University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Baselining UBC Vancouver Campus Urban Forest and Land Use

Developing and Validating Up-to-date Tree Inventory and Land Classification Map of the UBC Vancouver Campus

Prepared by: Yifei (Bill) Shao

Prepared for:

Course Code: FCOR 599

University of British Columbia

Date: 23 April 2021

Project Report: Baselining UBC Vancouver Campus Urban Forest and Land Use

Developing and Validating Up-to-date Tree Inventory and Land Classification Map of the UBC Vancouver Campus

Yifei (Bill) Shao

Master of International Forestry

The University of British Columbia

Table of Contents

Abstract

As urban forest provides ecological, social, and economic values to the residents, forest inventory can monitor forest health. Based on the land classification map of UBC Vancouver Campus, UBC Campus and Community Planning Team pays attention to tree health in the public green space. Working together, the forest inventory and land classification map are the priorities of urban planning and forest health in UBC. In order to solve the gap of no current inventory and land classification map on campus, this study aimed to update the UBC tree inventory and land classification map. R algorithms extracted individual trees' parameters and LiDAR metrics using the latest UBC LiDAR data of 2018. Random forest classification was applied to determine the tree species (coniferous/deciduous) with the metrics. Four major land cover types were classified by the supervised classification scheme using the orthophoto of UBC in 2020. The major results showed that there are 14165 trees (crown diameter more than 4 m) on campus, and the height estimation by the LiDAR method had an overall accuracy of 80%. The campus's total vegetation cover was 44%, which is higher than other towns in Vancouver. Considering the campus's topography, coniferous trees on the southwest campus provided potential ecological roles of water retention. Due to the three major roads connected to campus, the northern campus undertook linking public transports. The study provided the basis for future studies of trees, vegetation, and UBC Vancouver Campus land planning.

Keywords: UBC Vancouver Campus; Tree inventory; LiDAR; Orthophoto; Random forest classifier; Supervised classification

Acknowledgement

I would like to express my sincere gratitude to the course instructor and teaching assistant Dr. Paul D. Pickell and Francois du Toit, my topical mentors Emma Luker and Laura Maria Arango, as well as my technical mentor Amy Blood, who gave me the precious opportunity to do this wonderful project and helped me in R coding, study results analysis and report drafting.

Introduction

Forest health has become a heated topic in recent years. As urbanization processes create massive forest-urban intersect patches in the landscape, the patches are known as urban forests (Konijnendijk, Ricard, Kenney, & Randrup, 2006). Urban forests are indispensable parts of the urban ecosystem because well-managed urban forest benefits humans ecologically. For example, it plays an essential role in reducing air pollutants (Yang, McBride, Zhou, & Sun, 2005), surface rainwater runoff (Mcpherson & Ustin, 1998), and carbon sequestrations (McPherson, 1998). Urban forests also act as critical habitats for bird species (Kang, Minor, Park, & Lee, 2015), insects (Rodrigues, Brown, & Ruszczyk, 1993), and mammals (Villaseñor, Driscoll, Escobar, Gibbons, & Lindenmayer, 2014). Besides ecological implications, the urban forest provides social and economic values. Urban residents may spend their weekends in urban forest parks to relax from work. Maintaining the healthy status of urban forests is critical for attaining the benefits mentioned above.

Urban forest inventory can derive forest health and urban forest planning schemes (O'Laughlin & Cook, 2003). Located in the city area of Great Vancouver, the UBC Vancouver Campus is regarded as a successful example of urban forest planning. UBC urban forest goes through detailed planning, the Vancouver Campus Plan. Based on the campus's land classification map, the plan creates a sustainable and beautiful environment optimal for the teaching, learning, and research of teachers, scholars, and students (The University of British Columbia, 2017). The campus planning team pays great attention to public green areas. Campus trees compose the core of the plan since they distribute widely in the green areas on campus. UBC works with campus arborists and forestry experts to enhance campus trees' health since they contribute the ecological and social well-being (The University of British Columbia, 2020b). They also update the land classification map of UBC Vancouver Campus regularly for land planning purposes (The University of British Columbia, 2017). Thus, creating, updating the forest inventory, and constructing campus land classification maps are the priorities for the urban forest health and land planning in UBC Vancouver Campus.

Forest inventory plays an essential role in monitoring forest health. Many methods can be used to conduct the tree inventory, but light detection and ranging (LiDAR) technology is preferable as it conducts the inventory efficiently (O'Laughlin & Cook, 2003). The traditional methods of creating tree inventory need people to participate. It is labour-intensive and results in lower data quality (e.g. inaccuracy in location and tree height measurement) when the total number of trees is high in the inventory (Gordon, 2013). In contrast, LiDAR creates point clouds, uses metrics to calculate the data characteristics, and categorizes the data's mathematic features to identify the tree species (Carrasco, Giam, Papeş, & Sheldon, 2019; Hooper & Parlow, 2018). The data will automatically record the points' geographic coordinates, and it measures the tree parameters with high accuracy. The LiDAR point clouds will also be segmented into individual trees (Chen, Baldocchi, Gong, & Kelly, 2006). Thus, tree inventory conduction with LiDAR enjoys unique advantages of convenience than doing manually.

With tree inventory, the land classification map is a useful tool to monitor the land dynamics, especially the urban forest (Blackman & Yuan, 2020). A detailed classification map with detailed land-use types will potentially suggest land managers for future forest planning and land management practices (Fetene & Worku, 2013).

However, the UBC tree inventory derives from LiDAR, and the land classification map of the UBC Vancouver Campus is not perfect. The City of Vancouver created the LiDAR data of UBC in 2018 (City of Vancouver Open Data Portal, 2018), which is the latest LiDAR data. The UBC Campus and Community Planning Team have created a partial tree inventory of Vancouver Campus in 2018 (ubcjjb, 2019) based on the field measurements and LiDAR data. The issue is that some trees that may attract particular research interests (e.g. trees with big crowns) are not included in the inventory. The latest version of the land classification map of the UBC Vancouver Campus is in 2012 (The University of British Columbia Campus and Community Planning, 2017). Thus, there are gaps that nobody updated tree inventory and estimated the efficiency of the LiDAR methods applied to the UBC tree inventory, which may cause difficulties in managing the forest and monitoring forest health (O'Laughlin & Cook, 2003). It has also been eight years since the land classification map was produced as the land use of campus change rapidly in these years. A completed and up-to-date LiDAR tree inventory and land classification map will be useful for the land managers and researchers in UBC for the reasons above and generate further projects and research to tackle these issues. Hence, the project will focus on updating the tree inventory of the UBC Vancouver Campus, estimating the LiDAR methods' accuracy, and producing an up-to-date UBC land classification map for the campus.

Data and Study Site Summary

Study Area Description

The study area is the UBC Vancouver Campus. Figure 1 shows the campus with its location in the Great Vancouver Region. The UBC Vancouver Campus's legal boundary in Figure 1 shows the range of latitude from 49.2416 to 49.2731 and latitude from -123.2622 to -123.2265 in decimal degrees (The University of British Columbia Campus and Community Planning, 2013). The campus's total area is 402.56 hectares (The University of British Columbia Campus and Community Planning, 2013). The UBC Vancouver Campus climate is a moderate oceanic climate that has a mild dry summer and rainy autumn, winter, and spring (Wikipedia, 2020). The climate results in the broad diversity of vegetation on campus, especially tree species. The campus planning team estimated that at least 15 tree species grow on campus (Munro & Hauner, 1980).

UBC moved to the Point Grey (Vancouver) Campus in 1910 (The University of British Columbia, 2020a). In the past century, the UBC Vancouver Campus trees and urban forests went through massive decline due to the expansion of the campus area and the harvest practices for fuel woods and construction materials (Sutherland, 2012). Sutherland (2012) estimated that the canopy cover of the UBC Vancouver Campus declined by 24% from 2004 to 2009. Due to the decline of the urban forest, the current status of trees needs to be mapped and managed in future planning.

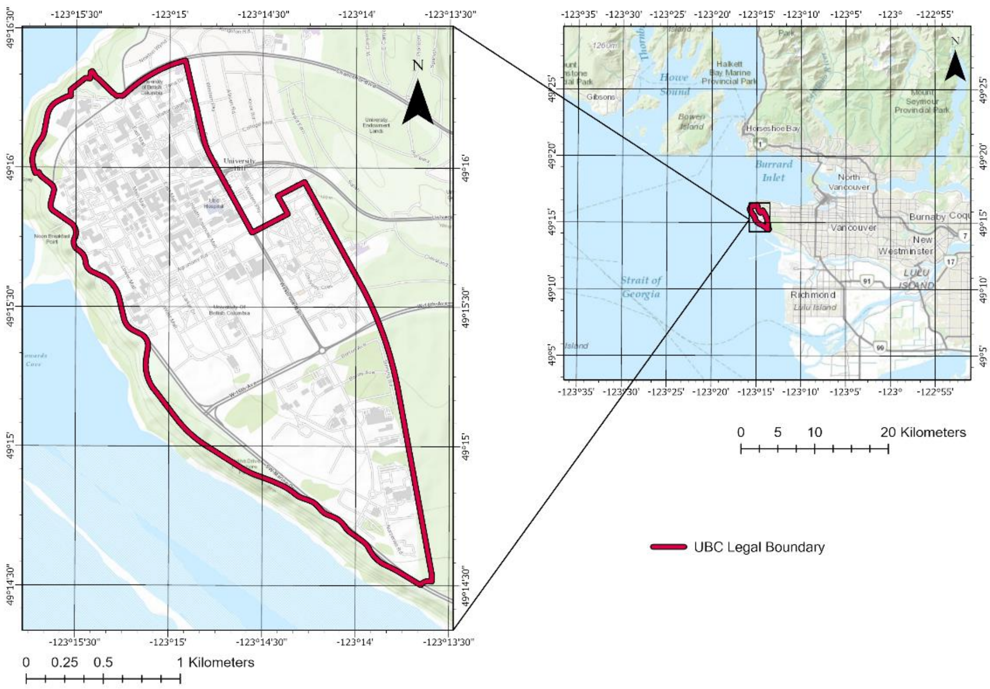


Figure 1. The map of the study area and its relative location in the Great Vancouver region. The data layer was retrieved from the University of British Columbia Campus and Community Planning (2013). The red line shows the legal boundary of the UBC Vancouver Campus (study area). The map was projected in NAD 1983 UTM Zone 10N. The base map comes from ESRI.

