Evaluating the Above-Ground Carbon Storage of Urban Trees on University of British Columbia Vancouver Campus

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Abstract

In response to growing concerns about the impacts of climate change and the need for sustainable urban development, urban forests have emerged as a crucial tool for mitigating climate change impacts and enhancing the quality of life in cities. Previous studies have established that urban forests provide a wide range of ecosystem services, including air purification, temperature regulation, and carbon sequestration. However, precise estimation of urban tree carbon storage remains a key challenge for effective urban forest management and planning. In this work, we expand on this body of work by investigating the carbon storage of trees on the UBC Vancouver Campus using 2018 Light Detection and Ranging (LiDAR) data sourced from the City of Vancouver. The aim was to determine the total carbon storage and the average carbon density of the campus. Tree height and structure were estimated using an existing model, which facilitated the calculation of individual tree biomass and carbon storage based on the LiDAR data. The results revealed that the UBC Vancouver Campus has a total carbon storage of 24.63 Gg and an average carbon density of 6.13 kg m^{-2}. These findings emphasize the significant role urban forests play in climate change mitigation and urban life improvement. Employing LiDAR data in conjunction with the existing model proved to be an efficient and effective method for estimating urban tree carbon storage. The results can inform urban planning and policy decisions, fostering the integration of urban forests into sustainable campus development.

Keywords: LiDAR point cloud; above-ground carbon storage, urban forest, climate change mitigation, individual tree segmentation, ecosystem services

1. Introduction

Over recent decades, climate change has emerged as a paramount global concern. Urban areas continue to expand, and it is estimated that by 2050, 68% of the world's population will inhabit urban regions (UN DESA, 2018). While urban areas serve as vital human habitats, they also contribute significantly to greenhouse gas emissions (Russo et al., 2014). In fact, 70% of global carbon emissions originate from urban regions, and urbanization is projected to further increase this percentage (Schreyer et al., 2014). In Canada, urban areas only account for approximately 0.25% of the nation's landmass, a stark contrast to many European countries and the United States (Statistics Canada, 2009). Despite their limited landmass, Canada is a highly urbanized country with over 80% of its population residing in cities (Statista, 2022). A majority of urban carbon dioxide emissions result from fossil fuel-dependent activities such as industrial production, transportation, heating, and cement production, as well as carbon dioxide emissions caused by disruptions and modifications to soils and vegetation due to urbanization (Strohbach & Haase, 2012). Given that cities are significant carbon emitters, urban vegetation possesses the potential to store vast amounts of atmospheric carbon dioxide (Gülçin & Konijnendijk, 2021).

Urban forests, defined as forests or clusters of trees growing within cities, towns, or suburbs, provide numerous economic and ecological benefits as integral components of the landscape (Zhang et al., 2015; Pasher et al., 2014). These forests not only influence the living environment of millions of Canadians but also support wildlife biodiversity by offering diverse habitats and resources (Pasher et al., 2014). Carbon sequestration, a critical environmental service, enables urban trees to act as carbon sinks, offsetting urban carbon dioxide emissions (Strohbach & Haase, 2012; Pasher et al., 2014). Prior research has demonstrated that urban trees reduce air pollution by absorbing atmospheric carbon dioxide through photosynthesis and storing excess carbon as biomass in their roots, stems, and branches (Pasher et al., 2014; Russo et al., 2014; Zhang et al., 2015). The annual rate of carbon sequestration during photosynthesis is proportional to a tree's biomass, which is influenced by factors such as species composition, age, and growth conditions, which may also differ between cities (Strohbach & Haase, 2012; Pasher et al., 2014). Previous studies across various countries have shown that urban trees capture a substantial amount of carbon. Human-induced changes and patterns in urban forests, coupled with the numerous biophysical forces at work, generate highly distinct patterns of carbon sequestration (Strohbach & Haase, 2012). Consequently, quantifying carbon storage in urban environments is crucial for enhancing ecosystem services-based urban landscape design and management (Gülçin & Konijnendijk, 2021).

Estimating carbon storage from above-ground biomass is feasible, but evaluating urban tree carbon stocks at the individual tree level is particularly relevant due to the diverse shapes and arrangements of trees found in urban settings (Schreyer et al., 2014; Gülçin & Konijnendijk, 2021). Several methods have been explored to identify individual trees, with many relying on canopy height models (CHM) derived from light detection and ranging (LiDAR) data, which are raster surfaces interpolated from LiDAR points that measure tree canopy height (Zhang et al., 2015).

The University of British Columbia (UBC) Vancouver campus comprises more than 50,000 students, faculty, and residents, establishing itself as a substantial urban area within the greater Vancouver city (Gülçin & van den Bosch, 2021). This study aims to augment the understanding of ecosystem services provided by UBC campus natural assets through an analysis of above-ground carbon storage within the campus ecosystem. Although previous MGEM SEEDS projects have assessed carbon storage in the Asian Garden of The University of British Columbia Botanical Garden (UBCBG), a knowledge gap persists regarding the above-ground tree carbon storage throughout the entire campus. To address this gap, this project's primary objectives are: (1) Estimating the above-ground carbon storage of UBC campus trees, (2) Mapping the tree carbon storage across the UBC campus, and (3) Providing policy recommendations in alignment with the UBC Climate Action Plan.

2. Study Area and Data Description

2.1 Study Area

The University of British Columbia's Vancouver campus (Figure 1.) is situated at the western extremity of the Point Grey Peninsula in Vancouver, British Columbia, Canada. Covering an area of 4.02 km², the campus is bisected by the 763-hectare Pacific Spirit Regional Park. The University Endowment Lands (UEL), governed by the province, is located directly to the east of the campus (UBC Campus & Community Planning, 2020). Initially established within a clearing of coniferous woodland, UBC has since 1925 planted an extensive array of trees on its campus (Sutherland, 2017). Approximately 8,000 planted trees and over 10,000 native trees exist in their natural habitats on the campus, with the dominant species being western redcedar (Thuja plicata), pin oak (Quercus palustris), and red maple (Acer rubrum) (UBC Campus & Community Planning, n.d.).

The campus is positioned within the Moist Maritime Subzone of the Coastal Douglas-Fir bio-geoclimatic zone, which is conducive to temperate mixed woods (BEC WEB, n.d.). In terms of landscape and climate, the property exhibits gentle terrain, with an average elevation of 87 meters above sea level (Government of Canada, 2022). The region experiences dry and warm summers, and moderate, rainy winters, lying within the rain shadow of Vancouver Island. The area has an average annual temperature of 11°C and receives 146 cm of precipitation (Government of Canada, 2022).

