UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC 2017 Stadium Neighbourhood Tree Inventory Project

Alexis Naveau, Alice Miao, Elliot Bellis, Thomas Ikeda

University of British Columbia

VOL 400

September 29, 2017

UBC 2017 Stadium Neighborhood Tree Inventory Project

Report prepared

By: UBC Student Tree Inventory Team

For: UBC Community and Campus Planning

Date: September 29, 2017

University of British Columbia Student Tree Inventory Team

Elliot Bellis, Thomas Ikeda, Alice Miao, Alexis Naveau

Acknowledgements

We would like to thank the SEEDS Biodiversity Coordinators, Emily Rennalls and David Gill, and the Director of Sustainability and Engineering at Community & Campus Planning, John Madden. We would also like give a special thanks to all of the groups and individuals who provided assistance including UBC Campus and Community Planning, members of UBC Building Operations, the Integrated Remote Sensing Studio, Nicholas Coops, Piotr Tompalski, Valerie LeMay, Jerry Mendel, Susan Hunt, Collin Varner, Tahia Devisscher, Cecil Konijnendijik, and all others.

Table of Contents

Executive Summary

In 1998, a professional surveyor was hired to complete a tree inventory of the Vancouver Campus for the University of British Columbia (UBC) Property Trust, creating a database of on-campus trees. The inventory included information on tree species, health condition, diameter at breast height (DBH), and general location of each tree. Unfortunately, the inventory was not kept up to date and we were unable to access the database. However, we were able to access the 2013 UBC Tree Inventory provided by UBC Building Operations. This tree inventory was conducted only for trees located around the academic corridor. It includes information such as tree species, tree condition, removal status, and general location. In addition, the 1998 tree inventory and the 2013 tree inventory are independent from each other as far as we know.

To address the lack of a continuous updated tree inventory, updated tree inventory, and in recognition of the importance of the urban forest on campus, UBC launched an initiative in the summer of 2017 to create an updated tree inventory as part of a larger campus Urban Forest Management Plan. The entire tree inventory survey area includes both the UBC Vancouver campus and surrounding residential neighborhoods, however, due to resource and time constraints, the full campus inventory was divided into multiple stages. Funded by Campus and Community Planning and Faculty of Forestry, in partnership with the UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program and the Integrated Remote Sensing Studio (IRSS), the tree inventory began in June of 2017 in the Stadium Neighborhood Area. This area was selected first because, as of the writing of this manual, there is a site analysis project planned for this area and second, UBC Community and Campus Planning (C&CP) is interested in evaluating this site's urban forest resources. The area represents a variety of urban forest types, including both dense forests and street trees (see **Map 1**).

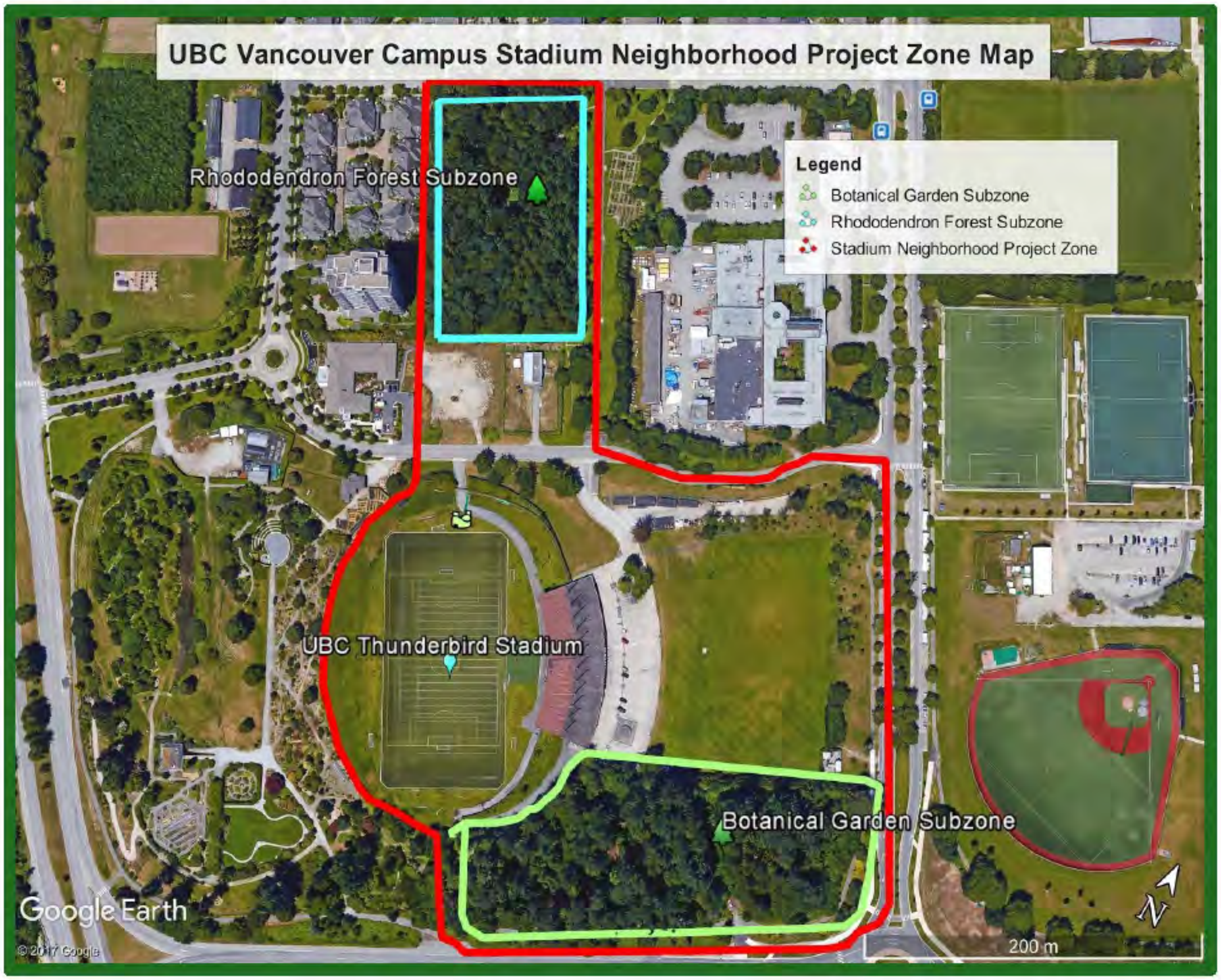
As part of UBC's larger initiative to develop a Urban Forest Management Plan and Biodiversity Strategy for the entirety of the Vancouver Campus, two main objectives guided this project:

1. To create a tree inventory of stadium neighborhood

2. To develop a handbook for future tree inventory projects at the UBC Vancouver campus

This project was completed in August of 2017. This report is intended to explain the project background, methodology, results, and provide recommendations for future campus tree inventories. A separate UBC Vancouver Campus Tree Inventory Handbook has also been prepared to train future inventory surveyors.

Ultimately, we measured 534 trees in-field at the Stadium Area zone. All 534 trees are measured for their height (m), diameter at breast height (DBH in mm), crown width (m), ground cover (%), overall health condition and risk of danger to the public. For further information about the data, please contact UBC Campus and Community Planning.