Data Summary

The study used UBC orthophotos 2018, 2020, and LiDAR point clouds of the UBC Vancouver Campus for the datasets to get the results. The UBC Vancouver Campus legal boundary and UBC legal area's geospatial data were used in the study area map to clip the orthophoto and the point cloud. Also, the field measured data of campus trees were used to validate species classification accuracy and height measurement accuracy.

The project used the orthophoto: "[Orthophotos, University of British Columbia Vancouver Campus], 2018" (McElhanney Consulting Services LTD., 2018).

McElhanney Consulting Services LTD. collected the data, and a Zeiss DMC 3 camera took it on an aircraft. The data type was the GeoTIFF files. The dataset contained eleven tiles (see Table 1). The dataset was downloaded from the link: https://abacus.library.ubc.ca/dataset.xhtml?persistentId=hdl:11272.1/AB2/1EQCYQ (McElhanney Consulting Services LTD., 2018). The spatial resolution of the data is 10cm. It contains three spectral bands: visible red, visible green and visible blue bands. It has an 8-bit pixel depth that the radiometric resolution is from 0 to 255 for the RGB channels. The author orthographically rectified the data, and the projected coordinate system was NAD 1983 UTM Zone 10N. The time of the data acquisition was April 26, 2018. The 2018 orthophoto was used for the visual validation of LiDAR tree inventory classification.

Similarly, the orthophoto in 2020: "[Orthophotos, University of British Columbia Vancouver Campus], 2020" was also included (McElhanney Consulting Services LTD., 2020) were included in the project. Similarly, McElhanney Consulting Services LTD. collected the data, and it was taken by a Zeiss DMC 3 camera on an aircraft. The data type was also GeoTIFF files. The dataset contained eleven tiles (see Table 1), and the dataset was downloaded from the link: https://abacus.library.ubc.ca/dataset.xhtml?persistentId=hdl:11272.1/AB2/6PFOWL (McElhanney Consulting Services LTD., 2020). The spatial resolution of the data is 10cm. Unlike the orthophoto in 2018, the 2020 photo contains four spectral bands: visible red, visible green, visible blue, and NIR bands. It has an 8-bit pixel depth that the radiometric resolution is from 0 to 255 for the RGB channels. Similarly, the author orthographically rectified the data, and the projected coordinate system was NAD 1983 UTM Zone 10N. The time of the data acquisition was April 6, 2020. The 2020 orthophoto was used for generating land classification map of UBC Vancouver Campus.

The project used eleven LiDAR point cloud sections (see Table 1), which shared the same metadata and data parameters. The City of Vancouver owns the dataset, and the aerial-LiDAR derived the dataset. The data type was the LAS file. The dataset was downloaded from the link: https://opendata.vancouver.ca/explore/dataset/lidar-2018/information/ (City of Vancouver Open Data Portal, 2018). The point density for the LiDAR data was 30 points per m^2. The owner rectified the data by categorizing the noise and data points. It had a vertical accuracy of 0.18 m and a horizontal accuracy of 0.36 m for a 95% confidence level (City of Vancouver Open Data Portal, 2018). The projected coordinate system of the LiDAR data was NAD 1983 UTM Zone 10N (City of Vancouver Open Data Portal, 2018). The data was acquired on August 27 and August 28, 2018. The LiDAR data will be used for updating the UBC tree inventory.

The name of geospatial data in the dataset is "[University of British Columbia Vancouver Campus. Campus and Community Planning data]" (The University of British Columbia Campus and Community Planning, 2013). The name of the UBC legal boundary shapefile is "LegalBoundaryL", and the UBC legal area's name is "LegalBoundaryP_1" (The University of British Columbia Campus and Community Planning, 2013). The projected coordinate system of the shapefiles (line and polygon) was NAD 1983 UTM Zone 10N. UBC Campus and Community Planning Team created the dataset on November 11, 2017. The dataset was downloaded from the link:

https://abacus.library.ubc.ca/dataset.xhtml?persistentId=hdl:11272.1/AB2/ETO8IU.

The validation data's name of campus tree is "ubc-geospatial-opendata", which was created by the GitHub user "ubcjjb" (ubcjjb, 2019). The dataset is stored in the file "ubcv_campus_trees.csv", which can be downloaded from the link: https://github.com/UBCGeodata/ubc-geospatial-opendata/blob/master/ubcv/landscape/README.md. It is a partial current tree dataset of the UBC Vancouver Campus. The trees' coordinates were derived from the 2019 UBC orthophoto, and the reference coordinate system of the trees is WGS 1984 (ubcjjb, 2019). Egan Davis identified tree species, and UFOR101 students measured the tree height (ubcjjb, 2019). Some of the trees in the dataset were also measured by LiDAR data. Not all the trees in the dataset have the species identified and height measured.

UBC Orthophoto 2018	UBC Orthophoto 2020	UBC LiDAR 2018
480E_5457N.tif	480E_5457N.tif	4800E_54570N.las
481E_5455N.tif	481E_5455N.tif	4810E_54550N.las
481E_5456N.tif	481E_5456N.tif	4810E_54560N.las
481E_5457N.tif	481E_5457N.tif	4810E_54570N.las
482E_5454N.tif	482E_5454N.tif	4820E_54540N.las
482E_5455N.tif	482E_5455N.tif	4820E_54550N.las
482E_5456N.tif	482E_5456N.tif	4820E_54560N.las
482E_5457N.tif	482E_5457N.tif	4820E_54570N.las
483E_5454N.tif	483E_5454N.tif	4830E_54540N.las
483E_5455N.tif	483E_5455N.tif	4830E_54550N.las
483E_5456N.tif	483E_5456N.tif	4830E_54560N.las

Table 1. The summary table of photo tiles and point cloud tiles names of UBC Orthophoto 2018, UBC Orthophoto 2020, and UBC LiDAR 2018.

Methods

I applied remote sensing methods, GIS methods, and statistical tests to the project to conduct the UBC Vancouver Campus's tree inventory, estimate the LiDAR methods' accuracy, and generate a land classification map. The tree inventory attribute table's primary columns include coordinates (longitude/latitude), tree species (coniferous/deciduous), heights, canopy area, canopy diameters, elevation, slopes, and aspects. Figures 2 and 3 show the proposed workflow of updating the tree inventory and constructing the land classification map.

Data Pre-processing

I used LiDAR data tiles from the City of Vancouver Open Data Portal (2018) as the project's database to conduct the UBC Vancouver Campus tree inventory. Though the LiDAR data has already been cleaned and preprocessed (City of Vancouver Open

Data Portal, 2018), I filtered the point cloud's duplicates to ensure the data quality.

The author of the data has already classified the data as Unclassified; Bare-earth and low grass; Low vegetation (height <2m); High vegetation (height >2m); Water; Buildings; Other; and Noise (City of Vancouver Open Data Portal, 2018). I clipped the tiles separately using the UBC legal area polygon in R. Then, I filtered the LiDAR point cloud of forested areas (high vegetation) manually to mask the point clouds of buildings and other non-vegetation areas.

Digital Terrain Model (DTM) Generation for Elevation, Aspect, and Slope

I used the portion of the forested areas for the study. To get the digital terrain model (DTM), I used the original projection of the LiDAR data "NAD 1983 UTM Zone 10N" as default. Using the "grid_terrain()" function of the "lidR" package in R (Roussel, Goodbody, & Tompalski, 2021), I transformed the LiDAR tiles into the raster file to create DTM. I used the inverse distance weighted (IDW) interpolation method in the package to create the DTM (Roussel et al., 2021). I generated the DTM in 0.3m*0.3m spatial resolution. To calculate the slope and aspect parameters from DTM, I used the "terrain()" function of the "raster" package in R according to the official document of the "raster" package (Hijmans et al., 2020). Then, I extracted the parameters of elevation, slope, and aspect by the x,y coordinates of trees (see "Tree Canopy Diameter and Area Calculation" section). The parameters were stored in the attribute table of the trees.

Tree Height Calculation and Validation

Again, I visually checked and removed the potential outliers before generating the canopy height model (CHM). Next, I normalized the LiDAR point clouds and generated CHM in forested areas (with buildings and other non-vegetation features masked) identified in the first section. I used the variable-sized dynamic window local maximum value method to detect individual treetops and extract the individual tree heights, adapted from the "lidR" package by Roussel, Goodbody, & Tompalski (2021). After the extraction of treetops, I compared the LiDAR-derived tree height to the field-measured tree height using the linear regression model (y=x) for validation. Fifty trees were selected randomly for validation after the individual trees are detected in the next section. Then, the coefficient of determination (R^2) was calculated to validate the accuracy of measurement results.

Tree Canopy Diameter and Area Calculation

The data of CHM is a combined point cloud that different tree canopies may overlap. After finding out the treetops in the previous section, I used the tree crown segmentation algorithm in the "lidR" package, adapted from Silva et al. (2016) to segment the original CHM to delineate the individual tree polygon. This was because the accuracy of the tree segmentation would be high using this algorithm in mixed forests (Silva et al., 2016), which is the characteristic of UBC forest. The x,y coordinates of each tree polygon's centers were determined as trees' coordinates. Then, I obtained the shape of the crowns. To calculate the tree canopy diameter, I used the circle's area formula, $S=pi*d^2/4$ (d represents diameter). After that, I used the "area" function in the "raster" package (Hijmans et al., 2020) to calculate the canopy area. I calculated the LiDAR metrics of individual trees directly using the "lidR" package in R Studio (Roussel et al., 2021). Then, the tree polygons derived from each LiDAR tile were merged into a shapefile.