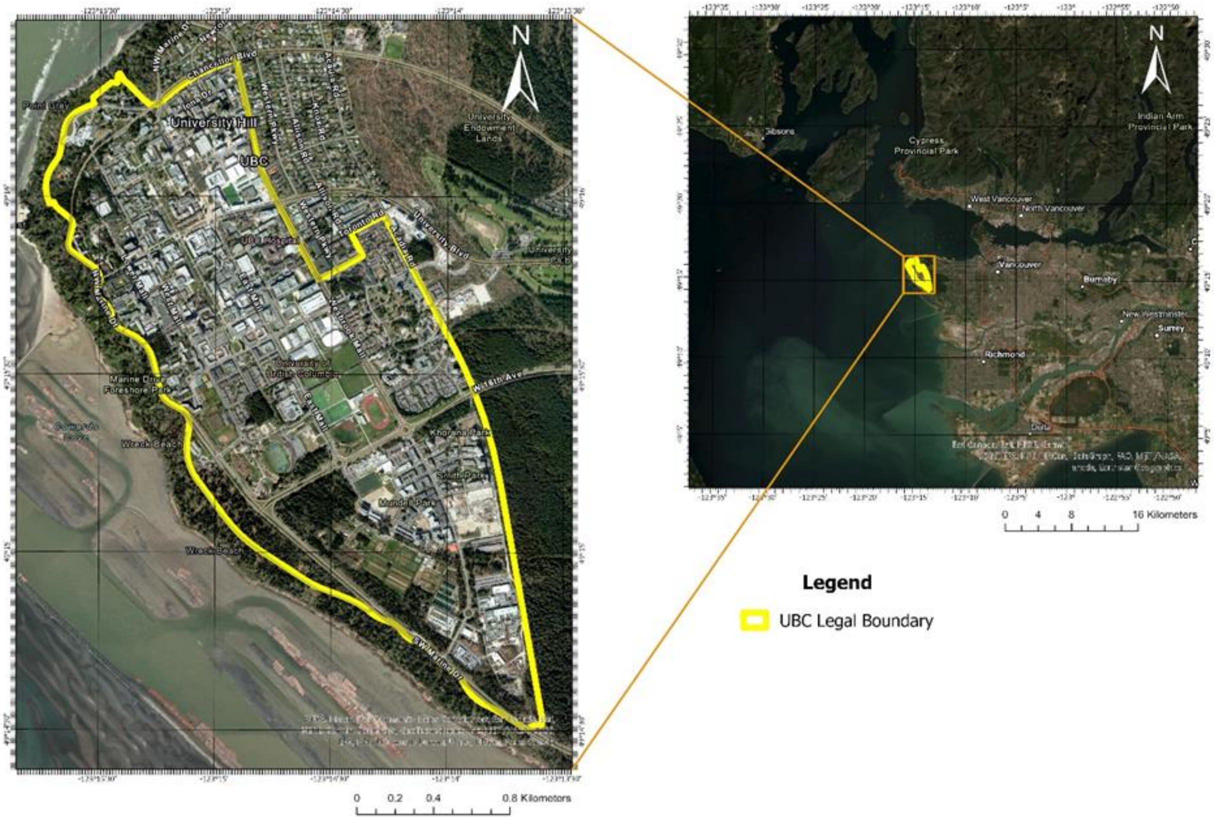


Figure 1. Map of the University of British Columbia Vancouver campus and its location in Vancouver, BC, Canada. The UBC legal boundary (49.273073-49.241704 °N and 123.262219-123.226483 °W) is shown on the map using the yellow solid line, data retrieved from UBCGeodata (2016). Base imagery is projected on NAD 1983 UTM 10N.

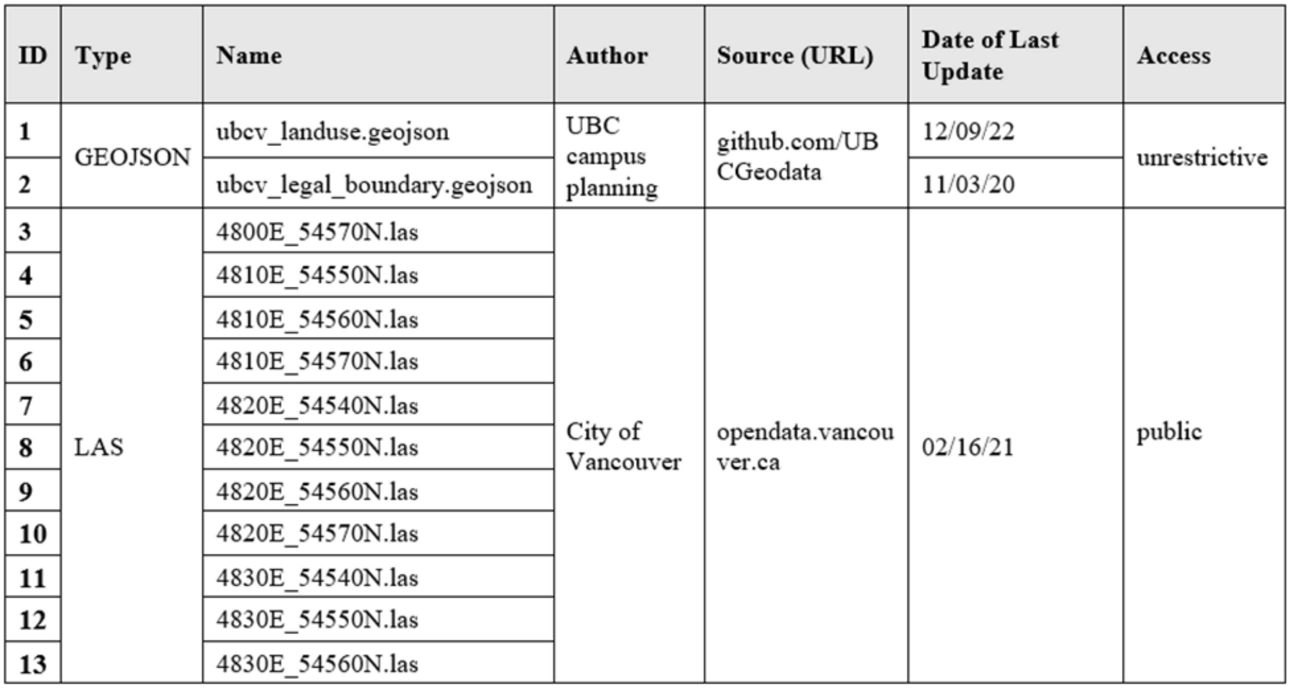
2.2 Data Description

Table 1. shows a summary of all data used in this study. The UBC Vancouver Campus LiDAR point cloud was used to detect individual trees and estimate tree carbon storage. The UBC Vancouver Campus legal boundary and UBC Vancouver Campus land use geospatial data were used to ensure the study area and calculate carbon storage for each land use.