Map 1. 2017 UBC Vancouver campus Stadium Neighborhood project zone

1.0 Introduction

1.1 Project Description

As part of a larger initiative to develop a new Urban Forest Management Plan and Biodiversity Strategy for the Vancouver Campus, the University of British Columbia (UBC) began developing a plan to create an updated tree inventory in the summer of 2017. Tree inventories are a foundational part of an effective approach to urban forest management. They can enable managers and planners to quantify ecosystem services (such as storm water management, energy efficiency, air quality improvement, etc), provide data to prioritize tree and urban biodiversity management, and aid in future campus development (Elmendorf, 2015). Particularly, it allows planners to monitor and manage campus forest resources as they change over time. The Stadium Neighborhood Project Area was specifically chosen because, as of the writing of this report, a site analysis project is currently being conducted to support the development of a new campus neighbourhood within the limits of the study area. Because of this, the area was a priority to survey for UBC Campus and Community Planning in order to analyze the urban forest resources and ecosystem services provided. This report introduces the project background, objectives and rationales, methods, and the findings from our field data. It also details the implementation of lidar for both project site and future use and proposes a protocol for continuation of the UBC Tree Inventory Project.

1.2 Site and Project Background

The Project Area is in the southern region of the UBC Vancouver campus between East Mall and West Mall (see **Map 1**). The area includes three main subzones: the **Rhododendron Wood subzone**, **street tree subzone**, and **Botanical Garden subzone**. Each subzone has a distinct tree composition and landscape style, resulting a need for differentiation (see **Appendix A.5** for an overview of canopy hight model for the project zone).

Rhododendron Wood is a 4.5 hectare closed-canopy forest well-used by the Hawthorn Place neighborhood residents. The forest was named after the, once abundant, rhododendrons.

However, the flowers perished in the early 1980's due to the Douglas-fir (*Pseudotsuga menziesii*) trees whose continued growth led to the closing of the upper canopy, preventing the flowers requirement of light. Additionally, the irrigation system fell into disrepair, affecting the water intake of the flowers. Unfortunately, this forest is an even-aged monoculture of Douglas-fir trees, making it heavily susceptible to abiotic/biotic disturbances. It should be noted that the woods hold significant cultural and historical value to the UBC campus acting as both a long-established anchor to southern campus and a frequently used greenspace.

1.3 Project Objectives and Rationale

Note: *For the cultural evaluation of the project zone, please contact the primary investigator, Cecil Konijnendijk.*

This pilot project is the first step towards UBC's initiative to create a tree inventory for the Vancouver campus. The main objectives for this project are as follows:

1. To create a tree inventory of Stadium Neighborhood
2. To develop a handbook for future tree inventory surveyors

In contrast to a forest inventory, commonly conducted in remote, mountainous areas with uneven terrain and relatively few tree species, an urban forest inventory faces unique challenges. These include construction barriers blocking the surveyor's view, frequent tree plantings/removals, and species identification challenges due to exotic plantings. Lidar is a valuable tool to address these challenges because tree location (coordinates), tree height (m), and tree crown area (m^2) can be extracted if nothing is blocking the tree vertically, making lidar both time and economic efficient. UBC collects lidar data of the Vancouver campus regularly every year, allowing the data to be used to analyze urban canopy cover change. Finally, it is possible to identify the species of every tree lidar identified when used alongside orthographic photos. However, by using different algorithms during lidar data processing, surveyors can extract data with different accuracy levels. The collection of accurate data is critical for a tree inventory's usability in future campus and community development. Therefore, a lidar tree crown identification accuracy assessment was incorporated in the project methodology.

The project consists of three procedures:

1. Collect field data to create a tree inventory for the stadium neighborhood
2. Analyze the lidar tree crown identification accuracy using field data to determine feasibility of lidar for the entire UBC Vancouver campus
3. Produce a working handbook to train future inventory surveyors

2.0 Field Data Collection

2.1 Methods

Please reference **Figure 1 and Map 2 for a timeline of our project methods.*

Initially, attributes were chosen for field work mensuration based off pre-existing tree inventory guidelines. According to the 2015 lidar data, a total of 627 trees were identified automatically within the project zone using initial tree identification algorithms, all of which the project team originally planned on measuring to create a forest database of the stadium neighbourhood. Additionally, to assess the accuracy of the lidar data, a ground-truthing survey was needed to measure all trees in the project area. Therefore, field work was initially conducted by measuring all individual trees within the project area. The mobile GPS application, Avenza Maps™, was used on an iPhone device to locate a tree on site based on the GPS location provided by lidar (see **A.1** for Avenza Maps™ example). In the beginning, all street trees near the Thunderbird Stadium were identified by species, and measured for their DBH (cm), height (m), crown width (m), ground cover (%), mortality, and health/risk levels (For definitions of each measurement attributes and criteria, see **A.2**). Furthermore, pictures were taken of trees in the field that were challenging to identify or were unique species.

Upon measuring the trees in the Rhododendron Wood subzone, the canopy density and small trees in the understory presented several problems. First, the dense canopy prevented a strong GPS signal, making it difficult for the survey crew to locate the trees lidar identified. Trees measure in-field in these subzones were not measured for their height because they were too tall and the stands were too dense to measure using the tools available to the team in the field. Additionally, lidar was not able to identify understory trees beneath the canopy so the estimate of 627 trees did not reflect the actual number of trees in the project area. This resulted in a shift in the methodology in the Rhododendron Wood and Botanical Garden subzones. Rather than conducting a full tree census, only trees with heights above 40 meters as measured by lidar were recorded for all attributes except their height. Upon completion, we had collected full data on all street trees and sufficient information for the Rhododendron Wood subzone to evaluate overall tree status in the two subzones; it was clear only a small sampling of data in the Botanical Garden subzone was sampled.

