approximately 63 m^2 (p = 0.696), which gives rise to their similar contribution in temperature cooling and air purification. In general, the garden provides a high level of biodiversity and education value thanks to its high species diversity. Regarding future directions in garden management, the removal of native trees and the planting location of cultivated trees in the garden should be carefully evaluated since they have higher level of ecosystem services and higher crown area to height ratio respectively.

Keywords: above-ground carbon sequestration, botanical garden, ecosystem services, individual tree segmentation, LiDAR, urban forestry

1. Introduction

1.1. Importance of Urban Trees as Carbon Sinks and the Role of Botanical Garden

Climate Change is the most crucial environmental, economic, and security issue the earth is facing (Russo, 2014). Owing to rapid industrialization and urbanization in the past centuries, global mean temperature has increased by an unprecedented 1°C (Russo, 2014). By 2030, it is projected that 60% of the world's population will be residing in cities (Rydin et al. 2012). Thus, it is expected that there would be increasing greenhouse gas emissions, which further exacerbate the effect of global warming. In response to such trend, the necessity of urban parks, green infrastructure and ecological connectivity is continuously increasing. Currently, the most notable ecological services include sequestering and storing carbon dioxide, mitigating air pollution levels, filtering surface water runoff and providing shades for cooling neighborhoods and buildings (Livesley, 2015). Among all services, carbon sequestration and storage are of paramount importance in managing the amount of carbon dioxide in the atmosphere by accumulation and release, and thus the long-term regional temperature (Livesley, 2015). Therefore, it is necessary to quantify ecosystem services and provide decision-makers and urban planners with data and information to predict changes in urban temperature. Appropriate policies and strategies such as landscape zoning, energy and transportation usage can hence be formulated (Hong et al., 2018). As a result, there is an increasing number of studies on the benefits of carbon sequestration in large cities. Nowak *et al.* (2013) revealed that urban street trees across 28 cities in the United States, including Atlanta, New York and Boston, provided an annual sequestration of 25.6 million tonnes, which was equivalent to a monetary value of $2 billion. Ariluoma *et al.* (2021) also predicted that trees inside residential area in Helsinki can absorb 330,000 tonnes of CO_2 in 50 years, while Tang *et al.* (2016) stated that urban trees are efficient in absorbing anthropogenic CO_2 along main streets in Beijing.

Among all urban green infrastructures, botanical gardens devote their resources to the scientific research and conservation of plants, and also publicizing the world's plant species diversity (Chen & Sun, 2018). Therefore, they play a key role in maintaining the well-being and resiliency in both social and ecological perspectives, upon provision of various ecosystem services (Krishnan, 2016). In particular, the University British Columbia Botanical Garden is the oldest university botanical garden in Canada and has more than 30,000 plants from 5,000 taxa (UBC Botanical Garden, 2021b), which has significant contribution in the provision of ecosystem services in the urban areas of Metro Vancouver region.

1.2. Absence of Quantitative Measurement between Carbon Sequestration and Ecosystem Services

Scientists and professionals in forestry have estimated the level of above-ground carbon sequestration and storage in large-scale forest in rural regions (Schreyer et al., 2014). Urban forests and green spaces are often neglected (Gülçin, 2021) due to limited space in urban areas for surveying and measurement of tree attributes such as tree height and canopy area, where their specific roles and ecosystem services are still ambiguous. Light Detection and Ranging (LiDAR) is an advanced remote sensing approach that has allowed for more reliable estimation. It detects the location of objects by calculating the ranges of light pulses between the scanner and the object

(Gülçin, 2021). After collecting the raw point cloud data, classification is done to identify individual trees. Researchers could therefore obtain the tree height and crown width directly for further calculation of diameter at breast height (DBH) and carbon biomass more feasibly (Gülçin, 2021). Maclean and Martin (1984) pioneered the method of retrieving tree attributes from LiDAR to investigate the natural forest canopy profiles and tree volume. But it was only until 2012 that Zhang and Qiu (2012) applied this technology in conducting treetop-based tree identification in urban environment. In recent years, there have been two publications measuring the amount of carbon storage in the Metro Vancouver region and the University of British Columbia (UBC) campus respectively with the aid of LiDAR data. Welham and his team (2017) estimated the carbon storage through the segmentation of forest layers from different regions in Geoinformation Science (GIS), while Gülçin (2021) focused on deriving the amount of carbon storage in individual trees through watershed segmentation and pit-free algorithm. None of these studies extended their discussion on how their results could be useful to help facilitate future planning strategies and landscape management.

1.3.Research Objectives

In light of the absence of discussion over how the level of carbon sequestration could provide insights in formulating future planning strategies, this study serves the purpose of estimating the level of above-carbon sequestration of native and cultivated tree species in the Asian Garden of The University of British Columbia Botanical Garden (UBCBG) using LiDAR data, and hence utilising the results to analyze respective ecosystem services using GIS.

The objectives of this research are:

1) To compare the attributes of native and cultivated tree species in the Asian Garden of UBCBG
2) To estimate the level of above-ground carbon sequestration of native and cultivated tree species in the Asian Garden of UBCBG
3) To discuss what other significant ecosystem services native and cultivated tree species can provide based on their respective attributes and level of above-ground carbon sequestration

Since Metro Vancouver has established a target of a 50% reduction of carbon pollution by 2030 and complete carbon neutrality for the region by 2050 (City of Vancouver, n.d.), in addition to the similar target of UBC (UBC, n.d.), this research aims to provide directions for formulating effective assessment operation and management plans in optimising urban forest ecosystem services that aid Vancouver and UBC to increase resilience towards future climate crisis. In addition to the special role of botanical gardens, UBCBG is an ideal study site due to its location within UBC and Metro Vancouver, as well as approximation towards urban areas. Besides, it offers insights to the UBCBG team in managing the number of native and cultivated species in the Asian Garden with regards to the ecosystem services provided.

2. Study Site

The study site of this research is the Asian Garden of The University of British Columbia Botanical Garden (UBCBG) at the University of British Columbia (UBC) Vancouver Campus (49.25394°N, 123.25126°W). Established in 1916, UBCBG is the oldest university botanical garden in Canada thanks to the research on native flora by John Davidson, the first provincial botanist in British Columbia (UBC Botanical Garden, 2021a). The UBCBG comprises three sites on the campus - Main Garden, Nitobe Memorial Garden and Botanical Garden Nursery. The Main Garden consists of several named garden areas and an area of undeveloped second-growth forest, which lies in the western of the Point Grey Peninsula in British Columbia, Canada, and the southwestern of the campus with an area of 0.215 km^2. Regarding the landscape and climate, the site has a gentle topography with an average elevation of 87m above sea-level (Government of Canada, 2021). Lying in the rain shadow region of Vancouver Island, the summers are dry and warm, while winters are wet and mild, with an annual mean temperature of 11° C and annual precipitation of 146cm (Government of Canada, 2021).