The Lidar point cloud data was obtained from the Open Data Portal of the City of Vancouver, originally released on November 20, 2019 and was owned and published by City of Vancouver (City of Vancouver, 2019). The LiDAR data was acquired on August 27th and 28th, 2018, with an average density of 30 points/m^2. Eleven LiDAR data tiles (1km × 1km) were used in this study. The data accuracy was provided by the author, the data was positioned with a horizontal accuracy of 0.36 m and a vertical accuracy of 0.18 m under a 95% confidence interval (City of Vancouver, 2019). The map projection was NAD1983 UTM 10N (Central Meridian 123 West). The City of Vancouver classified the point data as unclassified, bare-earth and low grass, low vegetation (height <2m), high vegetation (height >2m), water, buildings, other, and noise (City of Vancouver, 2019).

The legal boundary and land-use planning map of the UBC Vancouver Campus were GEOJSON data obtained from UBC open geospatial data on GitHub (UBCGeodata, 2016). The dataset was projected in the WGS84. The legal boundary of the UBC Vancouver Campus was used to obtain the polygon of the study area. The land-use map of the UBC Vancouver Campus was used to calculate the tree carbon storage for each land-use type.

Table 1. Summary of data used in this study.



ID	Type	Name	Author	Source (URL)	Date of Last Update	Access
1	GEOJSON	ubcv_landuse.geojson	UBC campus planning	github.com/UBCGeodata	12/09/22	unrestrictive
2		ubcv_legal_boundary.geojson			11/03/20	
3	LAS	4800E_54570N.las	City of Vancouver	opendata.vancouver.ca	02/16/21	public
4		4810E_54550N.las				
5		4810E_54560N.las				
6		4810E_54570N.las				
7		4820E_54540N.las				
8		4820E_54550N.las				
9		4820E_54560N.las				
10		4820E_54570N.las				
11		4830E_54540N.las				
12		4830E_54550N.las				
13		4830E_54560N.las				

3. Methods

3.1 Overview

In order to estimate the above-ground carbon storage and provide a comprehensive analysis of the University of British Columbia Vancouver campus's ecosystem services, we utilized LiDAR data and adopted a five-stage analytical process. The analysis comprised the following stages: (1) data pre-processing, including filtering, (2) generation of a digital terrain model (DTM) and height normalization, (3) creation and smoothing of a canopy height model (CHM), (4) individual tree detection (ITD) and individual tree segmentation (ITS), and (5) estimation of diameter at breast height (DBH) and above-ground carbon storage. The "lidR" package, designed for the R programming environment, was employed to perform the ITD and ITS algorithms (Roussel et al., 2022). The overall workflow is illustrated in Figure 2.

3.2 Data Pre-Processing

The first step of the analysis involved pre-processing and filtering the LiDAR data extracted from the point cloud. The LiDAR data tiles were clipped with the legal boundary of the UBC Vancouver Campus, given the difference in spatial coverage from the study area. The ground points and high vegetation class in the LiDAR data, which had already been classified, were filtered to exclude non-forested areas and buildings. While the LiDAR data has already been cleaned by the owner (City of Vancouver, 2019), high-level outliers or noise persisted, caused by flying objects such as birds or aircraft. To address this issue, a noise filter function was developed and applied to the filtered LiDAR data. This method employed an area-based approach to identify outliers by computing the 95th percentile of height in 10 x 10-m pixels and subsequently removing the points that exceeded this threshold in each pixel.

3.3 Digital Terrain Model (DTM) and Height Normalization

To create the DTM, I applied the Inverse Distance Weighting (IDW) method. Interpolation was done using a k-nearest neighbor (KNN) approach with IDW, specifically the knnidw algorithm. IDW is a simple and widely used method that provides a compromise between the Triangular Irregular Network (TIN) and Kriging methods.

The primary purpose of the DTM was to facilitate terrain normalization, which is necessary to eliminate the effects of terrain on above-ground measurements. This allows for comparison of vegetation heights above ground and facilitates analyses across acquisition areas (Roussel et al., 2022). In this study, a hybrid method of DTM normalization and point cloud normalization was applied. The interpolation of the ground points was computed on-the-fly, and the exact elevation of each point was estimated (Roussel et al., 2022).

3.4 Canopy Height Model (CHM)

The Canopy Height Model (CHM) was derived from the LiDAR point cloud by subtracting the Digital Terrain Model (DTM) from the Digital Surface Model (DSM) (Hanssen et al., 2021). The CHM provides valuable information on vegetation height and structure, which can be used to extract tree parameters and monitor forest dynamics (Gülçin & Konijnendijk, 2021).

To generate the CHM, a point-to-raster algorithm was used, which involves assigning the elevation of the highest point to each grid cell of a raster layer with a defined resolution (Roussel et al., 2022). In this study, a spatial resolution of 1 m was chosen to balance the level of detail and the data size. However, due to the uneven distribution of LiDAR points, some pixels may remain empty, especially in areas with sparse vegetation. To fill the gaps and simulate the circular shape of the laser footprint, a subcircle was created around each point in the point cloud, and the radius was set to 0.2 m (Roussel et al., 2022).

To improve the accuracy of individual tree detection, a 3 × 3 median filter was applied to the CHM to remove nearby local maxima caused by tree branches and other non-canopy features

(Gülçin & Konijnendijk, 2021). This filter smooths the CHM while preserving the main features, such as the crown size and shape. The resulting CHM can be used for a variety of forest analysis applications, including tree segmentation, biomass estimation, and habitat modeling.

3.5 Individual Tree Detection and Segmentation

The Local Maximum Filter (LMF) can detect individual tree tops from a dataset by applying it to a point cloud without using a raster. The LMF is included in the "lidR" package (Roussel et al., 2022). Alternatively, the detection procedure can be applied to a Canopy Height Model (CHM) to speed up the process, as there are fewer data to process. However, the output is more complex because it depends on how the CHM was constructed (Roussel et al., 2022). A constant 5 × 5 window size was chosen (Gülçin & Konijnendijk, 2021) and applied to the CHM using different algorithms and smoothing steps. The smoothed CHM with a resolution of 1 m, derived from the point-to-raster algorithm, was chosen based on a better result.

The "lidR" package provides several algorithms for tree segmentation, including Watershed segmentation (Pau et al., 2010), the top-to-bottom region growing method by Li et al. (2012), the Dalponte algorithm by Dalponte and Coomes (2016), and Voronoi tessellation by Silva et al. (2016). The Dalponte algorithm was chosen due to its highest accuracy (F score) in a previous study in a similar study area (Gülçin & Konijnendijk, 2021). The Dalponte algorithm is a tree-centric approach that identifies individual tree tops and crowns from point cloud data using the growing region technique (Dalponte & Coomes, 2016). This algorithm was applied to segment individual trees. After segmentation, the "crown_metrics" function was applied to the LiDAR data to delineate the crown shapes and calculate the area of the concave hulls.