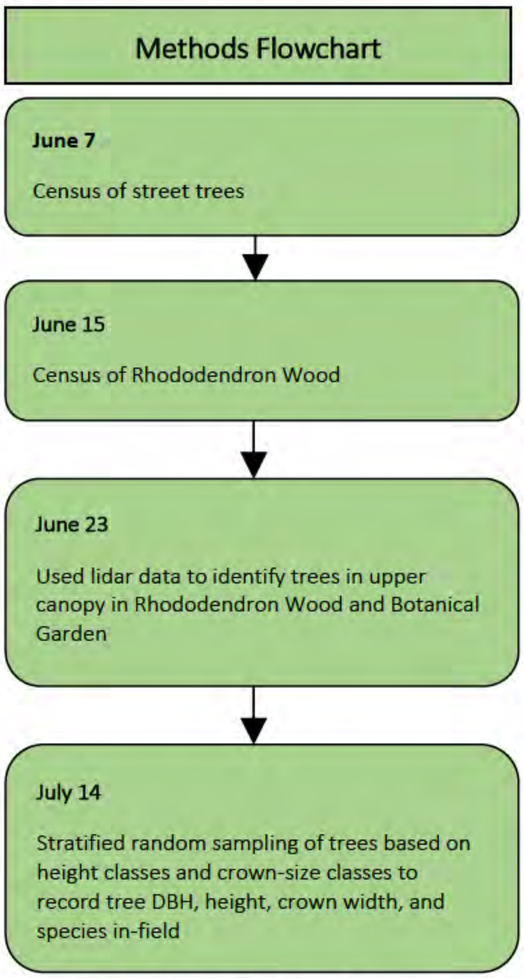
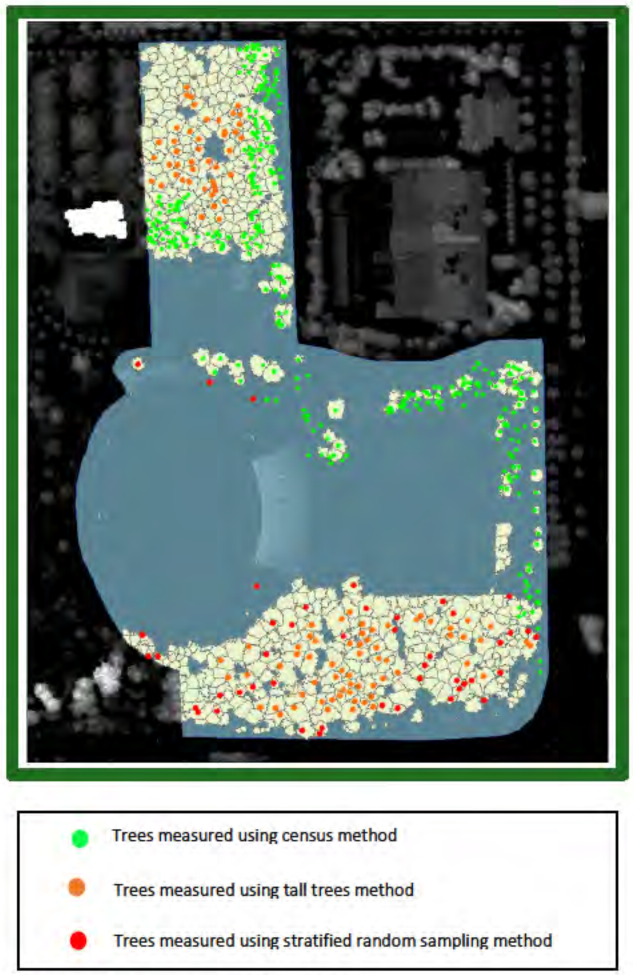


Figure 1: Flowchart of field work timeline and progress



Map 2: Tree mensuration stages

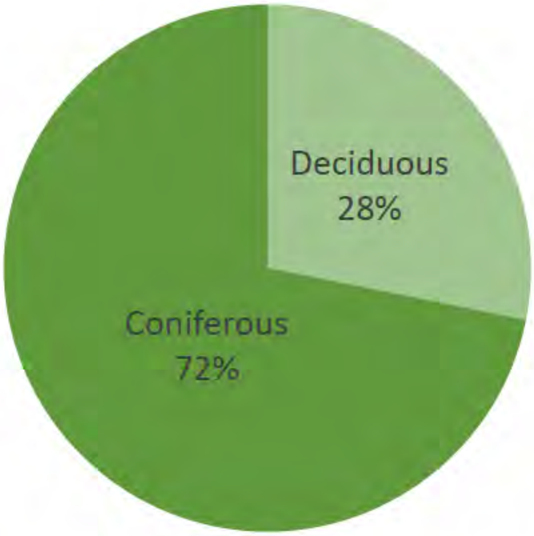
As we continued, we recognized the need for representation of other tree height and crown classes in the Botanical Garden subzone instead of only measuring tall trees. To account for this, a stratified random sampling method was implemented for this subzone. The lidar tree data was stratified into six main strata: small, medium, and large for both tree height (m) and tree crown area (m^2). 20% samples were randomly selected from each stratum to determine trees for field measurement. Using the lidar location for each detected tree, the survey crew then located the randomly selected trees in the field using the Avenza Maps™ application to complete the field measurements in addition to the tall trees previously measured in the Botanical Garden subzone. This allowed us to complete the field data collection, develop a survey method for the future campus-wide tree inventory, and understand the status of the forest in the Botanical Garden subzone.

2.2 Results

2.2.1 Species Distribution

A total of 534 trees were measured during the field work in the project area. **Figures 2 & 3** provide a summary of the distribution of coniferous and deciduous species as well as tree species distribution for the entire project zone (for specific tree species frequency, see **A.3**). **Figures 5- 10** provide the distribution of coniferous and deciduous species, as well as tree species richness for the three subzones individually. Section 2.2.2 shows a selection of four unique tree species that were found on site. Table 1 summarizes the average DBH (mm), height (m), crown width (m), point of failure and point of target for each subzone.

A. Project Zone Distribution



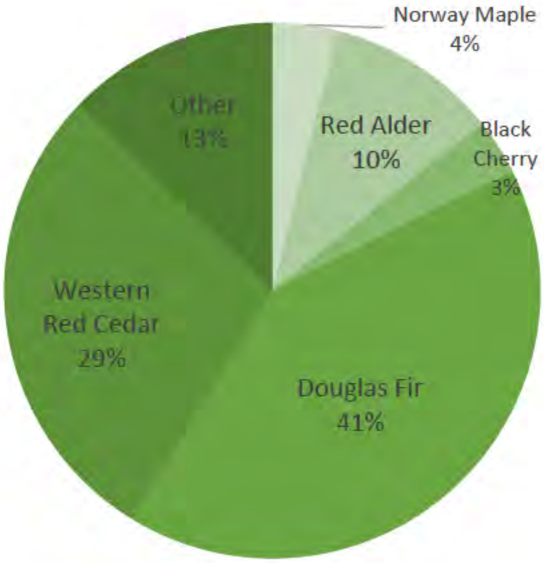
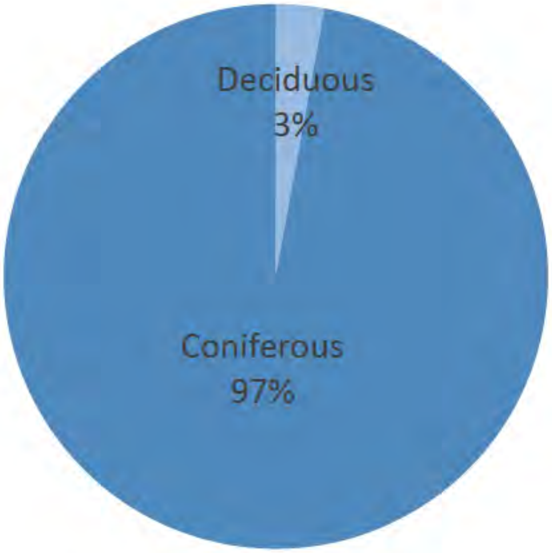