Being in the Moist Maritime Subzone, the area allows for growing a variety of plants from temperate regions, especially from British Columbia, eastern North America and Asia. Currently, the Garden curates around 8,000 accessions representing more than 30,000 plants from 5,000 taxa (UBC Botanical Garden, 2021b). UBCBG Main Garden is comprised of many smaller gardens which are characterized by plant communities that simulate different ecosystems and regions of the world, including Asian Garden, Alpine Garden and North American Gardens. In particular, North American Gardens comprises four distinct garden areas representing the biogeographical and floristic communities of four distinct regions, these are: the BC, Rain Forest Garden, the Pacific Slope Garden, the Garry Oak Meadow and Woodland Garden and the Carolinian Forest Garden. The Asian Garden is the largest among all gardens with 0.138 km^2, and extends from the southeast to the northwest of the Main Garden. According to the Binnie Survey conducted in 2016, the Asian Garden contains more than 2,300 native and cultivated trees (UBC Botanical Garden, 2016). Opened in 1981, the Asian Garden has displayed collections of Asian *rhododendrons* primarily from the Himalayas, China, Japan, and Korea, in addition with the background of native plants (UBC Botanical Garden, 2021b). Considering the native species in the whole garden, the three species that dominate are conifer, which are *Abies grandis* (Grand fir), *Pseudotsuga menziesii* (Douglas-fir) and *Acer macrophyllum* (Bigleaf maple). Some of the most representative collections in the Asian Garden include Rhododendrons, Maples, Magnolias, Sorbus and climbers.

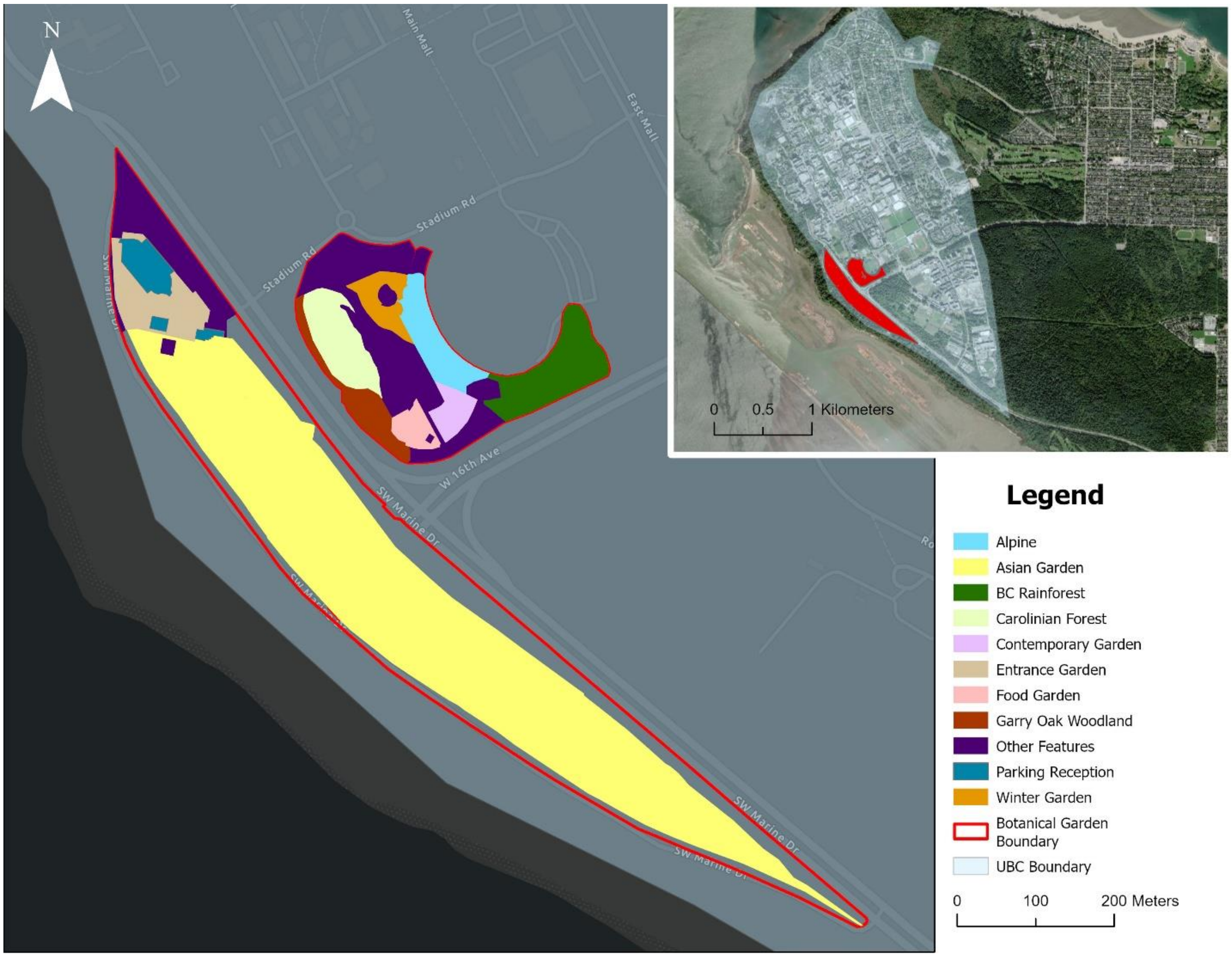


Figure 1: Map of UBCBG Main Garden, located in the southwestern part of UBC-Vancouver near the coast. It is split into two parts in an elongated and L-shape respectively by the Southwest Marine Drive due to multiple stages of expansion, which is bounded by the red line. The study was focused on the yellow section corresponding to the Asian Garden. The map was projected in NAD 1983 UTM Zone 10N on a base map from ESRI.

3. Data Summary

In order to compare the level of above-ground carbon sequestration between native and cultivated species in the Asian Garden of UBCBG, 2 data sets were used to estimate the above-ground carbon biomass including the point cloud data of trees and a table of trees attributes in UBCBG were required. Point clouds are a collection of points representing the X, Y and Z geometric coordinates of an object (Rodriguez & Sanchez, 2019), while the table consisted of a list of georeferenced trees with species names, diameter, elevation, etc.

3.1. University of British Columbia Point Grey Campus LiDAR

The point cloud data collected by LiDAR is owned by Eagle Mapping but was obtained from Abacus Library (University of British Columbia, 2021). Collected on 23rd June, 2021 from the altitude of 1400m, the data was released on 6th October, 2021and specified as 30 pulses/m^2, which is the most updated LiDAR data of the UBC area to be accessed and downloaded. The LiDAR had an average pulse density of 41 ppm with 94% of cells passed the accuracy test. Despite having a horizontal and vertical accuracy of +-0.3m and +-0.15m respectively, the only concern with this dataset was that no control was available to verify the absolute accuracy of the dataset. The data was then projected on NAD1983 UTM10N. It was used to derive a canopy height model and estimate the height of trees.