3.6 DBH and Carbon Models

The Diameter at Breast Height (DBH) is a widely used variable in urban forest studies due to its strong correlation with Tree Height (TH) and crown metrics such as Crown Area (CA) (Morgenroth et al., 2020; Gülçin & Konijnendijk, 2021). Using the CA and maximum TH obtained from crowns delineation in previous step, we can then estimate the DBH. In this study, we used the DBH estimation model presented in Equation (1), which has been adopted and proved acceptable in other previous studies (Schreyer et al., 2014; Gülçin & Konijnendijk, 2021).

$$DBH = b1 \times ((TH - 1.3)^{b2}) \times (CA^{b3}), \tag{1}$$

where DBH is our estimated DBH (cm), TH obtained from LiDAR data (m), CA is the crown area obtained from LiDAR data (m^2), b1, b2, and b3 are estimated parameters.

The parameter estimates given by Gülçin and Konijnendijk (2021) (b1 = 6.6597, b2 = 0.6145, b3 = 0.0817) were used in this study based on the similarity of study area. To improve accuracy, we filtered out trees with a height of less than 4 m and a crown area less than 12 m^2.

Using the estimated DBH, the above-ground carbon (C_{ag}) was estimated using an exisiting biomass model and with the assumption that carbon is 50% of biomass (Schreyer et al., 2014; Morgenroth et al., 2020; Gülçin & Konijnendijk, 2021).

$$C_{ag} = (\exp\,(a + b \times \ln DBH)) \times 0.50, \tag{2}$$

where C_{ag} is the estimated tree above-ground carbon (kg), DBH is the estimated DBH (cm), a and b are estimated parameters.

Despite the fact that the parameters a and b vary between species, it is common to use only one set of estimated parameters when the study area contains a large number of species (Schreyer et al., 2014; Gülçin & Konijnendijk, 2021). We used the estimated parameters (a = -2.48, b = 2.4835) developed for mixed deciduous forests in the United States of America (USA) by Jenkins et al. (2003) since the UBC Vancouver Campus urban forest has a diverse range of tree species. Finally, we calculated the total carbon storage for the study area by summing the estimated above-ground carbon of all individual trees.

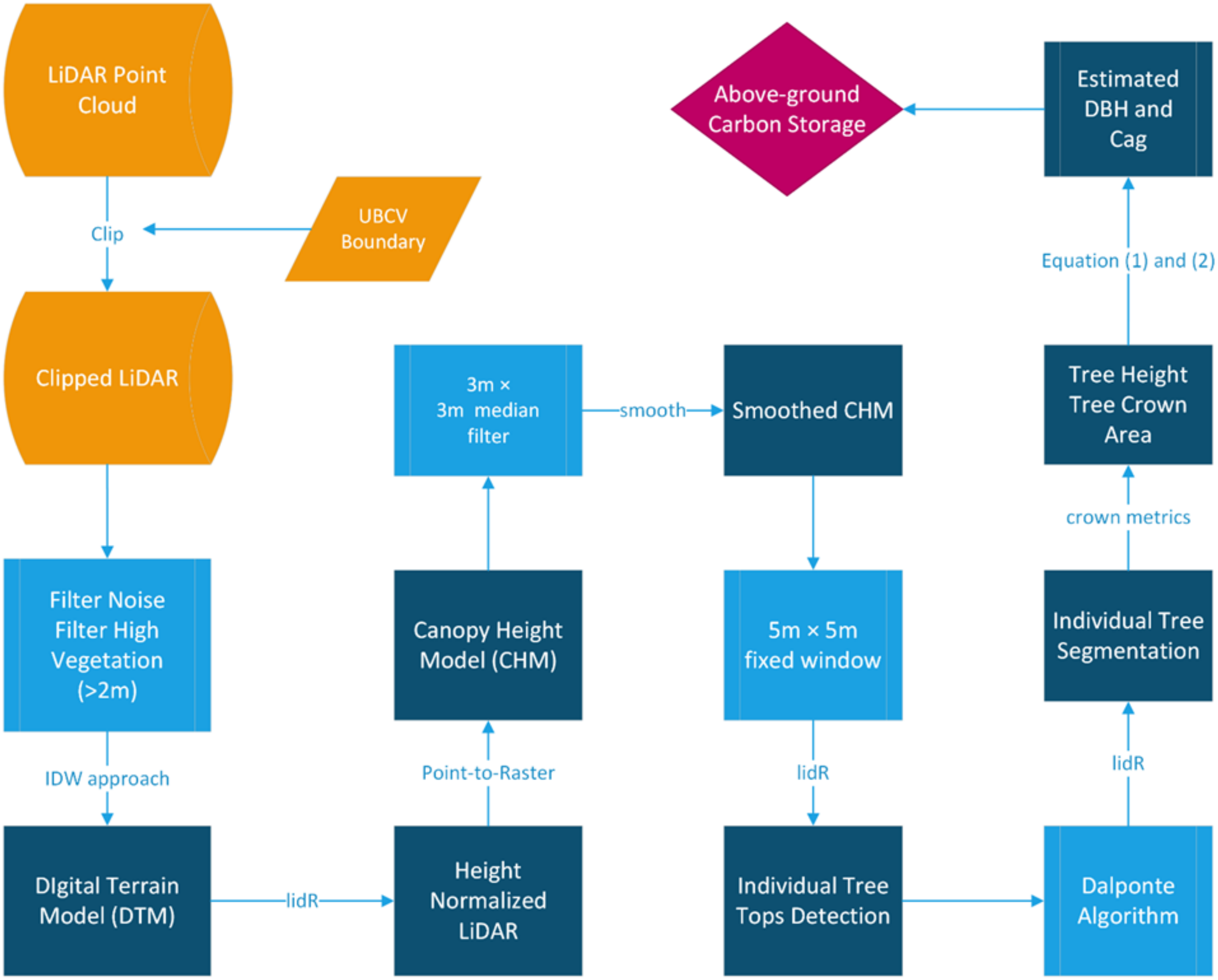


Figure 2. Workflow diagram for this study. Orange indicates the original LiDAR data, light blue indicates the important processing conditions, dark blue indicates processed results, rose color indicates the final result.

4. Results

4.1 Tree Segmentation Results

The Dalponte algorithm by Dalponte and Coomes (2016) was utilized to segment individual trees on the UBC Vancouver Campus based on LiDAR data. The resulting analysis showed that a total of 22,569 trees were detected and segmented on the campus (Figure 3).

According to UBC Campus and Community Planning, the estimated number of trees located in the urban forest of the campus is approximately 18,000. Our estimated results show a 25% higher count of trees than expected. However, it is common for tree segmentation algorithms to encounter challenges with omissions and commissions, which may lead to overestimation or underestimation of the number of trees present.