Since the shrubs and other non-tree vegetations would be included in the high vegetation of LiDAR data, and the small trees would receive lower accuracy due to the point cloud's density, the small trees detected under 4m diameter were removed from the polygons. Some of the crowns were manually adjusted (e.g. position) according to the 2018 UBC orthophoto to enhance a higher classification accuracy for the species classification section. Except for the fields changed due to adjustments (e.g. x, y coordinates for the position change), other tree polygons metrics were preserved. Finally, I made a tree canopy map (crown diameter>4m) of the UBC Vancouver Campus in the ArcGIS Pro as one of the deliverables.

Tree Species Classification (Coniferous/Deciduous)

As the single trees are delineated and tree metrics were calculated in the former steps, I used the "Forest-based Classification and Regression" tool in ArcGIS to identify tree species (ESRI, 2021). According to the articles on tree species identification, the ratio between tree height and crown area, the percentage of intensity returned below the 50th percentile of height, the skewness of intensity distribution, the skewness of height distribution, the ratio between 25/50/75th percentile of height distribution and tree height were used for the parameters of tree classification (Alonzo, Bookhagen, & Roberts, 2014; Gülçin & van den Bosch, 2021; Liu, Coops, Aven, & Pang, 2017). The coniferous trees and deciduous trees had a distinct difference in the crown metrics using the random forest approach. One hundred trees, including 50 coniferous and 50 deciduous trees, were selected using the orthophoto to conduct the training and validation data. The ratio between training and validation data is 7:3. Finally, the classification was applied to the big trees (crown diameter>4m) across the campus. One hundred trees were selected to generate a confusion matrix of the classification results. Using 2018 orthophoto, the tree polygons were further validated and corrected.

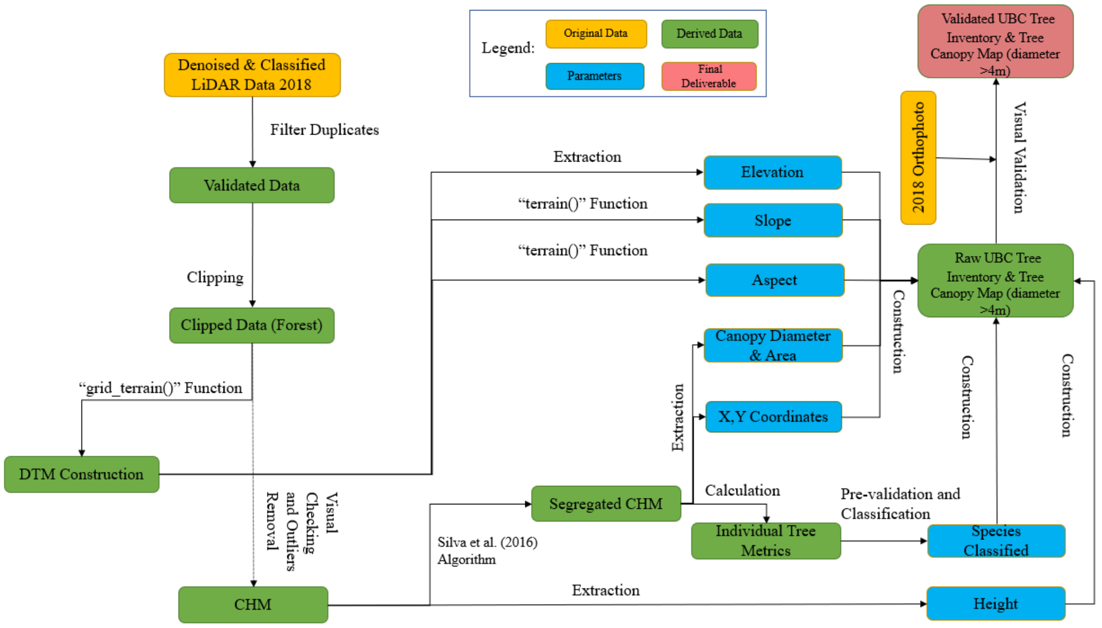


Figure 2. The study's workflow diagram of UBC forest inventory update using LiDAR Data. It is based on data validation, DTM generation, coordinates, tree height, canopy area, width, species classification, and land classification map construction. The legend indicates four types of elements: Original data, derived data, generated parameters, and final deliverable. Near the line, the diagram shows the major operation methods used between the elements. The dashed line in the figure does not intersect with solid lines.

Land Classification Map Construction

The photo tiles were merged. Then, I clipped the orthophoto to the extent of the campus using the UBC legal area polygon. I used the supervised classification to create the land classification map based on UBC Vancouver Campus 2020. I extracted the training areas and validation areas (Khatami, Mountrakis, & Stehman, 2016; Ma et al., 2017). To achieve area extraction, I used the Training Sample Manager in ArcGIS. To classify the UBC area, I included four land cover types: Forested Areas, Other Vegetation Areas, Developed Areas, and Shadows. Ten areas with four categories were extracted for each land use type's training areas. I halved the number of regions for the validation data. The location of the shapefiles is shown in Figure 4. Using the shapefiles of training and validation areas, I used the support vector machine (SVM) to conduct image classification and generate a confusion matrix., I calculated the overall accuracy, producers' accuracy, and users' accuracy of the classified image to validate the results. Then, I manually validated the classified orthophoto with the original orthophoto. The pixels' numbers calculated the proportion of each land-use class. Finally, I used the Downtown Vancouver classification map to compare the validated UBC land classification map (Arundel, Wong, & Chan, 2006).

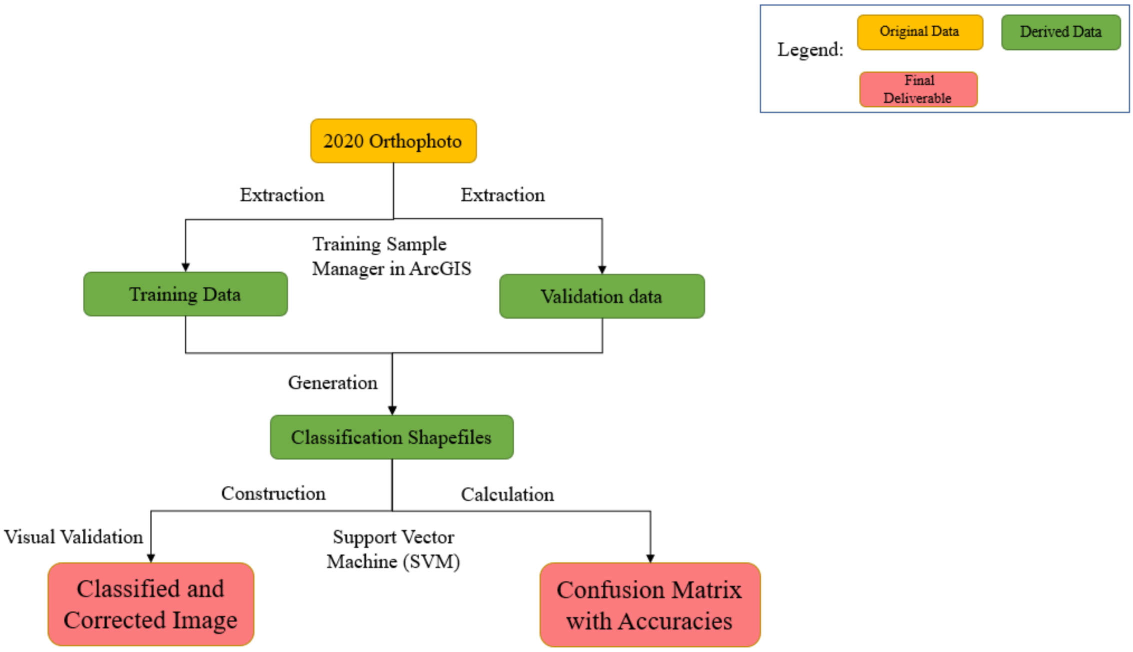


Figure 3. The study's workflow diagram of generating land classification of UBC Vancouver Campus. It is based on the 2020 Orthophoto of the campus, selecting training and validation data, shapefiles, classified image and confusion matrix. The legend indicates three types of elements: Original data, derived data, and final deliverables. Near the line, the diagram shows the major operation methods used between the elements.

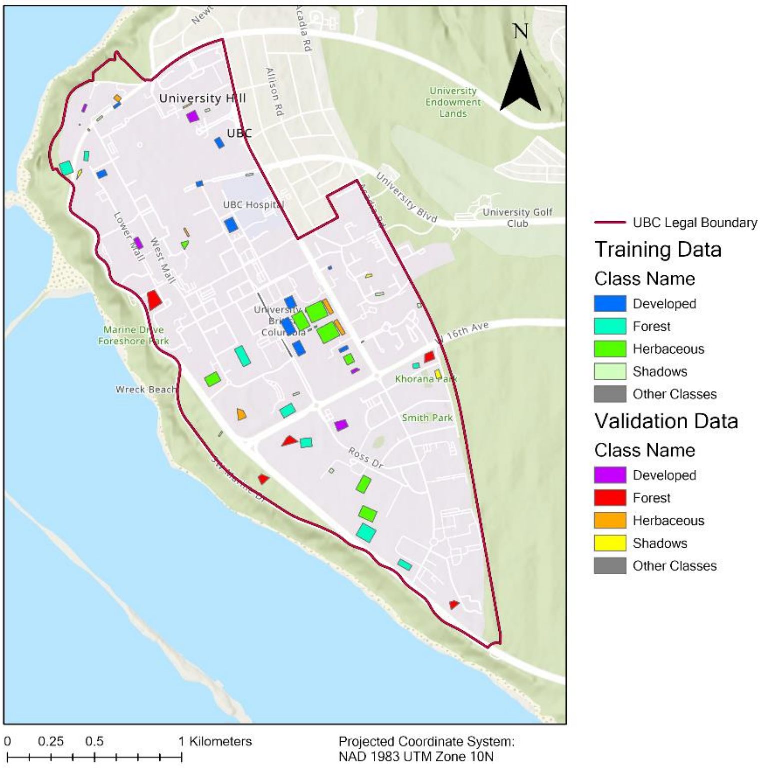


Figure 4. The map of training polygon and validation polygon of UBC Vancouver

Campus for supervised classification. Forty polygons are selected for the training data, and 20 polygons are chosen for the validation data. The polygons are shown in different colours. The base map comes from ESRI.