3.2. Plant Collections in Asian Garden

Data on georeferenced trees with field-measures was provided by the UBCBG Team. The attribute table in the vector layer contained various fundamental features of the 3,600 individual trees and plants in the Asian Garden. These included the accession number, the scientific and vernacular name, the plant family, whether plants were conifers or deciduous, coordinates in latitude and longitude of WGS1984, bed code referring to its location in the Garden, height, diameter, provenance (wild, garden or flora-on-site), the country of origin etc. (UBC Botanical Garden, 2016). The team took the data from the Binnie Survey in 2016 and used the unique coordinates to match it with the data from the IrisBG export of the collection. The trees that were not matched to a species and manually identified were then filtered out. The remaining trees were eventually categorized as ‘native’ and ‘cultivated’. The number of trees was updated nearly every year, where the last update was in 2019. However, the values of height and diameter of the trees were not up-to-date after growing in years, where the existing values could be derived from LiDAR.

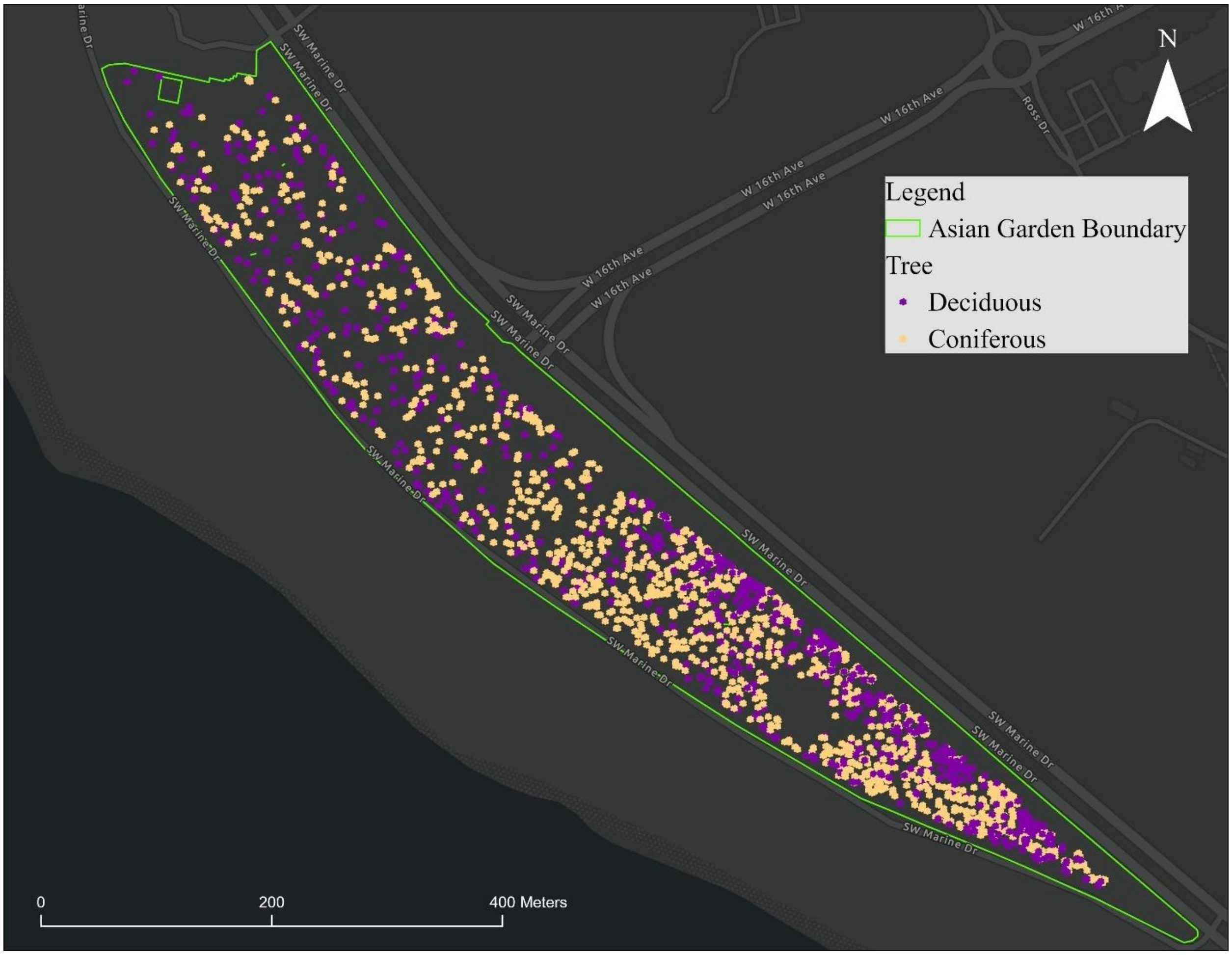


Figure 2: Coniferous and Deciduous in Asian Garden at the UBCBG. They were distributed in a scattered pattern. The map was projected in NAD 1983 UTM Zone 10N on a base map from ESRI.

Table 1: A Summary of the Source and Raw Data Type of the Two Major Datasets Required in the Project. The data used to calculate the level of above-ground carbon sequestration was displayed in the 'Derived data' column.

	UBC Campus LiDAR	***Plant Collections***
Source	Abacus Data Library	UBC Botanical Garden Team
Access	Free for public	Private access
Resolution	30 pulses/m^2	/
Raw data type	Point cloud	Vector
Derived data	Canopy Height Model for individual tree segmentation	Location of native and cultivated species for calculating the tree's carbon biomass

4. Methodology

4.1. Overview

Multiple methods were applied to estimate the level of above-ground carbon sequestration and compare the ecosystem services provided by native and cultivated trees in Asian Garden. These included data pre-processing, development of canopy height model, tree segmentation from LiDAR data, calculation of total level of above-ground carbon sequestration, and generation of heat maps using methods in ArcGIS. Figure 3 shows the proposed workflow of data processing.

4.2. Data Pre-processing

Pre-processing of LiDAR data were required due to incompatibility of its spatial coverage with the study area. Since the LiDAR data covered the entire territory of UBC Vancouver Campus, the tiles that include the Asian Garden of the UBCBG were first identified for point cloud data extraction. The selected tiles were then masked with the Asian Garden boundary polygon in R (Roussel, 2021), which filtered away the LiDAR point cloud outside the garden. Regarding the field-measured trees, 2286 trees were identified in the Asian Garden. Hence, they were classified into the category of either native or cultivated based on the information provided in the attribute table. Among these trees, 256 of them were regarded as unclassified and filtered away.

4.3.Development and Smoothing of Canopy Height Model

Canopy Height Model (CHM) represents the vertical difference between the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) (Hassen et al., 2019). In this project, the CHM was directly generated with resolution of 50 cm using point-to-raster method in the R package “lidR” (Roussel, 2021). Prior to the development of the CHM, removal of potential outliers, filtering the noise and normalization of the point cloud data was required to facilitate the geoprocessing time and increase the accuracy (Hanssen et al, 2019; Wu et al., 2019). The CHM was then derived as a raster layer. Moreover, smoothing of the CHM was completed to prepare for individual tree segmentation. The pit-free algorithm, which removes wide triangles with a series of sequential height thresholds (Roussel et al., 2021), was applied to avoid pits during computational process and smooth the CHM by minimising the number of empty pixels. Consequently, with regards to Hanssen *et al.* (2019), a median filter of 3m x 3m was applied to eliminate nearby local maxima caused by tree branches. The filter determined the boundary of the tree canopy and gave better results for identifying individual trees.