The crown delineation results (Figure 3) demonstrate that the Dalponte algorithm has a tendency to overestimate the number of trees, despite its effectiveness in segmenting individual trees. Taking into consideration the algorithm's tendency to overestimate, we still consider our estimated results to be acceptable.

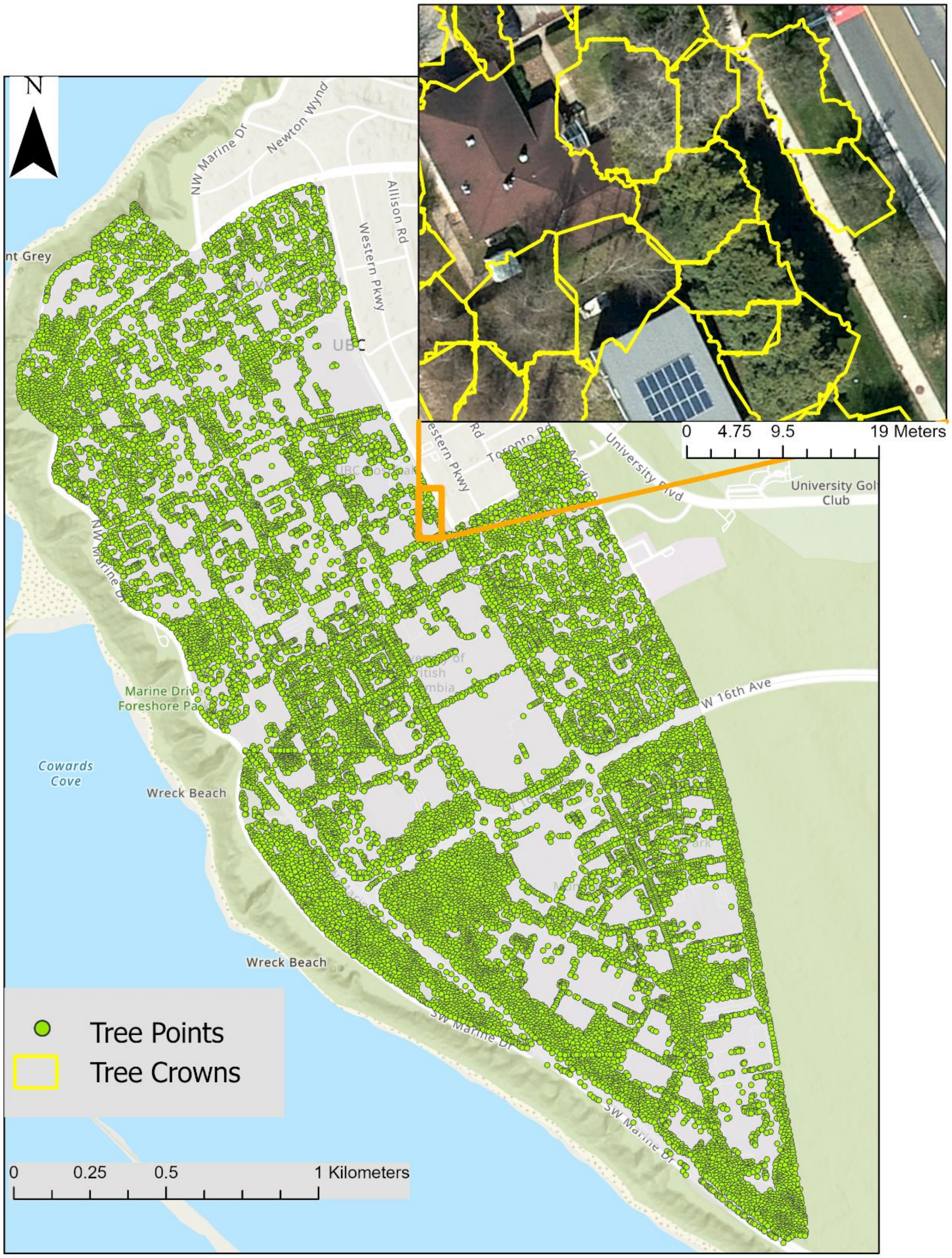


Figure 3. Individual tree segmentation (left) and a section of the crown delineation (right) results of the UBC Vancouver Campus. The overall distribution of estimated trees is visually consistent with satellite images. Crown delineation results show overestimation, where one large crown is delineated into several smaller ones. The projection coordinate system is NAD 1983 UTM Zone 10N on the basemap from ESRI.

4.2 TH and CA Structural of UBC Vancouver Campus

Structural analysis of the UBC Vancouver Campus urban forest was conducted using the tree height and crown area calculated from the segmented trees obtained from the LiDAR data. The "crown_metrics" function in the "lidR" package was used for this purpose. The results provide valuable insights into the characteristics of the urban forest.

Figure 4 presents the distribution of tree heights on the UBC Vancouver Campus. The tree heights were divided into 10 equal-value ranges, and the percentage of the number of trees in each range is presented as frequency. The analysis showed that tree heights range from 4.00 m to 62.94 m, with an average tree height of 18.93 m. About 60% of the trees are below 20 m, suggesting that the urban forest on the campus is relatively young. The number of trees shows a decreasing trend as the tree height increases.