Study Results

Individual tree segmentation and the tree crown delineation map of UBC Vancouver Campus

The results of individual tree segmentation and the tree crown delineation map are shown in Figure 5. According to the LiDAR data calculated by the algorithm by Silva et al. (2016), 14165 trees, including coniferous and deciduous species, are detected on the UBC Vancouver Campus. The average tree crown area of the study area is 79.44 m^2. The maximum crown area is 582.3 m^2. More than half of the tree crowns are around 12.6-60 m^2 (4 - 9m for diameter).

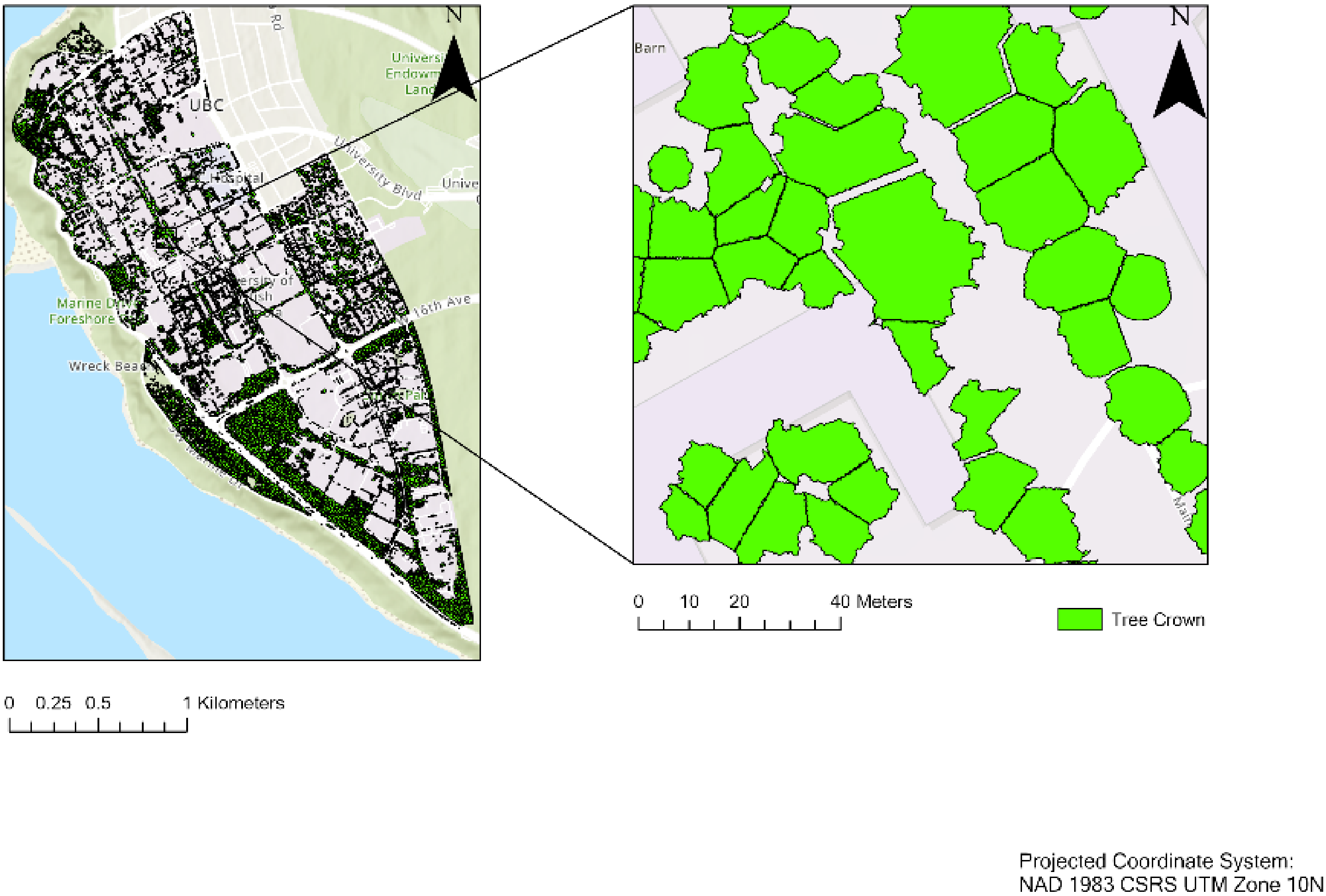


Figure 5. The results of individual tree detection using LiDAR point cloud of UBC Vancouver Campus. The green polygons in the maps illustrate the large tree polygons detected by the crown segmentation algorithm in both the UBC Campus and the Main Mall area within the legal boundary. The base map comes from ESRI.

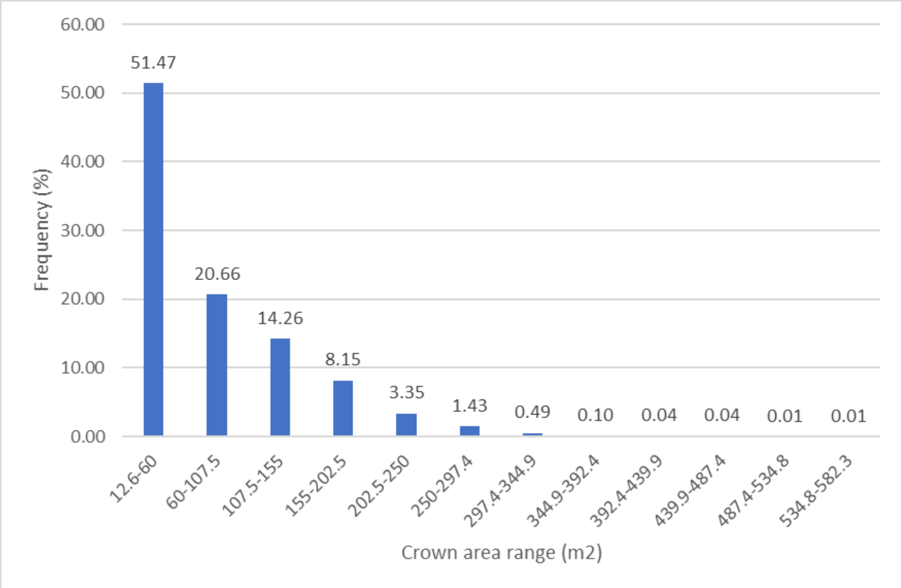


Figure 6. The distribution of the crown area of the big trees (diameter > 4m) of the UBC campus. It can be depicted that the number of trees decreases with the increase in the crown area.

Tree height estimation and validation

As stated above, 14165 trees are identified from the point cloud. In this case, the trees' maximum Z value was extracted from each tree with the "tree metric" function. These Z values represent the height of the trees. From Figure 7, it can be depicted that half of the trees in the study area are less than 15 meters. The maximum tree height in this area is 62.95m, and the average tree height is 19.06m. Due to the limitation of field-measured data, the maximum value of field-measured height for the validation is around 35m. Using the expected model of y=x, the R^2 of the model is 0.80 (Figure 8).

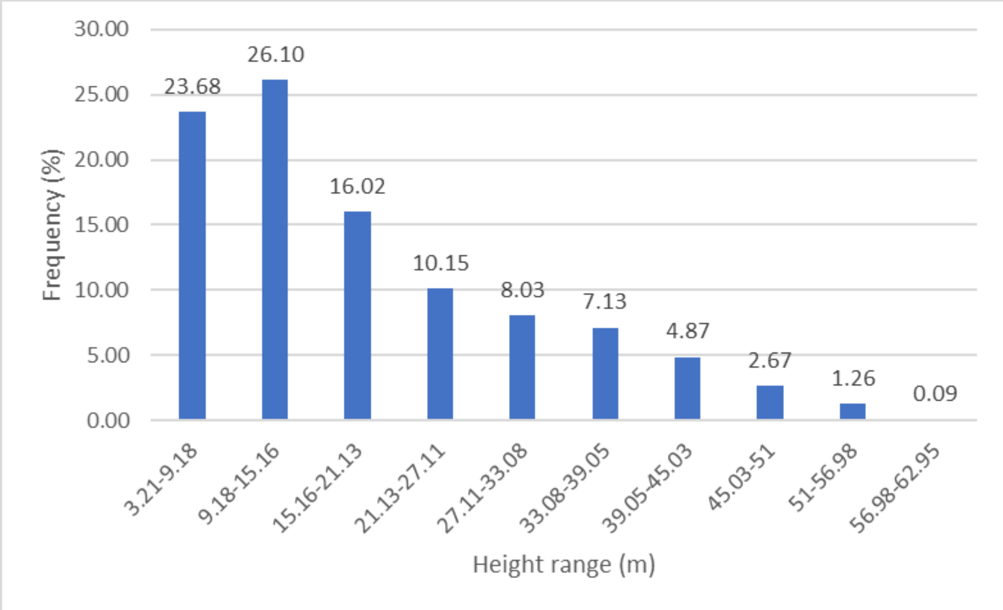


Figure 7. The frequency bar chart of the tree heights. Approximately 50% of the trees are below 15m. The number of trees begins to decrease after the tree height is more than 9m.