Figure 2: Project zone coniferous and deciduous tree distribution

Figure 3: Project zone tree species richness distribution

B. Rhododendron Wood Subzone Distribution



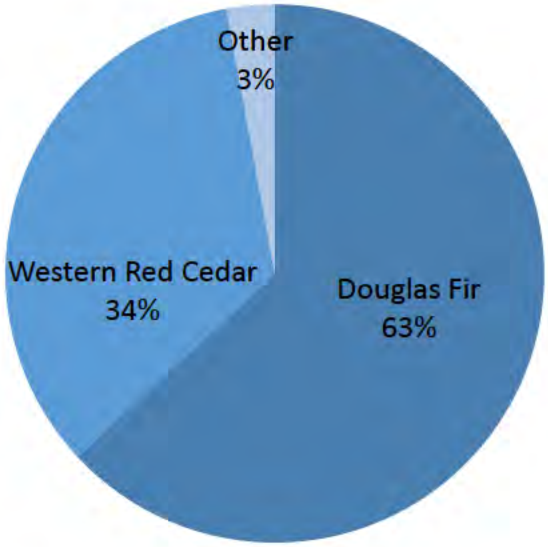


Figure 4: Rhododendron Wood coniferous and deciduous tree distribution

Figure 5: Rhododendron Wood tree species richness distribution

C. Street Trees Subzone Distribution

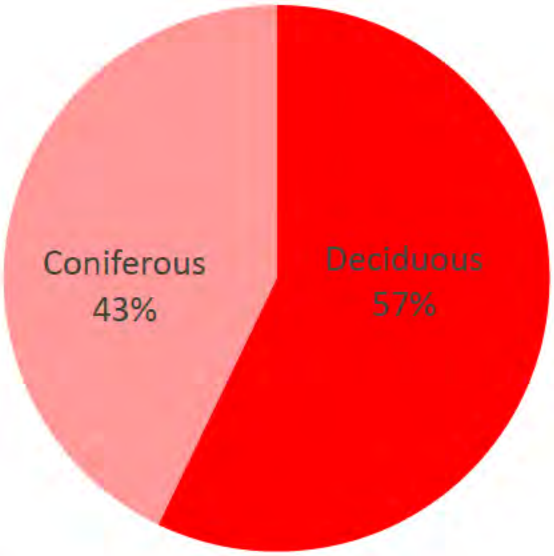


Figure 6: Street subzone coniferous and deciduous tree distribution

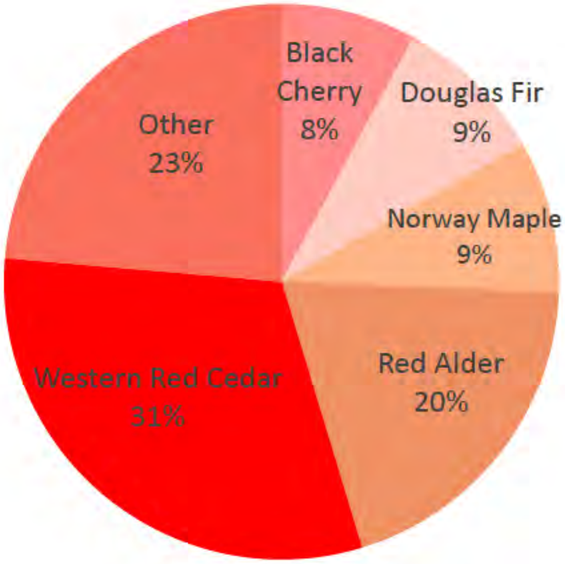


Figure 7: Street subzone tree species richness distribution

D. Botanical Garden Subzone Distribution

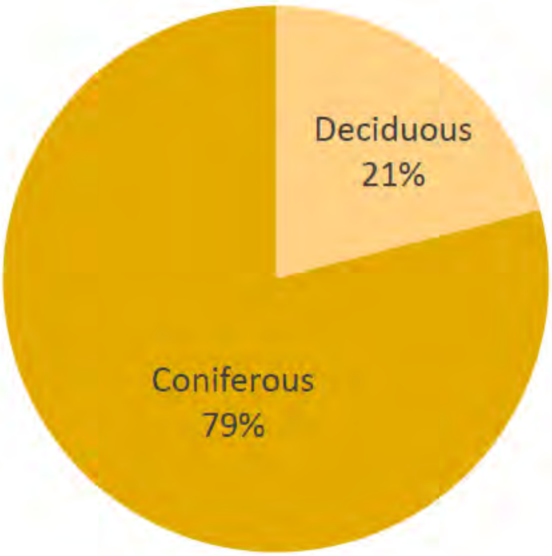


Figure 8: Botanical Garden coniferous and deciduous tree distribution

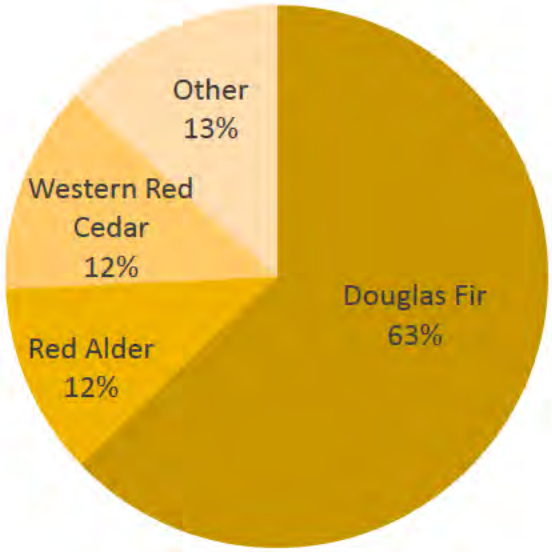


Figure 9: Botanical Garden tree species richness distribution

2.2.2 Unique Trees

The tree inventory team identified some unique tree species in the field. As seen below in **Figure 10**, we located a *Fagus sylvatica 'aspleniflolia'* (**10.a**) on the outskirts of Thunderbird Stadium. Commonly known as a cut leaf European beech, this cultivated tree produces a nut and undistinguished flowers (North Carolina State, n.d.). Located on the border of the Rhododendron Wood Subzone, a Japanese Snowbell (*Styrax japonicus*) (**10.b**) was found; this rather delicate species is known for its white hanging flowers and is native to China, Japan, and Korea (University of Connecticut, n.d.). In the parking lot of the Thunderbird Stadium, newly planted Amur maples (*Acer ginnala*) (**10.c**) can be seen and are a popular street tree species due to their sturdiness (Koetter & Zuzek, 2016). Finally, flowering Dogwood (*Cornus florida*) (**10.d**) was also found close to the Rhododendron Wood and unfortunately, due to insect and disease problems (University of Kentucky, n.d.), had presence of foliage damage.