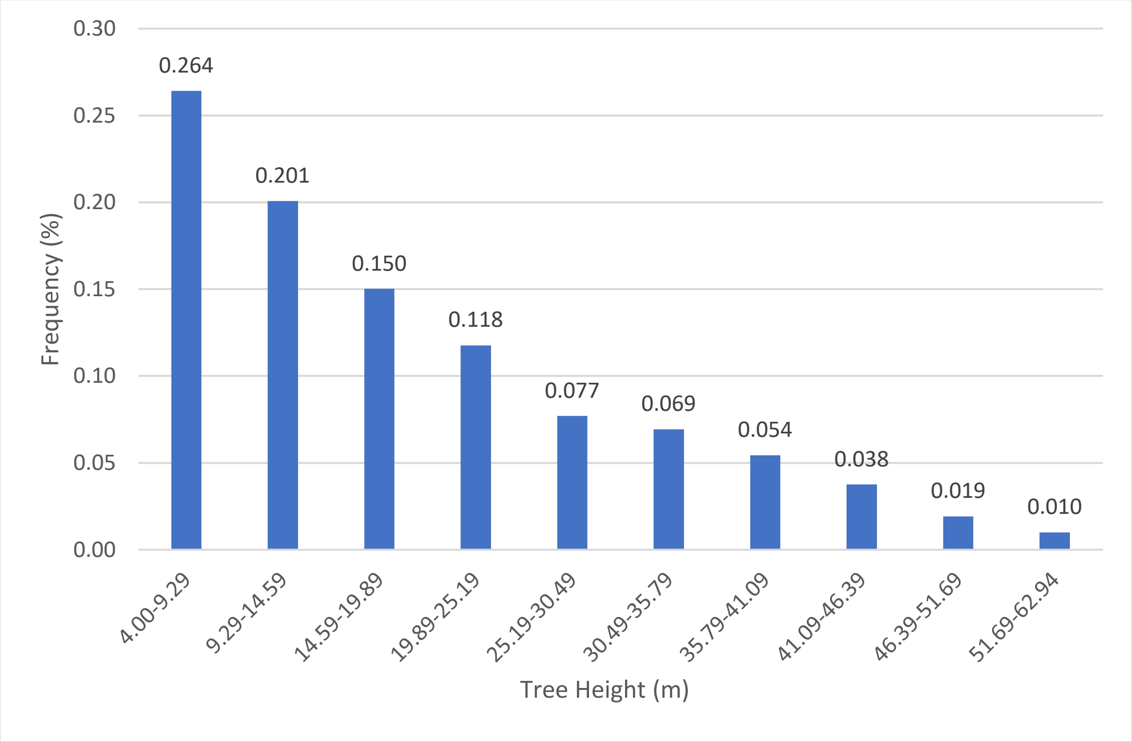


Figure 4. The distribution of tree heights on the UBC Vancouver Campus.

Figure 5 displays the distribution of tree crown areas on the UBC Vancouver Campus. The crown areas were also divided into 10 equal-value ranges, and the percentage of the number of trees in each range is presented as frequency. The analysis showed that the crown areas of segmented trees range from 12 m2 to 315.32 m2, with an average tree crown area of 76.04 m2. More than 50% of the trees have crown areas smaller than 72 m2, and the number of trees decreases as the crown area increases.

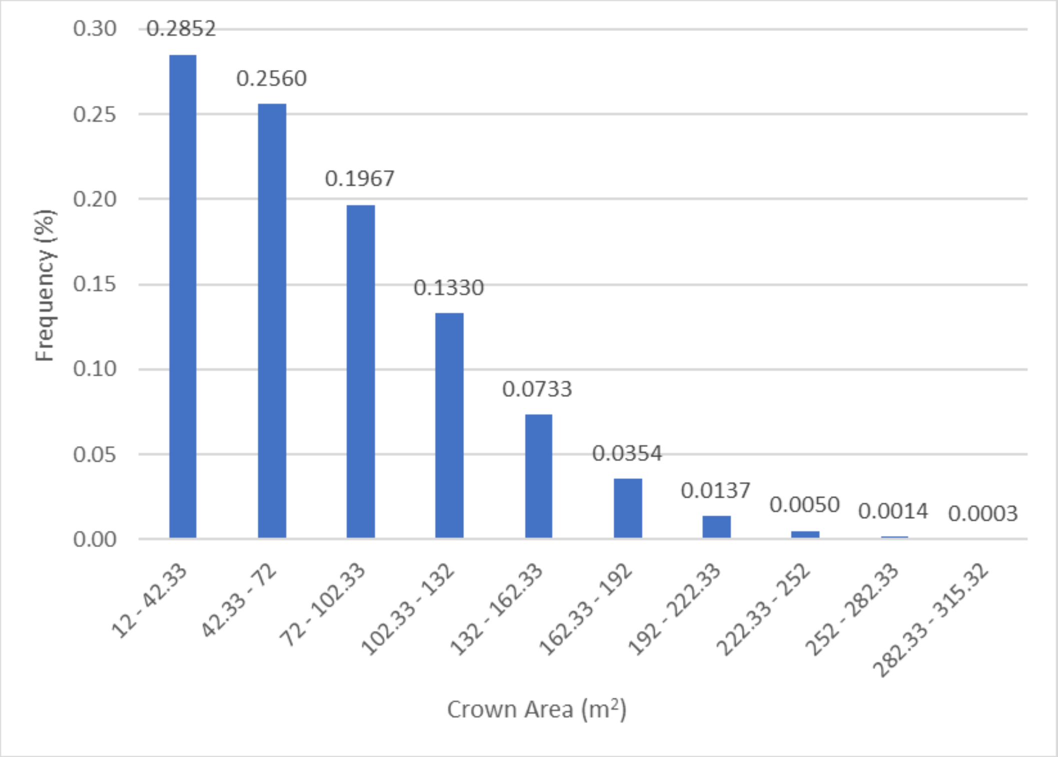


Figure 5. The distribution of tree crown area on UBC Vancouver Campus.

4.3 Above-ground Carbon of UBC Vancouver Campus

Using the TH and CA for each tree calculated using "lidR" package, the DBH values were estimated using the existing model. For each tree the DBH was then used to estimate above-ground carbon for each tree using Equation (2). Figure 6 shows the estimated above-ground carbon of each tree on the UBC Vancouver Campus. According to our results, the total urban forest carbon storage of UBC Vancouver Campus is estimated at 24.63 Gg. It is worth noting that there is a higher density of trees with high carbon storage on the southern part of the campus, where the UBC Botanical Garden and UBC Farm are located. Additionally, we observed relatively dense carbon storage at the northwestern corner of the campus, where the Nitobe Memorial Garden is located, as well as smaller areas at the middle part of the campus where the Rhododendron Wood and Totem Park Residence are situated.