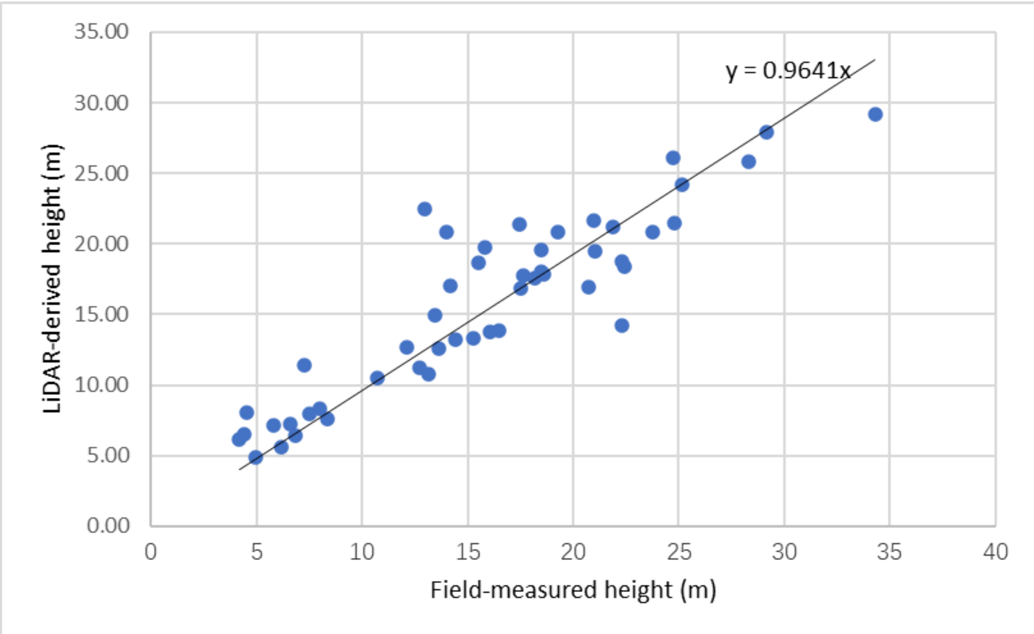


Figure 8. The result of the linear regression model of 50 selected trees. According to the regression line, LiDAR-derived heights are lower than the field measured heights (coefficient = 0.9641).

Slope/elevation/aspect of trees

The trees' parameters were extracted from the DTM of the UBC campus using the x,y coordinates of the trees. According to the results, most of the trees are at a slope of fewer than ten degrees. However, the aspect where the trees locate is evenly distributed from 0 to 360 degrees. According to the results, the average elevation where the tree locates is 79.96m.

Species classification (Coniferous/Deciduous)

The trees were classified as coniferous and deciduous trees. Evaluated by the random forest algorithm, the relative importance of the parameters in deciding the species category is listed in Table 2 below.

Parameters	**Relative Importance**
Tree height/Crown area	0.62
The percentage of intensity returned below the 50th percentile of height	0.05
The skewness of intensity distribution	0.10
The skewness of height distribution	0.11
25th percentile of height distribution/Tree height	0.06
50th percentile of height distribution/Tree height	0.03
75th percentile of height distribution/Tree height	0.02

Table 2. The table of parameter evaluation using the training data by the random forest algorithm. The ratio between tree height and crown area shows the highest relative importance.

The ratio between tree height and the crown area turns out to be the most critical parameter determining the species from the table. As identified, there are 6067 coniferous trees and 8098 deciduous trees on campus. The classification map of campus trees is shown in Figure 8. According to the classification results, the coniferous trees surround the campus. The coniferous trees are mainly detected in UBC Farm and UBC Botanical Garden. Table 3 shows the result of the tree species validation using 100 trees sampled from the field data. According to Table 3, the total accuracy of species classification is 84%.

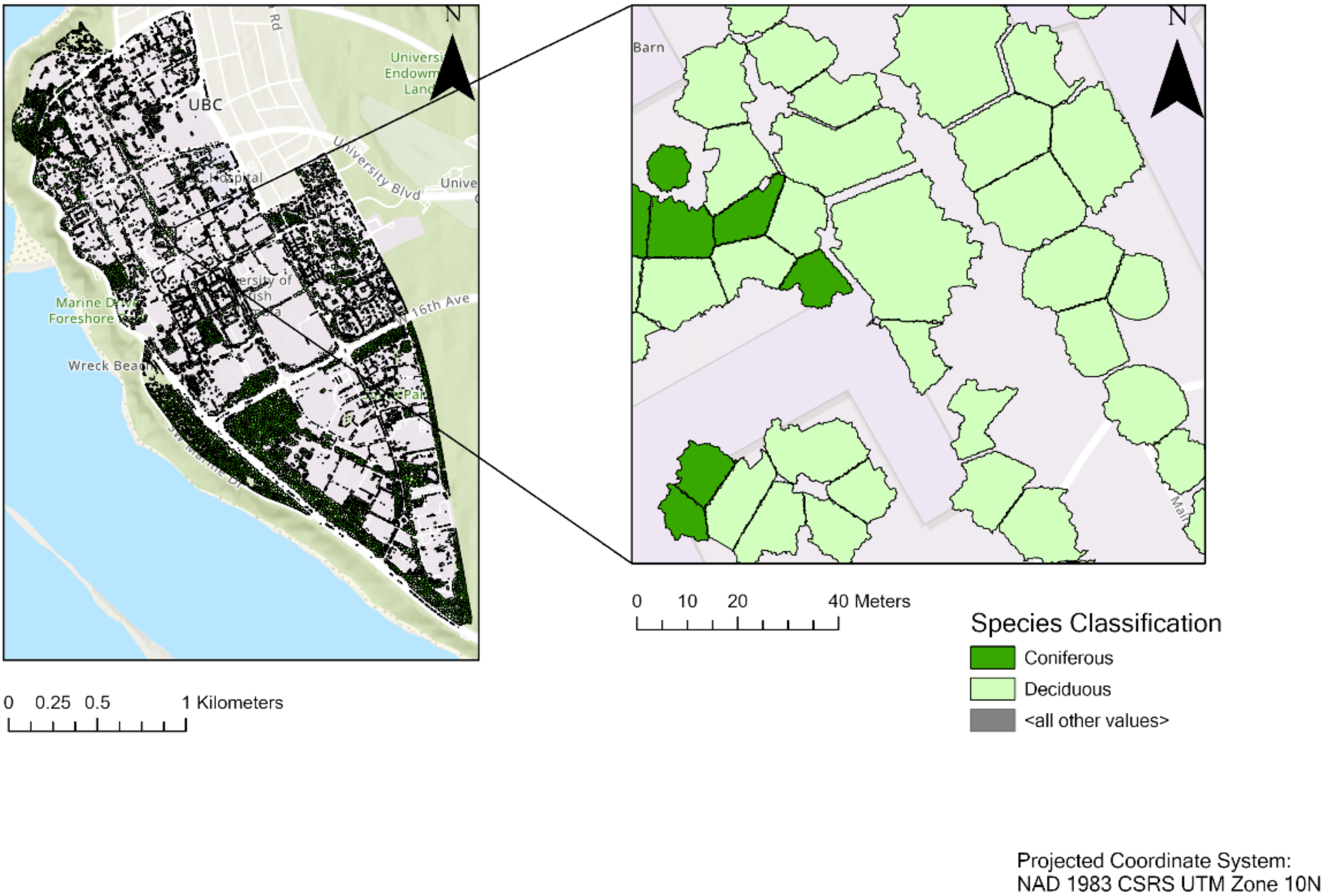


Figure 9. The results of tree species identification of UBC Vancouver Campus. The coniferous trees are coloured in dark green, while the deciduous trees are light-coloured. The inset map shows that deciduous trees dominate the Main Mall area. The base map comes from ESRI.

Field-measured	LiDAR-measured	Deciduous	Coniferous	
Deciduous		76	12	
Coniferous		4	8	
				84%

Table 3. The confusion matrix of species validations between field-measured trees and LiDAR-derived trees. The overall accuracy of the classification is 84%.

Land classification map using 2020 orthophoto

According to Figure 10, the land use map of UBC Vancouver Campus comprises of developed, forest, other vegetations, and shadows. The spatial resolution of the classification map is 0.1m. From the map, it can be depicted that the vegetation and forests are mainly located on the southern campus.