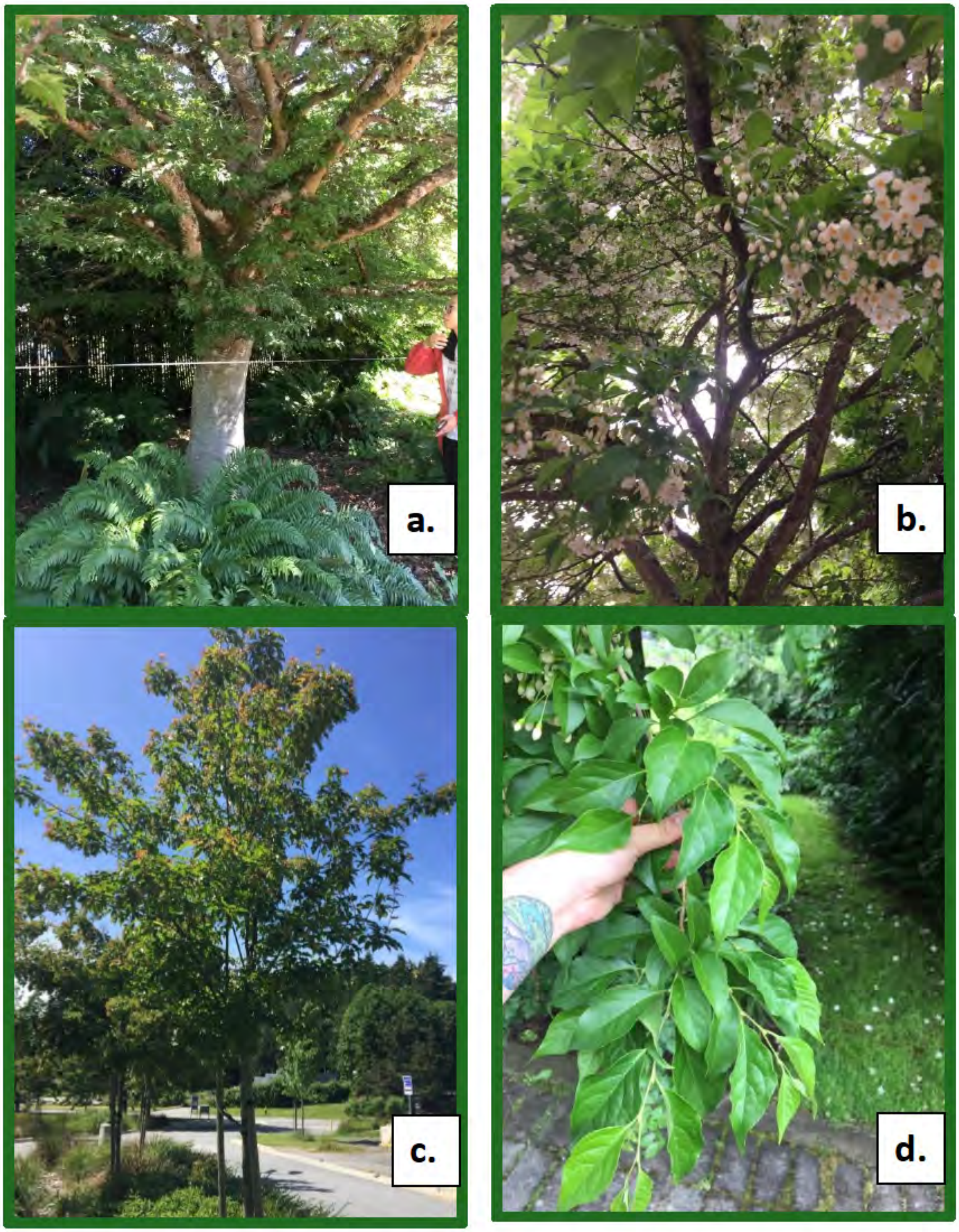


Figure 10 (a-d): Unique tree species found on site include (a) Cut leaf European beech (Fagus sylvatica 'Asplenifolia'), (b) Japanese snowbell (Styrax japonicas), (c) Amur maple (Acer ginnala), and (d) Flowering dogwood (Cornus florida).

2.2.3 Field Data Summary

Main findings from our field data collection can be seen in **Table 1** below. In summary, the Botanical Garden subzone had the largest average DBH and crown width but also had the largest average point of target due to mechanical impact from the residing Ropes Course tree platforms. The street trees subzone had the smallest DBH and the highest average point of failure likely because of the high frequency of trees with insect invasion as well as dead trees. Finally, the Rhododendron Wood subzone had the lowest average crown width and lowest average point of target.

Table 1. Tree physical characteristics in each subzone

	Rhododendron Wood Subzone	Botanical Garden Subzone	Street Trees Subzone
Average DBH (mm)	457.11	752.58	208.64
Average Height (m)	--	--	10.11
Average Crown Width (m)	6.54	8.71	6.63
Average Point of Failure	1.7	1.3	1.8
Average Point of Target	1.0	1.8	1.2

Notes: 1. Trees in Botanical Garden and Rhododendron subzones were not measured for height due to limitations of survey sites. Therefore, there is no information on the average height for the two subzones.
2. Point of failure is ranked from 1 to 5. "1" indicates a tree is health and has low possibility of failure. For detailed criteria see A.2
3. Point of Target is rank from 1 to 3 indicating the frequency of usage. "1" indicates occasional use by residents and "3" indicates heavy usage. For detailed criteria see A.2.

2.3 Discussion

As shown in **Figures 4 & 8,** even though conifers are the dominant species in both forested subzones, the species composition differs between the Rhododendron Wood subzone and Botanical Garden subzone. Although the Botanical Garden subzone has a similar percentage of Douglas-fir on site as the Rhododendron subzone, the Botanical Garden has a higher richness in species with less western red cedar (*Thuja plicata*) and a greater variety of deciduous trees (see **Figures 4 & 5**). In the street tree subzone, deciduous trees (57.14%) were the dominant classification of trees (see **Figure 6**). However, western red cedar appeared to be the most commonly planted street trees within the project zone, red alder the second most (19.7%), and Douglas-fir and Norway maple both were the third most commonly planted street trees (see **Figure 7**). Overall for the entire project zone, 72% of the surveyed trees were conifers and 26 different tree species were identified with a wide array of species richness (see **Figures 2, 3, & A.3**). A few notable and unique trees that were found in the project zone can be seen in **Figure 10**.

Regarding tree physical characteristics, the survey results show that the trees with the largest average DBH and crown width were found in the Botanical Garden subzone. Although the trees in all three subzones are relatively healthy with a low Point of Failure on average, the trees in the Botanical Garden subzone have the lowest average Point of Failure value, whereas street trees have the highest. In addition, the Botanical Garden experiences more frequent use and thus the trees in the garden have a higher Point of Target rating than the other two subzones. This is due, in part, to the activities in the rope course at the eastern side of the Botanical Garden subzone.

3.0 Lidar Tree Crown Identification Accuracy Assessment

3.1 Methods

3.1.1 Lidar Data and Algorithms

**Section 3.1.1 written by: Piotr Tompalski*

Lidar data was collected on May 31st, 2015 with the average point density of 25.7 points/m^2. Lidar returns that were classified as "ground" were used to normalize 'point heights' to 'heights above ground level'. A canopy height model (CHM) was then created to visually represent maximum height above ground for each 0.5 m pixel. The data was processed using a combination of tools available in Fusion and LAStools software packages.

An individual tree was detected by identifying local maxima on the CHM. The highest cell within a moving window is identified as a treetop, with the size of the window changing depending on the height of the cell upon which it is centered (i.e. the higher the cell, the larger the window). The variable window size allows adjustment for tree detection for varying crown sizes. A marker-controlled watershed segmentation was used to delineate tree crowns. The detected treetops were used to constrain the algorithm so that a tree crown is delineated only where a treetop exists, avoiding over-segmentation. The results were saved as vector files, with height and crown area derived for each detected tree. In total, there were 627 trees detected and measured by lidar within project boundaries.