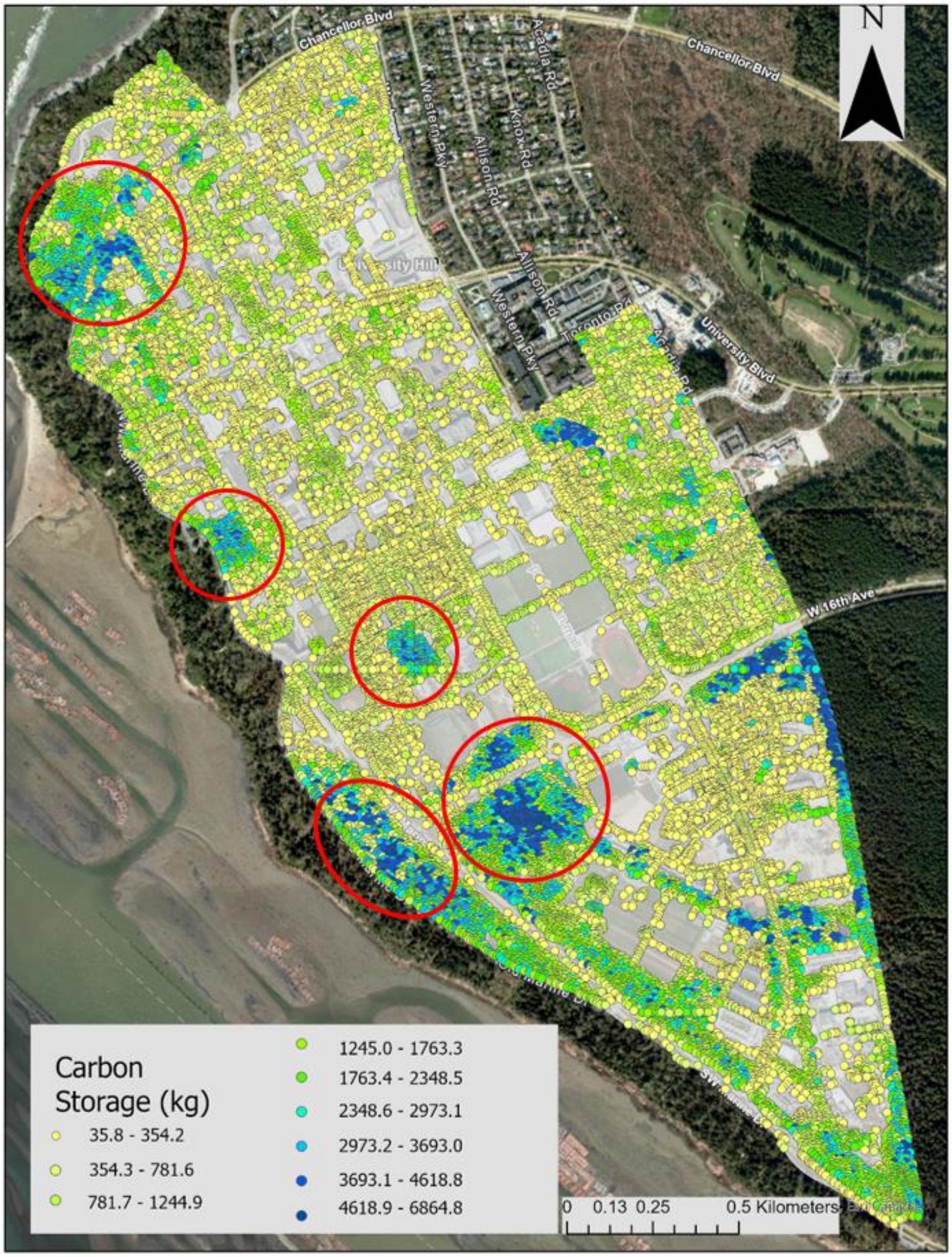


Figure 6. Above-ground Carbon Storage of Individual Trees in kg. Areas with dense trees and higher carbon storage are circled in red. The projection coordinate system is NAD 1983 UTM Zone 10N on the basemap from ESRI.

With the Cag of individual trees, we generated a kernel density map in ArcGIS, which presents above-ground carbon storage of urban forests on campus, the units is kg/m2 (Figure 7). Similar to the carbon storage map, areas with the highest carbon storage density are strongly agree with areas with dense high carbon storage trees. Based on our results, the average carbon storage of

UBC Vancouver Campus is 6.13 kg/m2. In addition, we combined our carbon storage results with the land use map of the campus. Our results indicated that academic land use had the highest amount of carbon storage of 18.57 Gg (72.4%), the neighborhood (residential) land use had 6.12 Gg of carbon storage (23.9%), and the future planned neighborhood areas had the least amount of carbon storage of 0.95 Gg (3.7%). The amounts of carbon in each land use type are in consistent with the area of land use types.

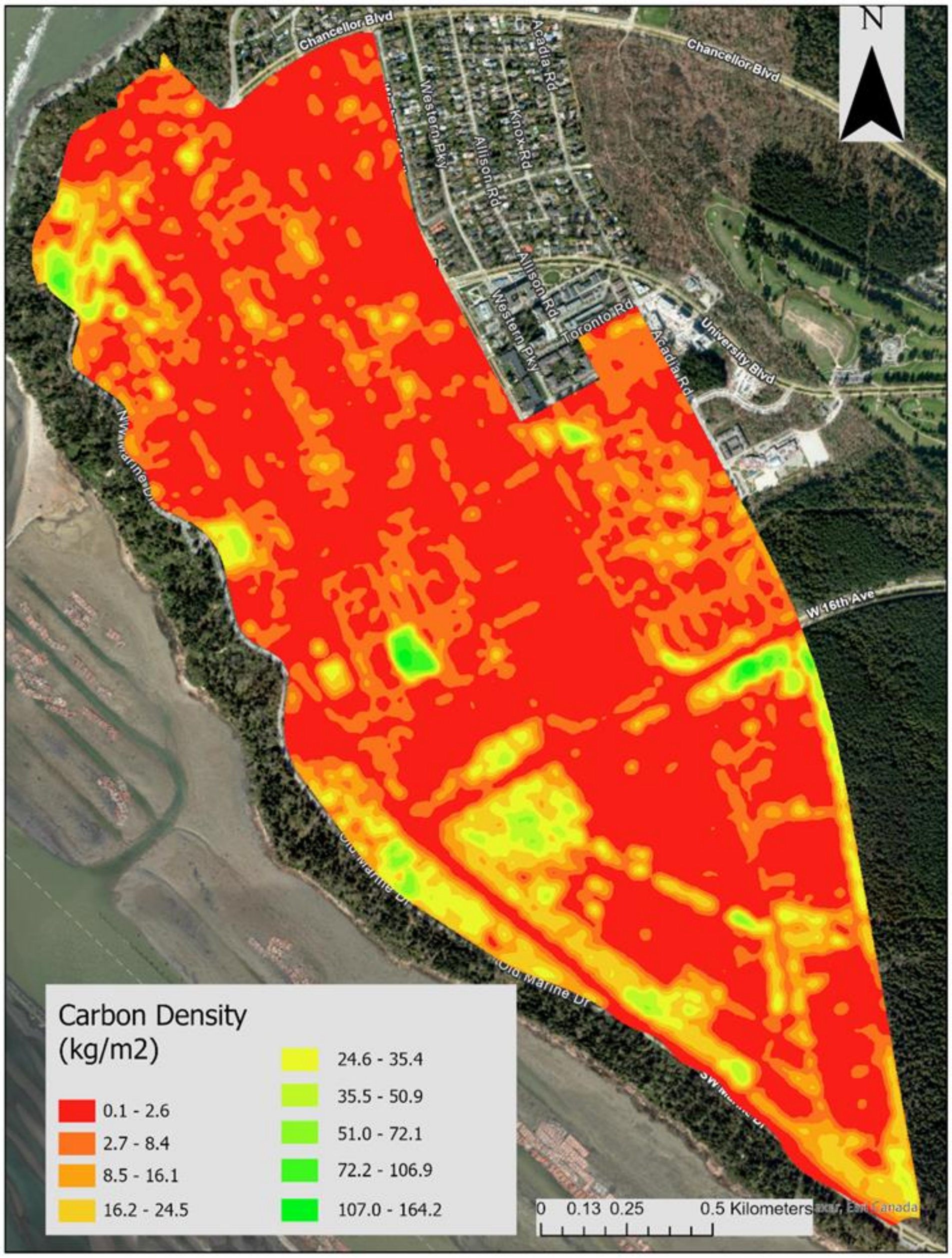


Figure 7. Kernel Density Map of Above-ground Carbon Storage of UBC Vancouver Campus. The units are kg/m2. The projection coordinate system is NAD 1983 UTM Zone 10N on the basemap from ESRI.