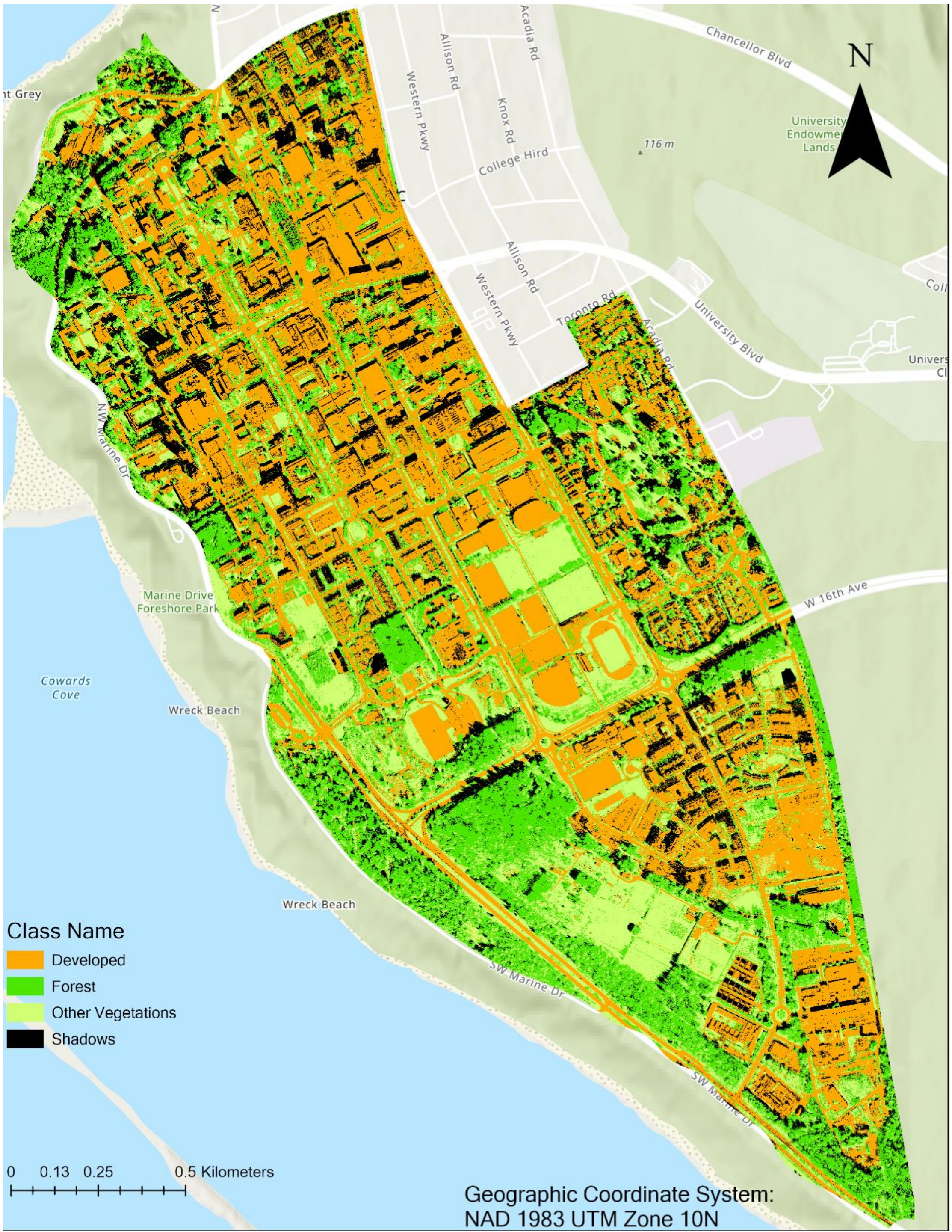


Figure 10. The validated land classification map of the UBC campus. The campus has been categorized into four categories: Developed, forest, other vegetations, and shadows. The base map comes from ESRI.

The proportion of each land use for UBC Vancouver Campus

Figure 11 shows the comparison of land uses between UBC forest and Downtown Vancouver. The land use data of Downtown Vancouver was adapted from Arundel, Wong, & Chan (2006). To make the comparison more straightforward, the forest and herbaceous areas were combined into one category. The result shows that the UBC Vancouver Campus's vegetation cover is 45%, almost two times as much as the vegetation cover in Downtown Vancouver (23%).

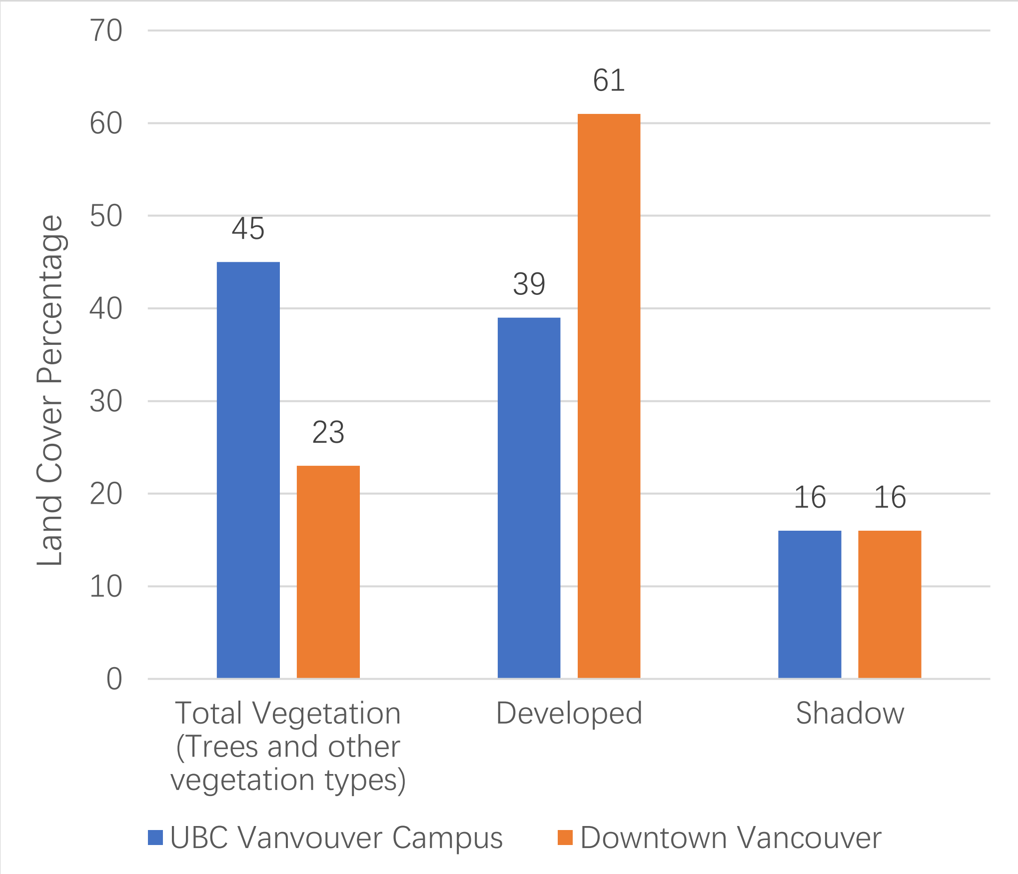


Figure 11. The comparison graph of land uses between UBC Vancouver Campus and Downtown Vancouver. It is well worth noticing that the vegetation cover of UBC is higher than in Downtown Vancouver. The data of Downtown Vancouver was adapted from Arundel et al. (2006).

The confusion matrix of the classification

According to Table 4, the users' accuracy and producers' accuracy of the raw image is about 80%. Kappa's coefficient is 75.7%, which means a relatively high accuracy of classification.

OBJECTID	Class Name	Developed	Forest	Herbeceous	Shadow	Total	User's Accuracy	Kappa's Coefficient
1	Developed	168	9	1	18	196	0.857142857	0
2	Forest	4	106	14	2	126	0.841269841	0
3	Herbaceous	1	23	69	0	93	0.741935484	0
4	Shadow	6	10	0	69	85	0.811764706	0
5	Total	179	148	84	89	500	0	0
6	Producer's Accuracy	0.938547486	0.716216216	0.821428571	0.775280899	0	0.824	0
7	Kappa's Coefficient	0	0	0	0	0	0	0.756759596

Table 4. The confusion matrix of the classification map. The total accuracy is 82.4%. The Kappa's coefficient is 0.757, which shows a relatively high classification accuracy.

Discussions

In this study, the UBC Vancouver Campus's tree inventory is conducted with different attributes. The LiDAR methods' accuracies in height estimation and species identification are high, which is shown in Figure 8 and Table 3. Also, the study produced a UBC land classification map for the campus using the UBC 2020 orthophoto. It has been classified into four categories, and it showed relatively high accuracy (82%).

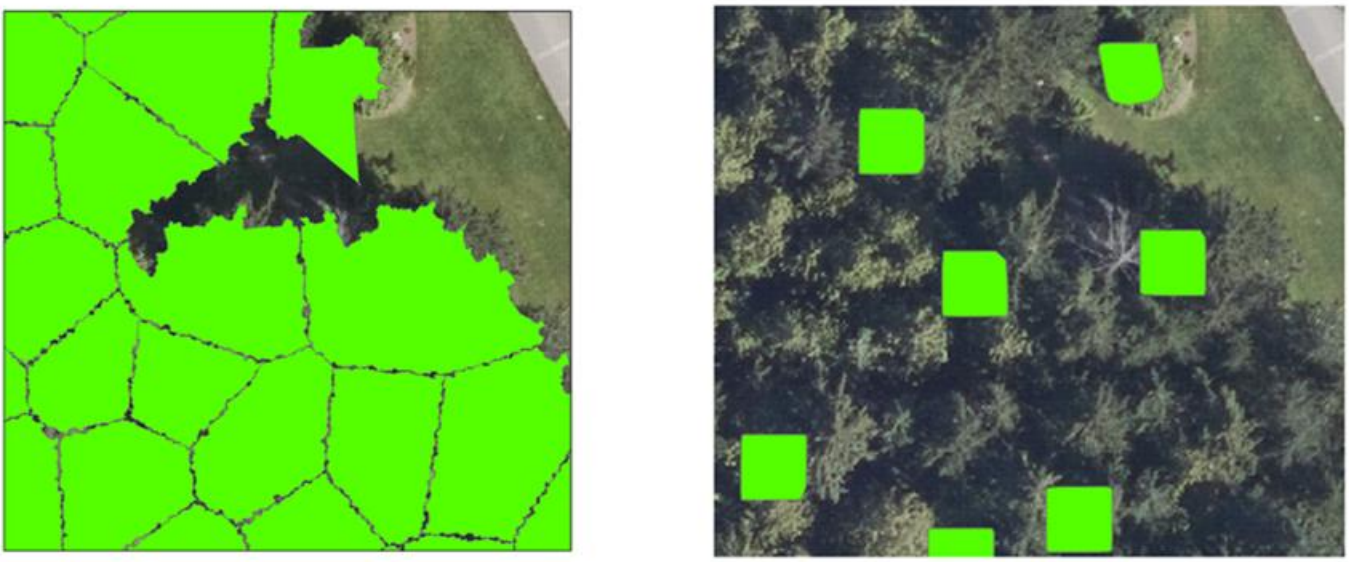
LiDAR-derived forest inventory: Height, species, and limitations

The study uses a similar approach to Gülçin & van den Bosch's (2021) work on UBC Vancouver Campus. However, Gülçin & van den Bosch (2021) used the tree segmentation algorithm by Dalponte & Coomes (2016). I applied the two algorithms separately and visually compared them in Figure 12. The algorithm by Silva et al. (2016) shows a better delineation of the trees' crowns from the figure. Not all the crown areas can be covered by the polygons generated by Dalponte & Coomes (2016). Hence, the algorithm by Silva et al. (2016) is used in the study. However, it does not perform well in detecting some of the big deciduous trees. From Figure 13, the crown of the red oak has been wrongly recognized as five coniferous trees. Because the crowns of deciduous trees may show different parts due to natural growth, the algorithm has difficulties detecting individual treetops.