4.4. Segmentation of Individual Trees

a) Individual Tree Detection and Segmentation using Dalponte Algorithm

There are a variety of methods and algorithms to segment individual trees from CHM, namely Dalponte algorithm, Watershed segmentation and Voroni tessellation. Dalponte algorithm is a tree-centric approach that identifies individual tree tops and crowns from point cloud data using a region-growing method (Dalponte & Coomes, 2016). When compared to Watershed Segmentation and Voroni tessellation, segmentation using Dalponte algorithm provided the lowest Akaike information criterion (AIC) value and root-mean square error (RMSE), which indicated a better model fit. Besides, this method was also widely deployed in various tree segmentation research, such as Pirotti *et al.* (2017) and Jakubowski *et al*. (2013). Therefore, the Dalponte algorithm was used for this project.

In this process, a local fixed filter was applied to determine the locations of treetops using lidR package (Roussel, 2021). This algorithm filtered pixels in the CHM with a 5x5 window (Gülçin & Konijnendijk, 2021). Individual tree tops were first extracted and reclassified as native and cultivated species from the individual tree data. Consequently, the tree crowns were identified using delineate crown function in lidR (Roussel, 2021). A vector layer of individual trees was generated, alongside with the information of attributes such as treetop location, tree height (TH), canopy width (CW) and canopy area (CA).

b) Accuracy Validation with Individual Tree Data

After the extraction of individual treetops, the derived individual tree location was compared to the field-measured tree location in the plant collections dataset. Since a high native tree density and a thick canopy cover was expected in the southeastern part of Asian Garden, native trees with a DBH of below 40cm were filtered away. Such removal of trees that were shorter than the top canopy could minimize the error of segmenting overlaying tree crowns.

To determine how well the field-measure trees and the derived trees were matched, an accuracy assessment was implemented to compare whether the derived tree locations were significantly different from the field-measured tree data. By using the spatial join with the closest match option in ArcGIS, the segmented trees were matched with the nearest field-measured individual tree.

The number of matched trees (MT) characterizes the segmentation quality; the number of omission errors (OE) and commission errors (CE) represents the under-and over-segmentation respectively. The accuracy of the matching was evaluated in terms of recall (Re), precision (Pr) and F-score (F) using the following equations:

$$(1)\ \dots\ Re = \frac{MT}{MT + OE}$$

$$(2)\ \dots\ Pr = \frac{MT}{MT + CE}$$

$$(3)\ \dots\ F = 2 + \frac{Re\ \times Pr}{Re + Pr}$$

4.5.Estimation of Total Carbon Sequestration Level and other Ecosystem Services

After segmenting individual trees and validation of the segmentation model, a set of algorithms were used to estimate the above-ground carbon sequestration level of individual trees using the tree height, canopy area and DBH. In the research of Schreyer *et al.* (2013), the mathematical relationship between tree height (TH), canopy area (CA) and DBH of native and cultivated species is represented as the below non-linear equation model:

$$(4)\ \dots\ DBH = b1\ \times (TH - 1.3)^{b2} \times CA^{b3}$$

where b1, b2 and b3 are model parameters.

After obtaining the DBH, two equations were used to estimate the above-ground carbon sequestration level of native and cultivated trees respectively to obtain a more precise result since the relationship between the two variables varies among species. Jenkins *et al.* (2004) developed unique equations between the level of above-ground carbon sequestration and DBH with regards to each common tree species in North America. Since 42% of the native trees in the Asian Garden were Western redcedar, Western hemlock and Bigleaf maple, the model parameters were averaged between the equations of these species, and thus used in equation (5) for the estimation of above-ground carbon sequestration level (CAG) of native trees. In comparison, since most of the cultivated species in the Asian Garden are from Asia, a general equation that was also developed by Jenkins *et al.* (2004) was used instead to correlate CAG and DBH of cultivated trees, as displayed in equation (6), where the constant values are the estimated parameters.

$$(5)\ \ldots\ CAG_{native} = \exp[-2.1949 + 2.3916\ \times \ln(DBH)]$$
$$(6)\ \ldots\ CAG_{cultivated} = \exp[-2.48 + 2.4835\ \times \ln(DBH)]$$

These equations were adopted in this project to estimate the level of above-ground carbon sequestration of individual trees, where a heat map would be generated to show the difference between native and cultivated species, and display the total above-ground carbon sequestration level in the Asian Garden. Two-sample unpaired t-test was eventually conducted to test whether the mean of above-ground carbon sequestration level between native and cultivated trees was different. The null hypothesis and alternative hypothesis are listed in below:

$$H_0: The\ difference\ in\ mean\ carbon\ sequestration\ level\ equals\ to\ zero$$

$$H_1: The\ difference\ in\ mean\ carbon\ sequestration\ level\ does\ not\ equal\ to\ zero$$

Consequently, other ecosystem services and future management strategies of the garden were discussed based on this result.