5. Discussion

5.1 Overview

In this study, we evaluated the above-ground carbon storage of urban forests on the UBC Vancouver Campus using LiDAR point cloud data. Our findings align with previous research that demonstrates the utility of LiDAR data for quantifying urban forest carbon storage (e.g., Strohbach & Haase, 2012; Gülçin & Konijnendijk, 2021). The total above-ground carbon storage for urban trees on campus is estimated at 24.63 Gg, with an average carbon storage of 6.13 kg/m². We generated a spatially explicit carbon storage map for the campus, with the primary objective of estimating the current carbon storage and informing future campus planning. This study contributes to the existing body of literature by providing a detailed analysis of carbon storage in a specific urban environment, showcasing the practical applicability of LiDAR technology in the field of urban ecology, and expanding upon prior research that has established the importance of urban trees in carbon sequestration.

5.2 The above-ground carbon storage in UBC Vancouver Campus

Based on land cover estimation, the average carbon storage for the UBC Vancouver Campus is 6.13 kg/m². Our results are consistent in magnitude with those from other cities in North America, Europe, and Asia, although they tend to be on the higher end of the range. The carbon storage for urban areas in the British Columbia Pacific Maritime region was reported at 2.95 kg/m² (Pasher et al., 2014). In the United States, carbon storage in cities ranged from 4.4 to 36 kg/m², with Oakland, CA (5.2 kg/m²) exhibiting the most comparable results to ours (Nowak & Crane, 2002). The average total urban tree forest density in US cities is 7.69 km/m² (Nowak et al., 2013).

In European cities, the average carbon storage was only 1.2 kg/m² in Leipzig, Germany (Strohbach & Haase, 2012), which is lower than our findings. Similarly, carbon density in Berlin, Germany was 1.37 kg/m² (Schreyer et al., 2014). Variations in carbon density between cities can be attributed to factors such as forest structure, species composition, climate zones, and methodological differences. Importantly, our study employs methods similar to those used by Strohbach & Haase (2012) and Schreyer et al. (2014), which bolsters the credibility of our results and their relevance to previous research.

Given the population density of the UBC campus, we believe the carbon density is reasonable, considering the two dense urban forests in the botanical garden and UBC farm. Furthermore, most studies of carbon storage in urban cities, including those cited above, showed a general trend of increasing carbon density with greater distance to the urban core (Strohbach & Haase, 2012; Schreyer et al., 2014). Although our study area is limited to the campus, we also identified a similar trend in Figure 7, with higher carbon density in the southern campus, further from the campus core area.

5.3 Limitations of RS approach for LiDAR-based carbon storage estimation

Remote sensing (RS) techniques provide an efficient and cost-effective means for estimating the above-ground carbon storage of urban forests using LiDAR data. Previous studies have indicated that LiDAR point clouds are valuable tools for quantifying the carbon storage of urban forests (Gülçin & Konijnendijk, 2021). However, it is crucial to recognize the challenges in detecting individual trees in LiDAR-based studies using RS techniques, as well as the potential errors inherent in this approach. For instance, generating a canopy height model (CHM) from LiDAR data is a simple and direct process, but errors arising in canopy cover results must be taken into account (Kelly et al., 2017; Gülçin & Konijnendijk, 2021). The complex shapes of tree crowns often lead to errors in individual tree segmentation outcomes (Gülçin & Konijnendijk, 2021). Although numerous segmentation algorithms have been developed and tested for different forest types, none are entirely free from potential error sources. In this study, we applied two distinct algorithms (Dalponte and Silva) to our data and selected the results generated by the Dalponte algorithm based on visual comparison. However, segmentation errors are still present in our findings, with some trees being missed or omitted during the tree top removal process. Additionally, large crowns were sometimes classified as multiple smaller trees, with branches identified as tree tops, likely contributing to the overestimation in our results (Zhang et al., 2015; Gülçin & Konijnendijk, 2021).

Furthermore, our method solely accounts for above-ground tree carbon, neglecting other urban tree carbon pools (e.g., below-ground carbon). This limitation makes the estimation of the carbon storage of urban forests not fully complete, as the below-ground carbon pool can make up a significant portion of a tree's total carbon storage. Another limitation in our results is tree species variation; we used the same parameters for a mixed deciduous forest to calculate above-ground carbon, but these estimated parameters can differ among tree genera and species. Consequently, future studies should incorporate tree species data in carbon storage assessments to more accurately quantify the carbon storage capacity of urban forests.

5.4 Urban Forests

Urban forests constitute vital components of urban ecosystems, offering a range of socio-economic and ecological benefits. They contribute to direct carbon storage and sequestration, as trees function as carbon sinks by fixing carbon during photosynthesis and storing it as biomass (Nowak et al., 2013). Urban forests can also influence carbon emissions in urban areas, as they release carbon back into the atmosphere upon tree death (Nowak et al., 2013). Comprehensive ecological evaluations of urban ecosystems necessitate the consideration of multiple ecosystem services, as they are interconnected to varying extents (Strohbach & Haase, 2012). To optimize planning and alleviate potential land use conflicts stemming from the complex interaction between human and urban ecosystems, the incorporation of spatially explicit information on ecosystem services could be beneficial for stakeholders and planners (Strohbach & Haase, 2012). Consequently, the maps and data on above-ground tree carbon generated from our study could contribute to broader ecological assessments.

5.5 Future Direction

Our findings can be employed to assess above-ground tree carbon storage at various scales, from campus-wide to city-wide, and to predict opportunities for creating additional green spaces on the UBC Vancouver Campus, as well as to estimate changes in carbon stocks within the community. Furthermore, the results could inform future campus planning by supplying data on carbon removal.

We recommend that future studies incorporate tree species data in carbon storage assessments to more accurately quantify the carbon storage capacity of urban forests. This would facilitate a more comprehensive evaluation of the carbon storage potential of different tree species and help identify the most effective species for carbon sequestration in urban settings.

Overall, our results suggest that the removal and planting of trees on the UBC Vancouver Campus should be carefully considered in future campus planning.

Reference

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