3.1.2 Lidar Tree Crown Identification Accuracy

The first step of determining lidar tree crown identification accuracy was to determine the percentage of trees found in the field that were accurately detected by lidar. As shown in **Figure 11**, if the GPS point placed in the field using the Avenza Maps™ app for a single tree overlapped within a tree crown as determined by lidar when these layers were overlaid onto each other in ArcGIS, it was referred to as an "accurate tree" (see **Figure 11 a**) and all else as an "inaccurate tree". Other scenarios we faced include 1) a tree found in-field whose GPS point did not overlap any canopy, as identified by the lidar algorithm (see **Figure 11 b**), 2) multiple GPS points for trees found in-field overlapping with the same, single tree crown identified by lidar (see **Figure 11 c**), and 3) no trees found in-field under a tree crown (often lidar mistook a street sign or other manmade structure as a tree) (see **Figure 11 d**).

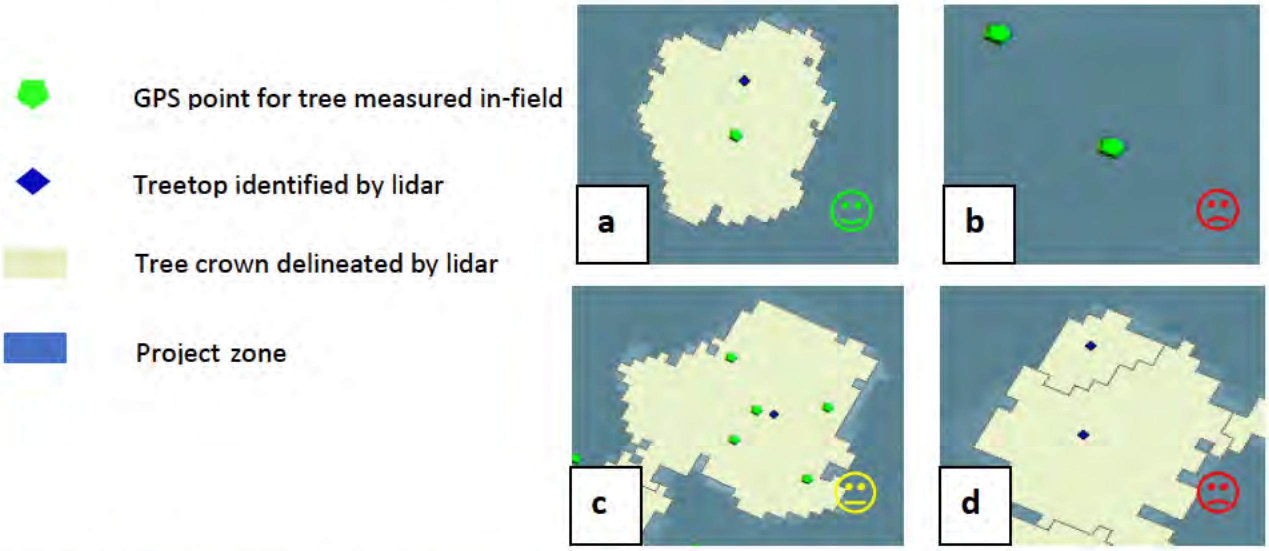
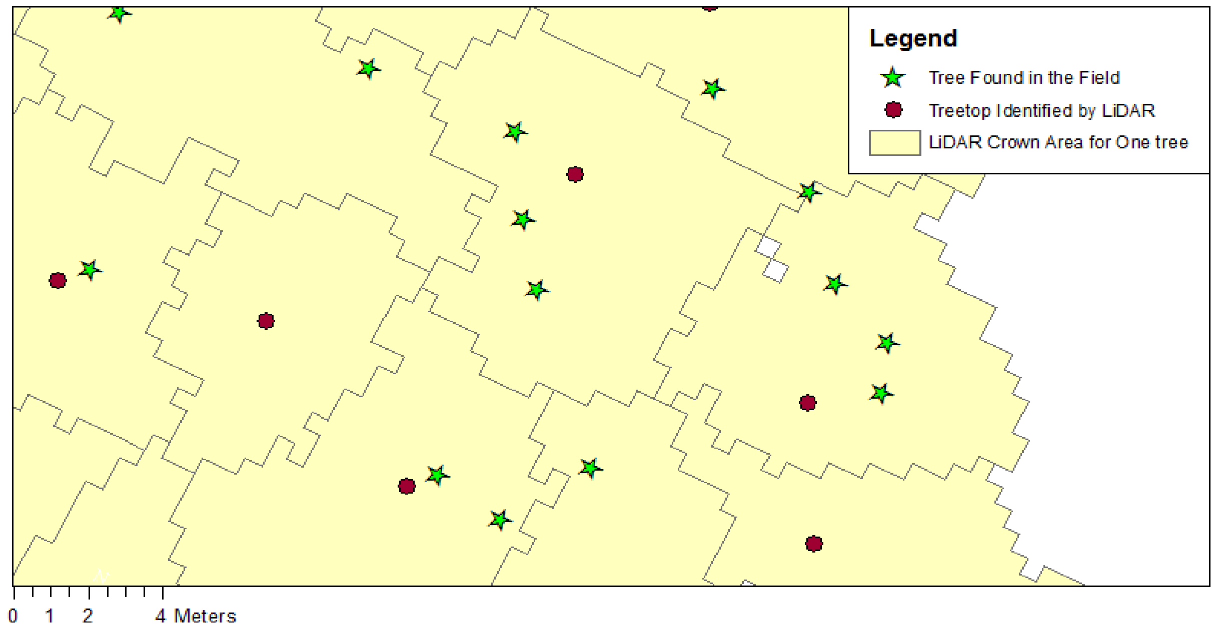


Figure 11: Lidar tree crown identification scenarios

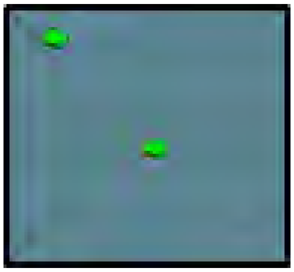
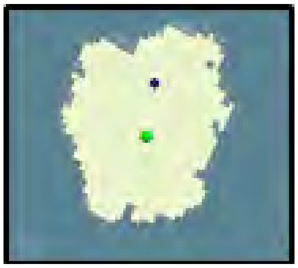
It is important to note, however, that the GPS device used (an iPhone) potentially contributed significant error, as the accuracy of the device is estimated to be within ±10 m of actual location. This was due to weak cellular signal received and interference under the forest canopy. However, the use of this GPS device still allowed surveyors to estimate how many trees were under a tree crown as detected by lidar. Often, we found several trees under a single crown in the heavily forested areas because, as expected, lidar tends to assign a 'treetop' to the tallest trees and fails to pick up understory trees (see **Figure 12** below).

Figure 12: Lidar canopies often failed to locate trees in the understory



Therefore, we developed a system to classify the GPS points collected in field into accurate and inaccurate trees. This attribute was included because lidar identifies only one of the trees-under-canopy (TUC) and the rest of the TUCs are not accounted for. The final attribute, "Accurate", indicates the accuracy of the lidar data compared to the ground-truthed trees. A "yes" indicates that the lidar algorithm accurately identified a treetop as identified in-field. A "no" indicates that the lidar algorithm did not accurately identify a treetop as found in-field. (see Table 2 for detailed breakdown of the different scenarios).