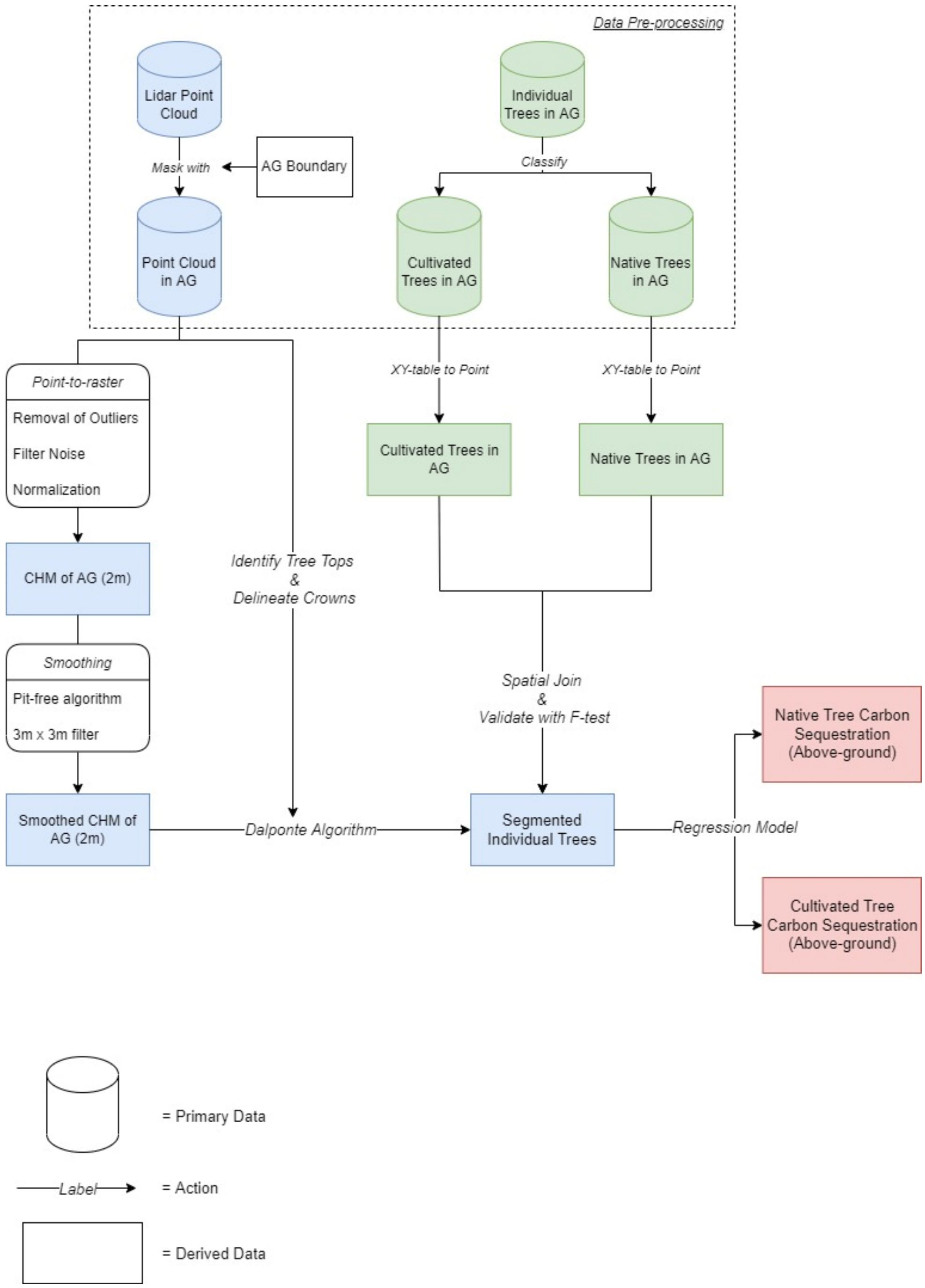


Figure 3: A Flowchart Explaining the Main Analyses and Data Types Used in this Study. AG stands for Asian Garden, blue indicates the data from LiDAR point cloud, green indicates the data in collections dataset provided by UBCBG, and red represents data of above-ground carbon sequestration level. The LiDAR data was used to generate a smoothed canopy height model, identify tree tops and delineate crowns for individual tree segmentation. The derived trees were spatially joined with the nearest field-measured trees prior to validation. Level of above-ground carbon sequestration of native and cultivated trees was estimated using respective regression models.

5. Expected Results

5.1. Garden Tree Attributes

There were a total 1890 trees in the Asian Garden that were documented with regards to unique ID, location in longitude and latitude, as well as species name. Of these, 1703 were native trees, in which 1150 were coniferous while the remaining 553 were deciduous. In contrast, the number of cultivated trees was 187, where only 7 of them were coniferous. Despite fewer cultivated trees than native, this category obtained 112 different species, which showed a higher diversity in terms of number of species. These include a variety of taxa from temperate regions of Asia, such as *Magnolia campbellii* (Campbell's magnolia), *Acer davidii* (Père David maples) and *Cercidiphyllum japonicum* (Katsura tree). In comparison, there were only 8 major species for native trees, including *Thuja plicata* (Western red cedar), *Acer macrophyllum* (Bigleaf maple) and *Tsuga heterophylla* (Western hemlock). A summary of characteristics of native and cultivated trees is presented in table 2.

Table 2: Characteristics of Native and Cultivated Trees in the Asian Garden. The number of native trees was much higher than cultivated trees in the Asian Garden. However, cultivated trees had a higher ratio of deciduous trees and number of tree species since most of the plants were imported from Asia.

	Native	**Cultivated**
Total number of trees	1703	187
Number of deciduous	553	180
Number of coniferous	1150	7
Number of species	8	112
Major species	*Thuja plicata* *Acer macrophyllum* *Tsuga heterophylla*	*Acer davidii* *Magnolia campbellii* *Cercidiphyllum japonicum*

Regarding the distribution of the trees, all cultivated trees were located in the northwestern part of the garden, while native trees were distributed over the garden (Figure 4). Tree density on the northwestern part of the garden was lower when compared to the southeastern part. There was no clustered pattern shown between native and cultivated trees in the northwestern region.

Figure 4: Map showing the Distribution of Native and Cultivated Trees in the Asian Garden. Cultivated trees were found only in the northwestern and centre region of the garden. The map was projected in NAD 1983 UTM Zone 10N on a base map from ESRI.

5.2. Lidar Segmented Trees Features and Matching Accuracy

A total of 1137 individual trees were segmented and delineated. The mean height of segmented trees in Asian Garden was 32.4 m (range = 10.15 - 63.18 m; mean ± 1 SE = 32.4 ± 10.23m). Considering the canopy area, the mean was 61.7 m^2 (range = 5.50 - 89.88 m; mean ± 1 SE = 61.7 ± 18.16 m^2). The results showed that the segmented trees had a large variety of sizes.

The segmented trees were matched with the field-measured Asian Garden trees in section 5.1 in order to identify whether they are native or cultivated. A total of 803 segmented trees were found to align with the field-measured trees, which showed a precision score of 70.6%. However, there were 370 garden trees omitted and identified as omission error (OE). Moreover, there were 334 segmented trees that could not find a matched pair with the field-measured trees and were identified as commission error (CE). By using the equation (5) and (6) in methodology section, the F-score calculated was 0.695, which was slightly below the acceptable threshold of 0.7. On the basis of the results in the accuracy testing, these 803 matched trees were selected for the classification into native and cultivated species, as well as the calculation of the above-ground carbon sequestration level.

Table 3: The Values of Accuracy Testing in Matching LiDAR-derived Trees and Field-measured Garden Trees. 803 segmented trees were matched with the garden trees. However, the omission and commission error were 370 and 334 respectively, which led to a relatively low F-score.

	Number
Matched Trees (MT)	803
Omission Error (OE)	370
Commission Error (CE)	334
Recall (Re)	0.685
Precision (Pr)	0.706
F-score	0.695

In general, native trees (mean ± 1 SE = 36.3 ± 8.18 m) were taller than cultivated trees (mean ± 1 SE = 25.86 ± 12.14 m) (t = 9.51, df = 155.2, $p = 2.2 \times 10^{-16}$). Considering the canopy area, both native and cultivated trees obtained a similar mean of approximately 63 m^2 as shown in figure 5b, indicating that native and cultivated trees had similar canopy area (t = -0.392, df = 195.89, p = 0.696).