The first reason for detecting big trees (crown diameter >4m) is that big trees provide more important ecosystem services than small trees (Lindenmayer & Laurance, 2017). For example, large trees can control soil erosion and sequester carbon. The second reason is that the small trees may not be measured accurately in the LiDAR measurement. Because the LiDAR data have a horizontal accuracy of 0.36 m, small trees are more likely to lose details like treetops if the LiDAR instruments do not detect the highest points. Similarly, large trees are also affected by the LiDAR measurement, but not as severe as small trees. If this is correct, it will explain in Figure 8 that the coefficient is less than one because some treetops may lose in the LiDAR measurement.

The R^2 value for the model y=x suggests that the accuracy of LiDAR height measurement is 80%. From the R^2 values in Table 5, the UBC project has the highest measurement accuracy among the four studies. This suggests that the LiDAR measurement works well in UBC tree height estimation. For species classification, the study can only use LiDAR metrics to classify the species due to the lack of hyperspectral data. The ratio between tree height and the crown area is the most critical factor (0.62). This is because the coniferous trees usually have higher height and smaller crown areas, while deciduous trees have lower height and larger crown areas. The structural features of the trees make it possible to classify the coniferous and deciduous trees. However, the limitations of field-measured data by UFOR101 students should be noticed. They just measured a part of the large deciduous trees in the northern campus. Hence, only the large trees can validate height and species, which may cause accuracy inflations. The lowest number of the field-measured tree for validation (50) among all the studies in Table 5 also reveals this. Thus, it is predictable that the accuracies will go down with the increase of measured trees.

Since the heights and species of the trees are identified, it can be concluded that the coniferous trees show a clustered pattern on the southwest campus because of the forest distribution. It has environmental implications for the UBC Vancouver Campus. According to the UBC topography map by the University of British Columbia Campus and Community Planning (2007), the campus slopes southwest means that the rainfall and underground water may move to the southwest campus by gravity. If this is correct, there will be a risk of soil erosion on the southwest campus. Hence, the root system clustering large trees can retain the aboveground and underground water. Thus, the big coniferous trees can control the soil erosion in the southwest campus. The campus planning team should pay special attention to the trees.



Tree segmentation by Silva et al. (2016)

Tree segmentaion by Dalponte & Coomes (2016)

Figure 12. The visual comparison of individual tree segmentation results using the algorithms by Silva et al. (2016) (left) and Dalponte & Coomes (2016) (right). Other R

code parameters remained the same, and the 2018 UBC Orthophoto was used as the background. The crown polygons by Dalponte & Coomes (2016) deviate from the actual tree crown.

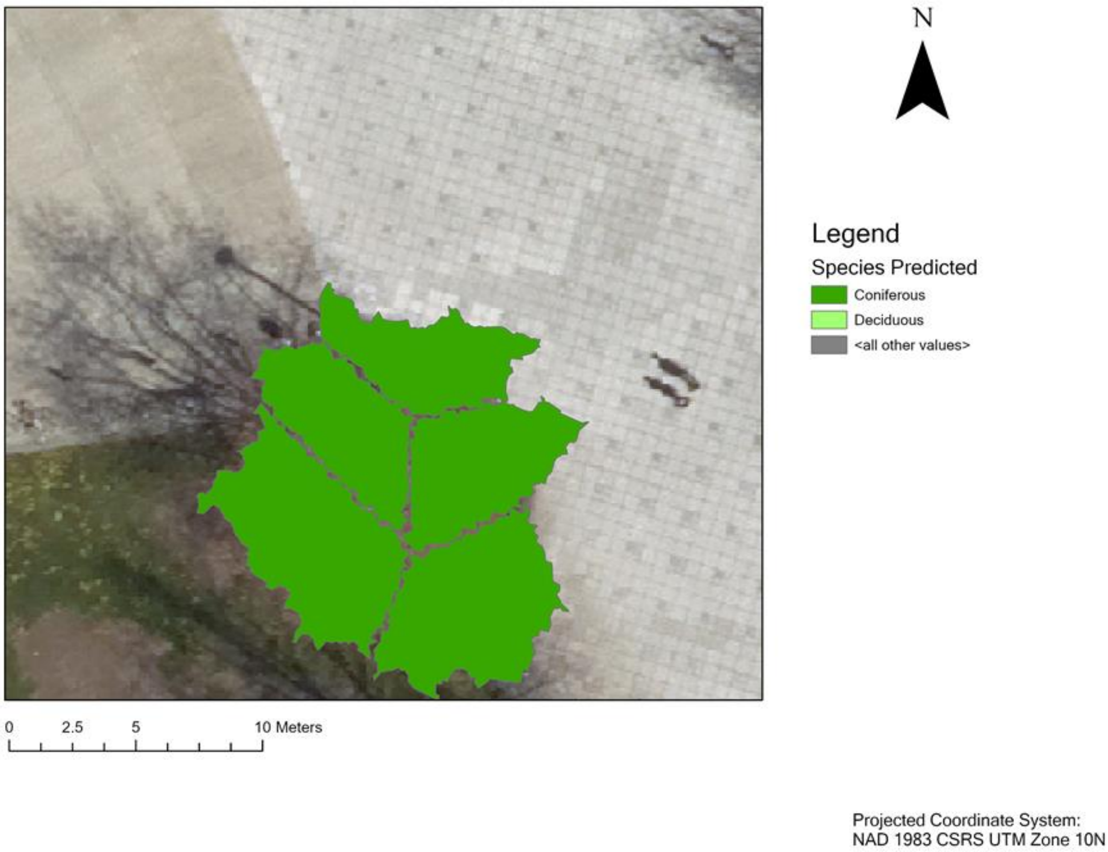


Figure 13. The crown delineation result of red oak on Main Mall. The crown has been segmented into five parts and wrongly recognized as coniferous trees.

Authors/Name of Study	Number of Trees Measured	R^2 Value
UBC LiDAR Tree Inventory (FCOR 599)	50	0.80
Kwak, Lee, & Lee (2006)	135	0.79
Su, Ma, & Guo (2017)	596	0.6
Moe, Owari, Furuya, & Hiroshima (2020)	178	0.53

Table 5. The comparison table of the studies in LiDAR-derived tree height vs. field-measured height after the literature review. The R^2 value decreases with the increasing field-measured trees.

Land classification of UBC Vancouver Campus: Spatial patterns, comparisons, and limitations

Figure 10 shows that most of the vegetation cover is located on the southern campus. This is because the UBC farm and UBC botanical garden located on the south of campus. These areas contain a large proportion of vegetation. In contrast, the northern campus is well-developed. The difference between the northern and southern campus suggests that the UBC Vancouver Campus Plan pays attention to developing the northern campus. This is likely because Chancellor Boulevard, University Boulevard, and West 16th Avenue connect to the northern campus. Combining public transit with the residential area and the academic area is the Vancouver Campus Plan's goal (The University of British Columbia, 2017).

The high vegetation cover in the southern campus results in a high vegetation cover of the whole campus. Compared to downtown, the high vegetation cover is that UBC uses public land to create public green areas (The University of British Columbia, 2017), while Downtown Vancouver is constructed with buildings. According to Doodles (2021), the vegetation covers of the District of North Vancouver (48.6%), City of Coquitlam (51.4%), and City of Port Moody are the urban areas that have higher vegetation cover than UBC Vancouver Campus. However, the difference between UBC and those cities is not big because if the vegetation in the shadows is taken into account, the vegetation cover of UBC will increase. Hence, the vegetation cover provides the campus planning implications that the Vancouver Campus Plan worked well in preserving vegetation cover.

In the classification process, it is well worth noticing that the producer's accuracy of the class "forest" is the lowest in Table 4. The error mostly comes from the other vegetation types. This suggests that the classification algorithm cannot distinguish the vegetation types well because the band number of UBC Orthophoto 2020 is limited. Also, I would like to add the bare soil to the land classification at first. However, the classification algorithm cannot distinguish the bare soil and buildings well. This also suggests that the limited band numbers of the orthophoto. Short-wave infrared bands and thermal infrared bands are necessary for distinguishing bare soil and urban area (Li & Chen, 2014) and distinguishing vegetation types (GISGeography, 2021). Hence, the orthophoto with more bands is crucial if we want to classify the bare soil and different vegetation.

Future directions

The limitations mentioned in the previous sections point out the future directions of the study. First, as the algorithms may wrongly detect the trees, manual corrections of the tree polygons are necessary to conduct an accurate tree inventory. It is necessary to include more trees for the validation. Second, as the study provides baseline tree inventory, new tree parameters like DBH can be predicted using the inventory and regression models' parameters. Then, the biomass and carbon storage can be estimated (Gülçin & van den Bosch, 2021). Third, using the random forest approach, the study constructs a tree species classification scenario in the urban forest. Hence, if UBC Vancouver Campus's hyperspectral data can be accessed in the future, trees' classification can be conducted to species level. As the study indicates that the trees on the southwest campus have implications on soil erosion control, species identification in this area should be the priority. Finally, the classification map indicates the vegetation cover percentage that the land planning should attain under the Vancouver Campus Plan. This can be considered when planning other cases like UBC Okanagan Campus.