Table 2. Tree accuracy scenarios

Accurate?	Description	Illustration
NO	Tree detected by LiDAR that was not found in field.	
NO	Tree GPS point outside of any tree crown area. • Often small tree in the understory or new planting after lidar data was collected	
NO	A TUC whose treetop was not detected by LiDAR in terms of the height but its crown was included as a part of a nearby tree's crown. • Often a tree hidden by the canopy of a taller tree.	
YES	A TUC with the height nearest to that which lidar had identified as the height of the treetop for this specific tree crown. • Often a taller tree in the upper canopy covering trees in the lower canopy.	
YES	A single stem tree with no other trees under its canopy.	

Note: "TUC"- Tree under canopy.

To verify the lidar identification accuracy, we outlined two areas within our project zone based on forest type: the forested and the street tree areas. The forested area consists of two subzones, the Botanical Garden and the Rhododendron Forest, and the street tree subzone captures the trees from the rest of the project zone (**Map 1**).

The two areas were created because the forested areas have a denser and more continuous canopy than the street tree area. This requires the use of different algorithms to develop models for accurate treetop and tree crown identification. This could potentially result in different levels of lidar tree crown identification accuracy between the two areas. To analyze this, we compared the total number of trees to the number of accurate trees within each area.

3.2 Results

Table 3 shows the percentage of accurate trees in relation to the total number of trees measured in-field for the two areas, both of which were below 50%.

Table 3. Summary of lidar tree crown identification accuracy

	Forest trees	Street trees
Total number of trees	182	187
Total number of ‘accurate’ trees	74	72
Final lidar tree crown identification accuracy	40.7%	38.5%

Figure 13 shows the lidar tree crown identification accuracy for trees in the street tree area, classified into different height classes. The height class with the highest accuracy was trees 13-19 meters tall at 72.0%. The height class with the lowest accuracy was trees 3-5 meters tall at 17.2%.

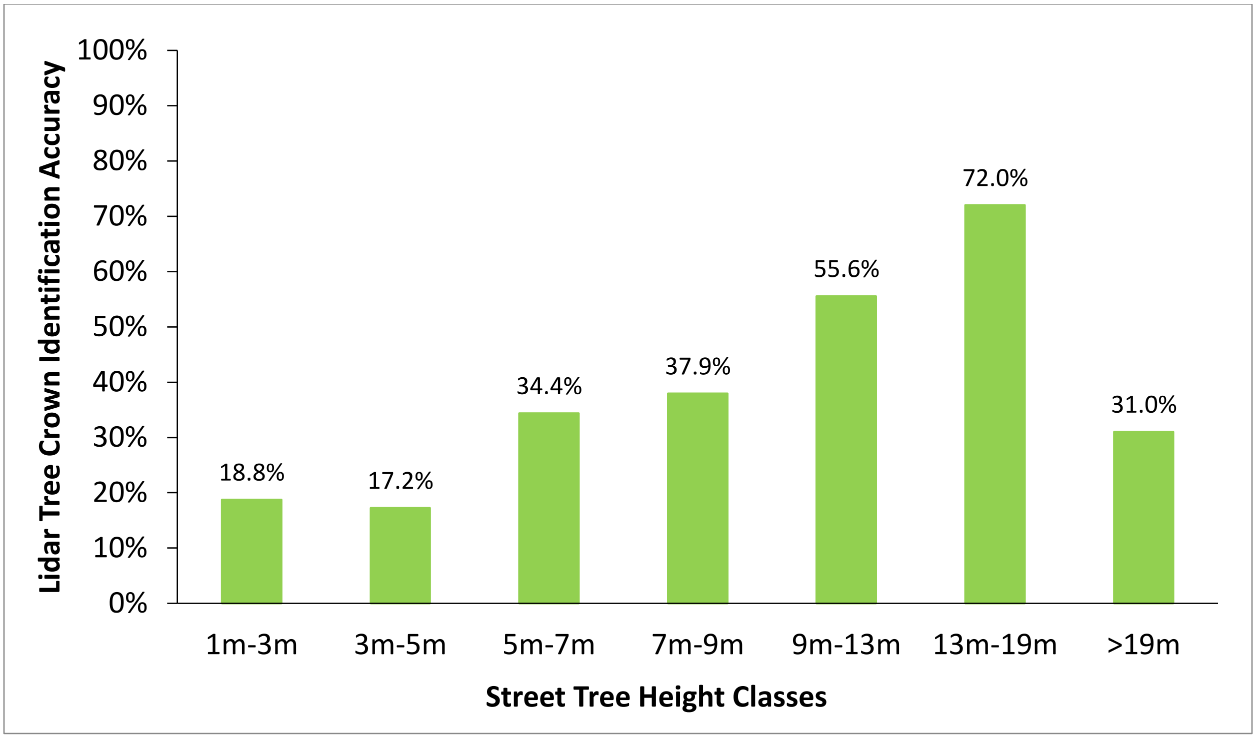


Figure 13: Diagram of the lidar accuracy for different tree height strata in the Street Tree area

3.3 Discussion

Based on our results, the accuracy of the algorithm used for identifying tree crowns was relatively low in identifying trees in both forested and street tree areas as compared to the expected accuracy. Below are a list of possible explanations for the low lidar tree crown identification accuracy for each area:

Factors potentially influencing the low accuracy for the street tree area:

- Abundance of trees smaller than 5 m
- Large amount of noise in lidar data, especially below 5 m
- New tree plantings in the project zone after date of lidar data collection (2015)
- Large margin of error for GPS location

Factors potentially influencing the low accuracy of the forested area:

- Tree canopy interference with GPS
- Large margin of error for GPS location

- Lidar has difficulty penetrating the upper canopy and detecting understory
- The lidar algorithm has difficulty identifying trees located on the forest edge

The purpose of **Figure 13** was to analyze the lidar accuracy in relation to tree height We were only able to do this for the street tree area because we were unable to collect tree height data for the forests, as explained in section 2.1. So, there is a general trend that the lidar accuracy improves for trees in taller height classes. This trend is expected as lidar algorithms are better able to identify features that are taller in relation to their surroundings. However, the tallest height class for trees greater then 19 meters tall goes against this trend as it is the third lowest. One potential reason for this is that there were many multi-stemmed trees in this height class. If the split in the stems was below 1.3 meters, the stems were measured as individual trees whereas if the split was above, the tree was measured as one. Lidar identified one treetop because the multi-stemmed trees were roughly in the same location. These trees were given the same GPS coordinates, however we decided that only one of these trees could be considered an accurate tree. Another graph comparing the same analysis of tree height classes and tree crown identification accuracy considering multi-stemmed trees can be found in the **A.4**.

4.0 UBC Campus Canopy Cover

A further analysis on estimated campus canopy cover in previous years can be found in a SEEDS report, “UBC’s Urban Tree Canopy: Growing Towards Sustainability or a Declining Resource?” (Sutherland, 2012). Sutherland calculated a canopy cover of 30% for UBC campus using 2009 lidar data. However, the 2017 tree inventory team calculated an estimated canopy cover of 27% using 2015 lidar data which suggests a decline in campus canopy cover. **Map 3** below provides an overview as to where campus trees are located, assuming the lidar algorithm used provides 100% accuracy.