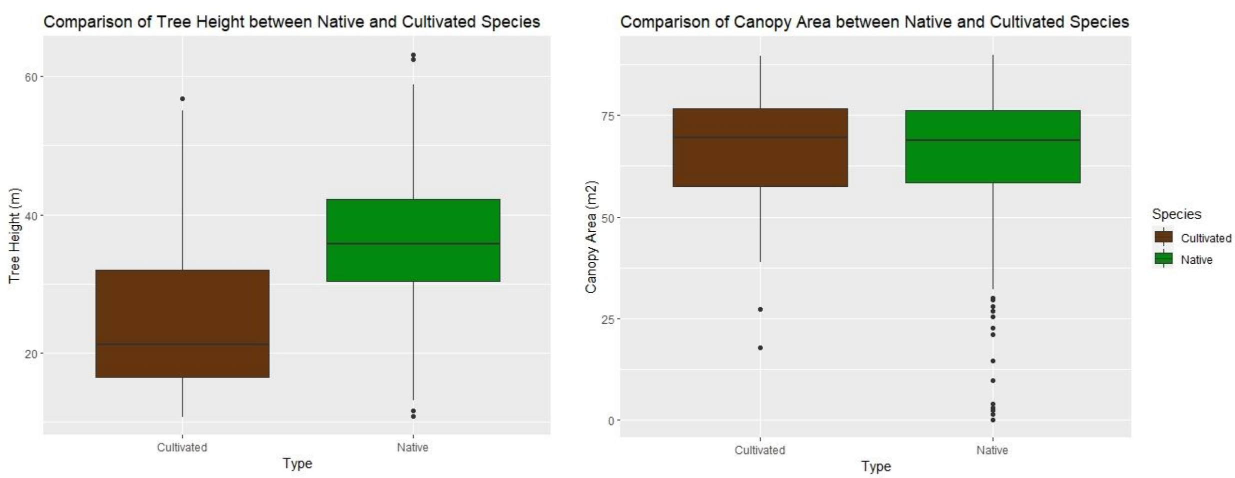


Figure 5: a) Tree Height and b) Canopy Area of Segmented Native and Cultivated trees. In general, the average height of native trees was higher than that of cultivated trees as the upper quartile, mean and lower quartile of native trees obtained a larger value. Both native and cultivated trees obtained similar mean and range in canopy area.

5.3. Level of Above-ground Carbon Sequestration of Segmented Native and Cultivated Trees

In hopes of deriving the DBH from the estimated tree height and canopy area of the LiDAR-segmented trees, a non-linear regression model for native and cultivated species was developed with regards to the sample data of DBH from 100 field-measured trees. The statistical summary of the model was shown in table 4. All three coefficients were considered to be significant parameters in the model with a RMSE of 0.2626, which implies the model was valid for estimation. By inputting the value of coefficient into equation (4), the model equation for estimating DBH from tree height (TH) and canopy area (CA) is as follow:

$$DBH = 4.7853 \times (TH - 1.3)^{0.5615} \times CA^{0.1952}$$

Table 4: Parameters and Summary of the Non-linear Regression Model. All three coefficients have a p-value of lower than 0.05, which shows that they are significant model parameters. The RMSE and number of iterations prove that the model was valid for usage.

Coefficient	Estimate	p-value	RMSE
b_1	4.7853	0.04325	0.2626
b_2	0.5615	0.00479	**Number of iterations**
b_3	0.1952	0.02678	14

The results of DBH between native and cultivated species showed a similar pattern as those of tree height in figure 5a. Native trees (mean ± 1 SE = 79.04 ± 12.37 m) generally had a higher DBH than cultivated trees (mean ± 1 SE = 63.65 ± 17.96 m) (t = 9.41, df = 156.34, $p = 2.2 \times 10^{-16}$). Besides, the DBH among cultivated trees was more dispersed and varied more than native trees.

Consequently, the estimated DBH of each tree was input into equation (5) and (6) in the methodology section according to whether the tree was native or cultivated. The total level of above-ground carbon sequestration of the Asian Garden was 3,071,931.8kg, where native trees had a higher contribution of 87.5% than cultivated trees of 12.5%. The mean above-ground carbon sequestration level of native trees was 4000 kg (range = 165.3 - 9562.3 kg; mean ± 1 SE = 4000 ± 1409 kg), which was higher than that of cultivated trees of 2904.6 kg (range = 678.3 - 9256.7 kg; mean ± 1 SE = 2904.6 ± 2078.7 kg). Despite native trees having a large range, the distribution of level of above-ground carbon sequestration of cultivated trees was more dispersed than native trees.