References

Alonzo, M., Bookhagen, B., & Roberts, D. A. (2014). Urban tree species mapping using hyperspectral and lidar data fusion. *Remote Sensing of Environment*, *148*, 70–83. https://doi.org/10.1016/j.rse.2014.03.018

Arundel, R., Wong, C., & Chan, E. (2006). GREEN VANCOUVER: An investigation of vegetation cover distribution in downtown vancouver in relation to the urban heat-island effect. Retrieved January 23, 2021, from https://ibis.geog.ubc.ca/courses/geob370/students/class06/wong/discussion.html

Blackman, R., & Yuan, F. (2020). Detecting Long-Term Urban Forest Cover Change and Impacts of Natural Disasters Using High-Resolution Aerial Images and LiDAR Data. *Remote Sensing*, *12*(11), 1820. https://doi.org/10.3390/rs12111820

Carrasco, L., Giam, X., Papeş, M., & Sheldon, K. (2019). Metrics of Lidar-Derived 3D Vegetation Structure Reveal Contrasting Effects of Horizontal and Vertical Forest Heterogeneity on Bird Species Richness. *Remote Sensing*, *11*(7), 743. https://doi.org/10.3390/rs11070743

Chen, Q., Baldocchi, D., Gong, P., & Kelly, M. (2006). Isolating individual trees in a savanna woodland using small footprint lidar data. *Photogrammetric Engineering and Remote Sensing*, Vol. 72, pp. 923–932. https://doi.org/10.14358/PERS.72.8.923

City of Vancouver Open Data Portal. (2018). LiDAR 2018. Retrieved October 27, 2020, from https://opendata.vancouver.ca/explore/dataset/lidar-2018/information/

Dalponte, M., & Coomes, D. A. (2016). Tree-centric mapping of forest carbon density from airborne laser scanning and hyperspectral data. *Methods in Ecology and Evolution*, *7*(10), 1236–1245. https://doi.org/10.1111/2041-210X.12575

Doodles, M. (2021). Land Use, Roads (and Parking). Retrieved February 27, 2021, from https://doodles.mountainmath.ca/blog/2016/02/29/land-use/

ESRI. (2021). Forest-based Classification and Regression (Spatial Statistics)—ArcGIS Pro | Documentation. Retrieved April 9, 2021, from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/forestbasedclassificationregression.htm

Fetene, A., & Worku, H. (2013). Planning for the conservation and sustainable use of urban forestry in Addis Ababa, Ethiopia. *Urban Forestry and Urban Greening*, *12*(3), 367–379. https://doi.org/10.1016/j.ufug.2013.03.004

GISGeography. (2021). Landsat 8 Bands and Band Combinations - GIS Geography. Retrieved February 27, 2021, from https://gisgeography.com/landsat-8-bands-combinations/

Gordon, J. S. (2013). Conducting a Community Tree Inventory. *Mississippi State University*. Retrieved from https://extension.psu.edu/conducting-a-community-tree-inventory

Gülçin, D., & van den Bosch, C. C. K. (2021). Assessment of Above-Ground Carbon Storage by Urban Trees Using LiDAR Data: The Case of a University Campus.

Forests, *12*(1), 62. https://doi.org/10.3390/f12010062

Hijmans, R. J., van Etten, J., Sumner, M., Cheng, J., Baston, D., Bevan, A., … Wueest, R. (2020). *Package "raster" Type Package Title Geographic Data Analysis and Modeling*. Retrieved from https://cran.r-project.org/package=raster

Hooper, T., & Parlow, M. (2018). Using LiDAR to identify tree species. In U. Michel & K. Schulz (Eds.), *Earth Resources and Environmental Remote Sensing/GIS Applications IX* (Vol. 10790, p. 36). https://doi.org/10.1117/12.2326569

Kang, W., Minor, E. S., Park, C. R., & Lee, D. (2015). Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. *Urban Ecosystems*, *18*(3), 857–870. https://doi.org/10.1007/s11252-014-0433-5

Khatami, R., Mountrakis, G., & Stehman, S. V. (2016). A meta-analysis of remote sensing research on supervised pixel-based land-cover image classification processes: General guidelines for practitioners and future research. *Remote Sensing of Environment*, *177*, 89–100. https://doi.org/10.1016/j.rse.2016.02.028

Konijnendijk, C. C., Ricard, R. M., Kenney, A., & Randrup, T. B. (2006). Defining urban forestry - A comparative perspective of North America and Europe. *Urban Forestry and Urban Greening*, *4*(3–4), 93–103. https://doi.org/10.1016/j.ufug.2005.11.003

Kwak, D., Lee, W., & Lee, J. (2006). Predicting Forest Stand Characteristics. *MAPPS/ASPRS 2006 Fall Conference*, (Dcm). Retrieved from https://www.researchgate.net/publication/228418816

Li, S., & Chen, X. (2014). A new bare-soil index for rapid mapping developing areas using landsat 8 data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *40*(4), 139–144. https://doi.org/10.5194/isprsarchives-XL-4-139-2014

Lindenmayer, D. B., & Laurance, W. F. (2017). The ecology, distribution, conservation and management of large old trees. *Biological Reviews*, *92*(3), 1434–1458. https://doi.org/10.1111/brv.12290

Liu, L., Coops, N. C., Aven, N. W., & Pang, Y. (2017). Mapping urban tree species using integrated airborne hyperspectral and LiDAR remote sensing data. *Remote Sensing of Environment*, *200*, 170–182. https://doi.org/10.1016/j.rse.2017.08.010

Ma, L., Li, M., Ma, X., Cheng, L., Du, P., & Liu, Y. (2017, August 1). A review of supervised object-based land-cover image classification. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 130, pp. 277–293. https://doi.org/10.1016/j.isprsjprs.2017.06.001

McElhanney Consulting Services LTD. (2018). *[Orthophotos, University of British Columbia Vancouver Campus], 2018* (V1 ed.; U. of B. C. C. and C. Planning., Ed.). V1 ed. https://doi.org/hdl:11272.1/AB2/1EQCYQ

McElhanney Consulting Services LTD. (2020). *[Orthophotos, University of British Columbia Vancouver Campus], 2020* (V1 ed.; U. of B. C. C. and C. Planning., Ed.). V1 ed. https://doi.org/hdl:11272.1/AB2/6PFOWL

McPherson, E. G. (1998). Atmospheric carbon dioxide reduction by Sacramento's urban forest. *Journal of Arboriculture*, *24*(4), 215–223.

Mcpherson, E. G., & Ustin, S. L. (1998). Infiltration, Runoff and Erosion Processes

View project Remote sensing ecosystem function View project. In *Article in Journal of Arboriculture*. Retrieved from https://www.researchgate.net/publication/265225006

Moe, K. T., Owari, T., Furuya, N., & Hiroshima, T. (2020). Comparing individual tree height information derived from field surveys, LiDAR and UAV-DAP for high-value timber species in Northern Japan. *Forests*, *11*(2), 223. https://doi.org/10.3390/f11020223

Munro, S. A., & Hauner, L. M. (1980). Campus Trees: A Self-guided Tour. Retrieved November 9, 2020, from The University of British Columbia website: https://www.library.ubc.ca/archives/campus_trees_2.pdf

O'Laughlin, J., & Cook, P. S. (2003). Inventory-based forest health indicators: Implications for national forest management. *Journal of Forestry*, *101*(2), 11–17. https://doi.org/10.1093/jof/101.2.11

Rodrigues, J. J. S., Brown, K. S., & Ruszczyk, A. (1993). Resources and conservation of neotropical butterflies in urban forest fragments. *Biological Conservation*, *64*(1), 3–9. https://doi.org/10.1016/0006-3207(93)90377-D

Roussel, J.-R., Goodbody, T. R. H., & Tompalski, P. (2021). The lidR package. Retrieved February 12, 2021, from https://jean-romain.github.io/lidRbook/

Silva, C. A., Hudak, A. T., Vierling, L. A., Loudermilk, E. L., O'Brien, J. J., Hiers, J. K., … Khosravipour, A. (2016). Imputation of Individual Longleaf Pine (Pinus palustris Mill.) Tree Attributes from Field and LiDAR Data. *Canadian Journal of Remote Sensing*, *42*(5), 554–573. https://doi.org/10.1080/07038992.2016.1196582

Su, Y., Ma, Q., & Guo, Q. (2017). Fine-resolution forest tree height estimation across the Sierra Nevada through the integration of spaceborne LiDAR, airborne LiDAR, and optical imagery. *International Journal of Digital Earth*, *10*(3), 307–323. https://doi.org/10.1080/17538947.2016.1227380

Sutherland, I. (2012). *UBC's Urban Tree Canopy: Growing Towards Sustainability or a Declining Resource?* Retrieved from https://open.library.ubc.ca/collections/18861/items/1.0108617

The University of British Columbia. (2017). Vancouver Campus Plan. *Campus and Community Planning*, 1. Retrieved from https://planning.ubc.ca/planning-development/policies-and-plans/campus-land-use-planning/vancouver-campus-plan

The University of British Columbia. (2020a). A Brief History of UBC. Retrieved November 9, 2020, from University Archives Blog website: https://archives.library.ubc.ca/general-history/a-brief-history-of-ubc/

The University of British Columbia. (2020b). Public Realm Plan | UBC Campus & Community Planning. Retrieved October 26, 2020, from https://planning.ubc.ca/planning-development/policies-and-plans/public-realm-planning/public-realm-plan

The University of British Columbia Campus and Community Planning. (2007). UBC Natural Systems Study. Retrieved February 27, 2021, from https://architizer.com/idea/141455/

The University of British Columbia Campus and Community Planning. (2013). *[University of British Columbia Vancouver Campus. Campus and Community Planning data]* (V1 ed.; U. of B. C. C. and C. Planning, Ed.). V1 ed. https://doi.org/hdl:11272.1/AB2/ETO8IU

The University of British Columbia Campus and Community Planning. (2017). Land Use Plan. Retrieved December 5, 2020, from https://planning.ubc.ca/planning-development/policies-and-plans/campus-land-use-planning/land-use-plan

ubcjjb. (2019). UBC Geospatial Opendata. Retrieved October 27, 2020, from GitHub website: https://github.com/UBCGeodata/ubc-geospatial-opendata/tree/master/ubcv/landscape

Villaseñor, N. R., Driscoll, D. A., Escobar, M. A. H., Gibbons, P., & Lindenmayer, D. B. (2014). Urbanization Impacts on Mammals across Urban-Forest Edges and a Predictive Model of Edge Effects. *PLoS ONE*, *9*(5), e97036. https://doi.org/10.1371/journal.pone.0097036

Wikipedia. (2020, October 21). Climate of Vancouver. Retrieved November 9, 2020, from https://en.wikipedia.org/wiki/Climate_of_Vancouver

Yang, J., McBride, J., Zhou, J., & Sun, Z. (2005). The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening*, *3*(2), 65–78. https://doi.org/10.1016/j.ufug.2004.09.001