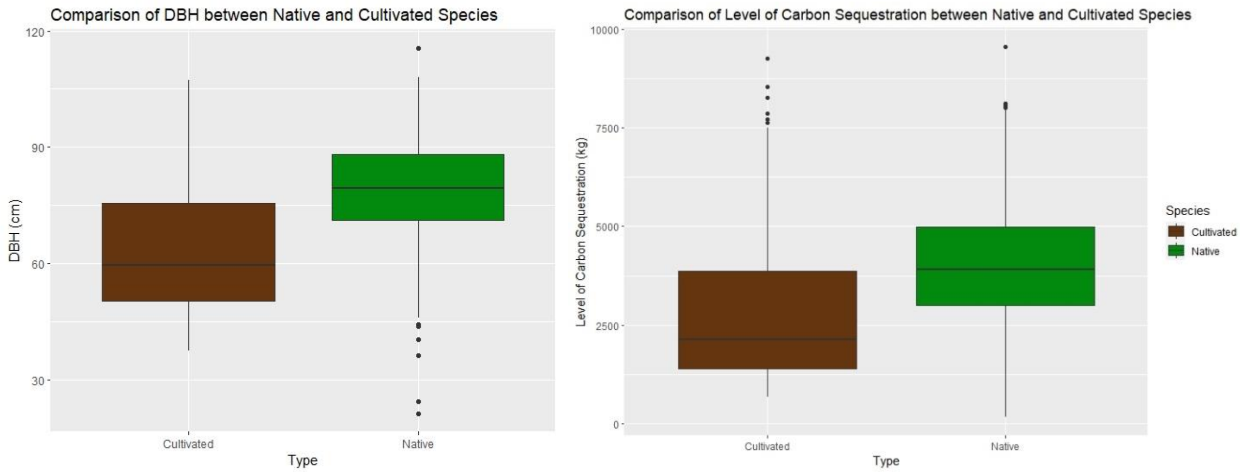


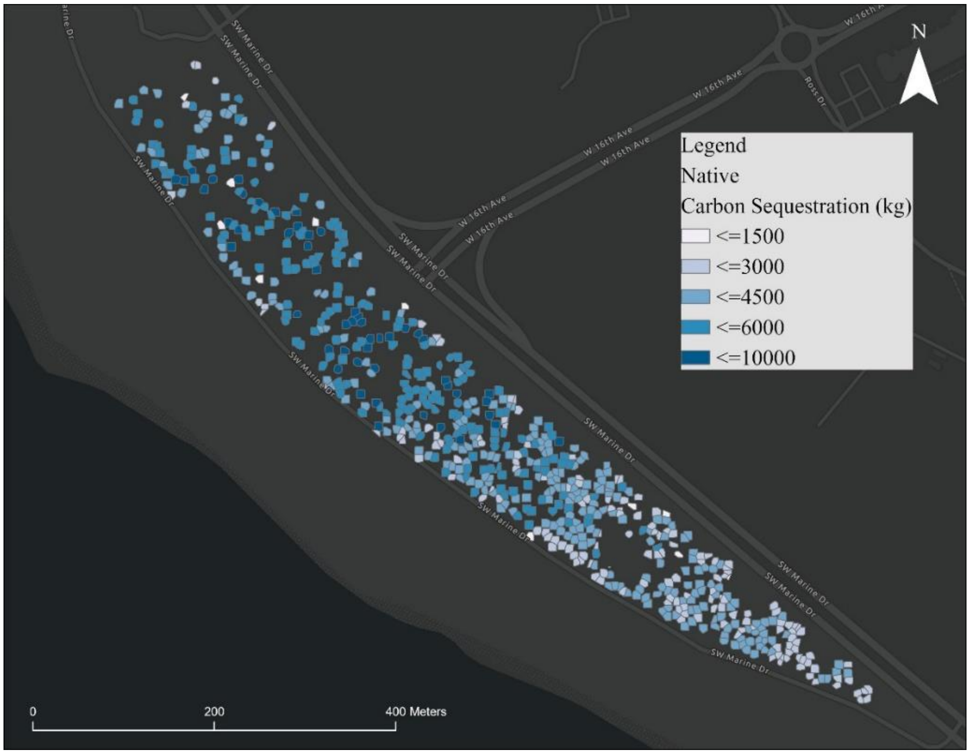
Figure 6: a) DBH and b) Level of Above-ground Carbon Sequestration of Native and Cultivated trees. In general, the average DBH and level of carbon sequestration level of native trees was higher than that of cultivated trees by obtaining a larger value in the upper, quartile mean and lower quartile.

Table 5: A Summary Table between the Level of Above-ground Carbon Sequestration of Native and Cultivated Trees. The values of cultivated trees varied to a larger extent than that of native trees by obtaining a higher standard deviation.

	Native	**Cultivated**
Total	3,071,931.8	
Total (by species)	2,688,519	383,412.8
Total Percentage	87.5 %	12.5%
Mean	4006.7	2904.6
Standard Deviation	1409.0	2078.7

In terms of geographical distribution, a majority of the native trees located in the northwestern and the centre of the garden had a level of between 6000 kg to 10000 kg, which was higher than those located in the southeastern part of the garden with a level of around 3000 kg to 6000 kg (figure 7a). Most of the cultivated trees located in the northwestern region obtained a level of above-ground carbon sequestration below 3000 kg (figure 7b).

By conducting an unpaired two-samples T test, it was concluded that the above-ground carbon sequestration level of native trees was significantly different from that of cultivated trees since their differences in mean did not equal to zero (t = 5.83, df = 155.5, $p = 3.045 \times 10^{-7}$) after rejection of the null hypothesis as stated in the methodology section.



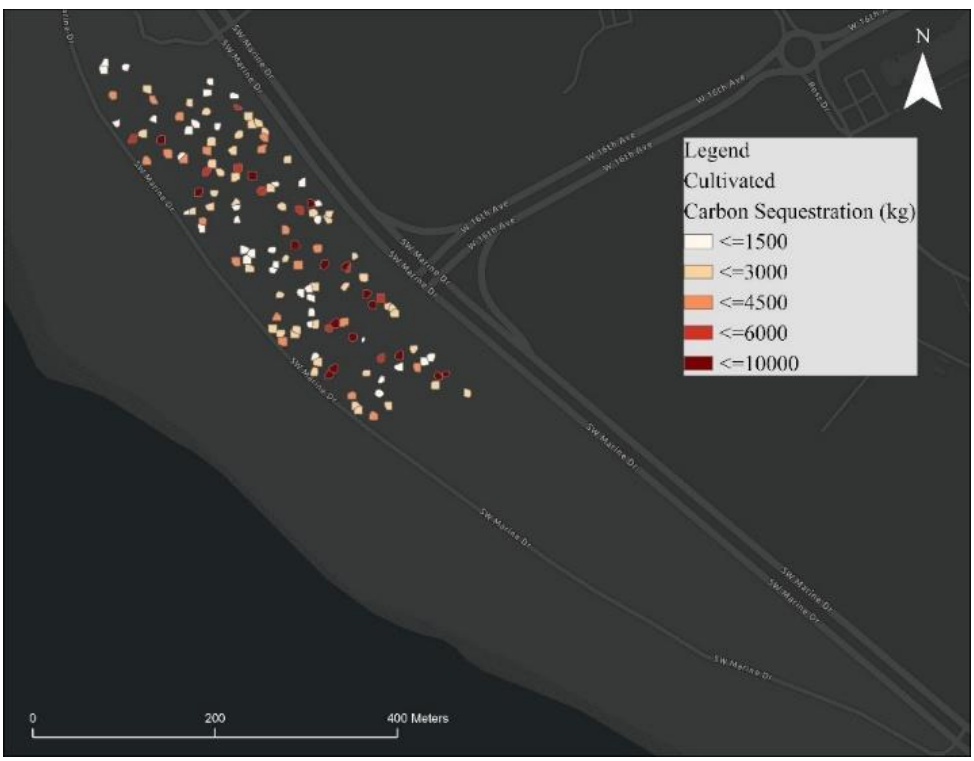


Figure 7: Above-ground Carbon Sequestration Level of a) Native Trees and b) Cultivated Trees. The above-ground carbon sequestration level of native trees was generally higher in the northwestern part than the southeastern part of the garden. The maps were projected in NAD 1983 UTM Zone 10N on a base map from ESRI.

6. Discussion

There were several significant results highlighted. In terms of tree features, there were significantly more georeferenced native trees than cultivated ones, yet the latter had a larger variety of species. While native trees were generally taller ($p = 2.2 \times 10^{-16}$), the average crown size of both types of trees were similar ($p = 0.696$). The average level of native trees was higher than that cultivated trees regarding DBH ($p = 2.2 \times 10^{-16}$) and level of above-ground carbon sequestration ($p = 3.045 \times 10^{-7}$). In terms of geographical distribution of trees, the trees with higher level of above-ground carbon sequestration and DBH were mainly located in the northwestern part of the garden, meanwhile the tree density was higher in the southeastern part of the Asian Garden. Therefore, the respective ecosystem services from these results would be discussed in this section.

6.1. Similar Effects in Regulatory Services between Native and Cultivated trees

Given the average crown size of both native and cultivated trees were similar ($p = 0.696$), and the average tree height of native trees were larger than cultivated trees ($p = 2.2 \times 10^{-16}$), cultivated trees had a higher canopy area to tree height ratio than native ones. A possible reason could be the differences in characteristics between Asian and North American tree species. Since cultivated trees consisted of over 100 species from Asia, the relationship between canopy area and tree height was less consistent. For instance, the calculated canopy area of Campbell's magnolia and Père David maples were around 80 m^2, but the average height of the former was lower than the latter by 10 m. In contrast, Marks and Muller-Landau (2016) suggested that the maximum tree height and canopy area had a consistent linear relationship among species in North American.

Consequently, when projecting the ecosystem services related to canopy area, both native and cultivated trees provided similar level of services. Nowak and Heisler (2010) indicated that a larger canopy area was more effective in lowering the surface temperature since the canopy cover could reduce the amount of solar short-wave radiation reaching the ground and thus the long-wave radiation emitted from the ground. Furthermore, since the temperature beneath the canopy cover was lower, it resulted in a higher pressure when compared to surrounding area, and creating wind with cooling effects flowing inside the area under canopy cover (Nowak & Heisler, 2010). Apart from temperature cooling, a larger canopy area supported a higher level of air purification since it contained more leaves to carry out photosynthesis and absorb carbon dioxide (Cabaraban et al., 2013). A larger canopy area could also intercept airborne particles, deposit nitrogen dioxide and reduce the emission of volatile organic compounds (Cabaraban et al., 2013). Therefore, in terms of regulatory ecosystem services, both native and cultivated trees had similar effect in temperature cooling and air purification due to similar canopy area.

6.2. Higher Level of Above-ground Carbon Sequestration Facilitates Higher Amount of Soil Carbon

In terms of supporting ecosystem services, results of this study indicated that native trees had a significantly larger contribution in the aspect of above-ground carbon sequestration ($p = 3.045 \times 10^{-7}$). To further investigate the contribution of the amount of carbon storage by native and cultivated trees, a raster layer of carbon soil processed by Welham and Seely (2019) from

3GreenTree Ecosystem Services was joined with the layer of above-ground carbon sequestration level. The mean carbon soil under native trees was 124.48 tC/ha, which was slightly higher than that under cultivated trees of 122.09 tc/ha. Furthermore, Pearson's correlation test was conducted with a score of 0.22. It represented that there was a weak but positive correlation between above-ground carbon sequestration and the amount of carbon soil, which showed similar results as in the research by Cruz-Amo *et al.* (2020). Since Lawrence *et al.* (2021) suggested that the amount of soil carbon was essential in controlling soil moisture alongside and stabilizing other soil minerals, higher soil carbon could lead to better long-term soil development by accumulating moisture and minerals such as Iron and Aluminium. Consequently, it was possible that native trees were more effective in soil formation.

6.3. Native and Cultivated Trees Provide a High Level of Supporting and Cultural Ecosystem Services

Apart from directly comparing the ecosystem services provided individually between native and cultivated trees, it was vital to understand the services provided by geographical distribution of native and cultivated trees as a whole. Therefore, the species diversity index of different areas of the garden were calculated to observe the area composition and species richness. The range of index lies within 1-3, where a larger index indicates a higher species diversity. By referring to the Shannon Index (1948), the equation is shown as follow:

$$(7) \ldots\ H = -\sum[(p_i) \times \log(p_i)]$$

where H is the species diversity index, p_i is the proportion of individuals of i^{th} species in the whole garden.

It showed that the index of the whole garden is 2.66, which reflected that the Asian Garden showed high diversity. A large variety of tree species also contributed in cultural ecosystem services by providing a higher value of education and tourism, where visitors could know more types of different species and understand their relative importance in the ecosystem. However, when dividing the garden into 4 regions, the index varied across the distribution of cultivated trees. The index of the two regions in the northwestern part of the garden were 3.51 and 2.64, which were significantly higher than that in the southeastern part of the garden with 1.74 and 1.39. Such results aligned with the geographical distribution of trees as aforementioned, where cultivated trees were mostly located in the area of northwestern part. Such unequal distribution of trees could be further addressed and discussed in the future growth of the garden.

6.4. Future Planning and Research Directions of the Garden

Given the above findings and discussions that answered all the objectives of this research, there are several planning directions in the future development and management of the Asian Garden. First, UBCBG could introduce more cultivated species with higher canopy area to tree height ratio in the future that is more efficient in providing regulatory ecosystem services. Yet, conifers may be more preferred as these species can continue to provide service in air purification in the winter.

Furthermore, the location of planting new cultivated trees could be examined and planned since the crown area would increase when growing up and obstruct the growth of nearby trees.

Apart from tree planting, the garden should also carefully evaluate the number of native trees that should be removed for the sake of planting more cultivated species since native trees have more significant impacts in above-ground carbon sequestration level, amount of carbon soil and soil formation. Considering the spatial planning of the garden in the future, the garden could consider planting more cultivated species in the southeastern region in hopes of balancing the diversity of tree species within the Asian Garden in spatial context, which can further increase the biodiversity and education value of the garden.

For future research directions, the garden could further investigate the relationship between above-ground carbon sequestration of trees and ecosystem services, by using quantitative methods and statistical models. This approach could deliver more precise and solid results over the benefits brought by trees with higher above-ground carbon sequestration level. Moreover, the impacts of existing geographical distribution of trees towards the habitat of other organisms could be examined. For instance, a spatial correlation analysis could be conducted to observe whether such unequal distribution of trees affects the distribution of insects' habitat. Such analysis could provide insights to the complexity of UBCBG's ecosystem and future planning directions on whether the garden wants a high species diversity.

6.5. Limitations and Suggestions

There were several limitations of this research. Considering the data of field-measured trees, some of the recent plantings, which were mostly cultivated trees, in the southeastern part of the Asian Garden were not georeferenced and these were not included in this study. Furthermore, more than 250 of the field-measured trees were unable to be classified into native and cultivated. Therefore, there was a significant underestimation of the level of above-ground carbon sequestration, as well as a less inaccurate comparison between native and cultivated trees. To improve the data quality and management, the garden should complete a more detailed survey of the recently-planted trees in the garden by collecting the geographic coordinates and the basic attributes of the trees such as taxon and date of planting, and thus add the information into the existing collections database. The garden should also regularly update the collections database to ensure the accuracy of the information of individual trees that were surveyed in the past few years.

The distribution of trees in the garden was another concern. Since the density of trees in the southeastern part was high, the canopy cover of shorter trees was covered by taller trees, where they were filtered away for further estimation of level of above-ground carbon sequestration. Such underestimated the level of above-ground carbon sequestration of native trees. To avoid the problem, since the forest structure of the garden is simple, ground LiDAR data could be used instead of airborne LiDAR to obtain better tree segmentation results.

In conclusion, this study estimated that the average level of above-ground carbon sequestration level of native trees was higher than cultivated trees in the Asian Garden of UBCBG, provided with the limitations of over-segmentation of trees using LiDAR and negligence of recently-planted trees in the garden. Both native and cultivated trees played important roles in the provision of ecosystem services such as local temperature regulation, air purification, biodiversity and education. Therefore, this study suggested that the removal of native trees, the planting location of cultivated trees, and the importance of existing geographical distribution of native and cultivated trees in the garden should be carefully evaluated in the future.

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