Map 3: UBC Vancouver campus canopy cover distribution using 2015 lidar data

5.0 Conclusion

5.1 Field Data

To summarize our findings from the in-field data collection, 26 different tree species were found in the project zone (see **A.3**), with Douglas-fir and western red cedar being the two most common species. In terms of tree height and crown area, trees found in the Botanical Garden and Rhododendron Wood subzones are taller in height and larger in crown area than in the street tree subzone. The trees within the project site were determined to generally be in good health and have a low risk of failure.

5.2 Lidar Implementation

Regarding the accuracy of the lidar algorithms, we found that it was relatively low in both the forested and street tree areas comparing to the expected accuracy. For the creation of a tree inventory, it is desirable to get as close as possible to 100% accuracy. To address this, accuracy can be improved by training lidar using different algorithms on various urban forest types which would accommodate the varying forest composition of the Stadium Project Area. Furthermore, by combining up-to-date rectified orthographic photos with lidar data:

1) the UBC campus could use lidar data to analyze ecosystem services for the entire campus including both street trees and forested areas
2) lidar data could be used to support future maintenance procedures for campus trees by providing year-by-year canopy cover for comparison

5.3 Handbook for Future Tree Inventory

For the future development and maintenance of the UBC Vancouver campus tree inventory, the survey team prepared a tree inventory handbook detailing the work so far, the steps required to establish a campus tree inventory based of the assumption that the lidar data is accurate, the field work procedures including a sampling method, and maintenance procedures for the tree inventory. The handbook also introduces a potential modeling method to estimate tree DBH using R, which in turn will be used to project the carbon volume of the urban forest on campus, thus quantifying UBC ecosystem services.

5.4 Limitations and Recommendations

With the completion of the project zone, we recognize the limitations of the study and suggest some recommendations to aid in future projects. Completion of the pilot project led us to deduce three limitations:

1) Time restriction

2)Access to equipment

3) Lack of rectified up-to-date orthophotos

With only three months to complete the pilot project, we could not conduct a full tree census of the entire project zone. Restricted access to equipment during the duration of our project, such as a GPS unit and laser range finder, limited the accuracy of the measurements we collected thus, affecting our data. Finally, absence of rectified and up-to-date orthographic photos constricted our ability to conduct a complete species composition analysis and create a model to estimate DBH.

For future continuation of the UBC Vancouver campus tree inventory project, we recommend addressing the previously stated limitations, particularly:

- obtaining rectified orthographic photos
- improving lidar algorithms
- increasing frequency and seasons lidar is collected
- conducting analyses on the various attributes collected

Once the accuracy of lidar tree crown identification is improved, we can have a tree inventory protocol relies on lidar data. This inventory data will allow us to further calculate tree volume, determine campus carbon storage status, and estimate above/under-ground biomass. This will in turn, help assess campus carbon balance. The protocol consists of below steps:

5.5 Future Steps

Future steps to be taken for continuing campus-wide tree inventory project are as followed:

1) **Refine Canopy Cover**
   a) Time required: 1-2 days
   b) Labour: 1 person, well-trained in lidar data
   c) Purpose: to refine the accuracy of vegetation classification to achieve an accuracy of 70-90%
   d) Action: to manually distinguish building from high vegetation (canopy)
2) **Improve Accuracy of Tree Crown Detection-Field Work**
   a) Time required: 1 month
   b) Labour: 3 full time students
   c) Purpose: to obtain reference data from different forest types
   d) Action: to measure 500 trees for DBH and height on main mall and street trees near forestry
3) **Improve Accuracy of Tree Crown Detection-Algorithm Testing**
   a) Time required: 2.5 weeks
   b) Labour: Piotr Tompalski
   c) Purpose: improve lidar detection accuracy by testing different algorithms
4) **Rectify orthographic photo**
   a) Time: 1-1.5 months per 1 year orthographic photo. Maybe faster if all orthographic photos align perfectly (unlikely)
   b) Labour: 1 to 2 full time, trained student(s)
   c) Purpose: to know tree species (species groups) to help build models
   d) Action: Manually rectify orthographic photo in both ENVY and ArcGIS
5) **Create DBH Model**

Finally, creating and maintaining a campus tree inventory is a major step towards UBC's initiative to create an Urban Forest Management Plan along with the Biodiversity Strategy, both foundational plans aiding in UBC's vision to be a world leader in urban forest management. Utilizing remote sensing technology to assist in the creation and maintenance of the tree inventory will help UBC to best manage their trees in a time saving way. Further, the need for continued maintenance both enables UBC to monitor the changes of campus urban forest resources and provides an opportunity for community engagement between volunteers, students, and/or a full time UBC employee. A campus tree inventory enables UBC and the campus community to form an ongoing connection with its landscape which is critical in creating a greener campus environment.

References

Brand, M. H. (n.d.). University of Connecticut Plant Database: Styrax japonicus. Retrieved August 28, 2017, from http://www.hort.uconn.edu/plants/detail.php?pid=478

Elmendorf, W. (2015, January 14). Conducting a Commmunity Tree Inventory *PennState Extension*. Retrieved August 29, 2017, from http://extension.psu.edu/natural-resources/forests/news/2015/conducting-a-community-tree-inventory

International Society of Arboriculture. (2013). ISA Basic Tree Risk Assessment Form. First Edition. Retrieved August 29th, 2017, from http://www.isa-arbor.com/education/onlineresources/basictreeriskassessmentform.aspx

i-tree. (2017). I-tree ECO field guide. Available from https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6_FieldManual.pdf [accessed on May 6, 2017]

Koetter, R., & Zuzek, K. (2016). University of Minnesota Extension: Amur maple. Retrieved August 28, 2017, from http://www.extension.umn.edu/garden/yard-garden/trees-shrubs/amur-maple/index.html

Marthews TR, Riutta T, Oliveras Menor I, Urrutia R, Moore S, Metcalfe D, Malhi Y, Phillips O, Huaraca Huasco W, Ruiz Jaén M, Girardin C, Butt N, Cain R and colleagues from theRAINFOR and GEM networks (2014). Measuring Tropical Forest Carbon Allocation and Cycling: A *RAINFOR-GEM* Field Manual for Intensive Census Plots (v3.0). *Manual*, Global Ecosystems Monitoring network, http://gem.tropicalforests.ox.ac.uk/

North Carolina State College of Agriculture & Life Sciences. (n.d.). Fagus sylvatica 'Asplenifolia'. Retrieved August 28, 2017, from https://plants.ces.ncsu.edu/plants/all/fagus-sylvatica-asplenifolia/

Östberg, J., Delshammar, T., & Busse Nielsen, A. (2013). *Standards for Conducting Tree Inventories in Urban Environments* (1st ed., Publication No. 2012:7). Alnarp, Sweden: Swedish University of Agriculture Sciences.

Pokorny, J. (n.d.). *Urban Tree Risk Management: A Community Guide to Program Design and Implementation* (Publication). Retrieved August 29, 2017, from USDA Forest Service website: https://www.na.fs.fed.us/spfo/pubs/uf/utrmm/urban_tree_risk_mgmnt.pdf

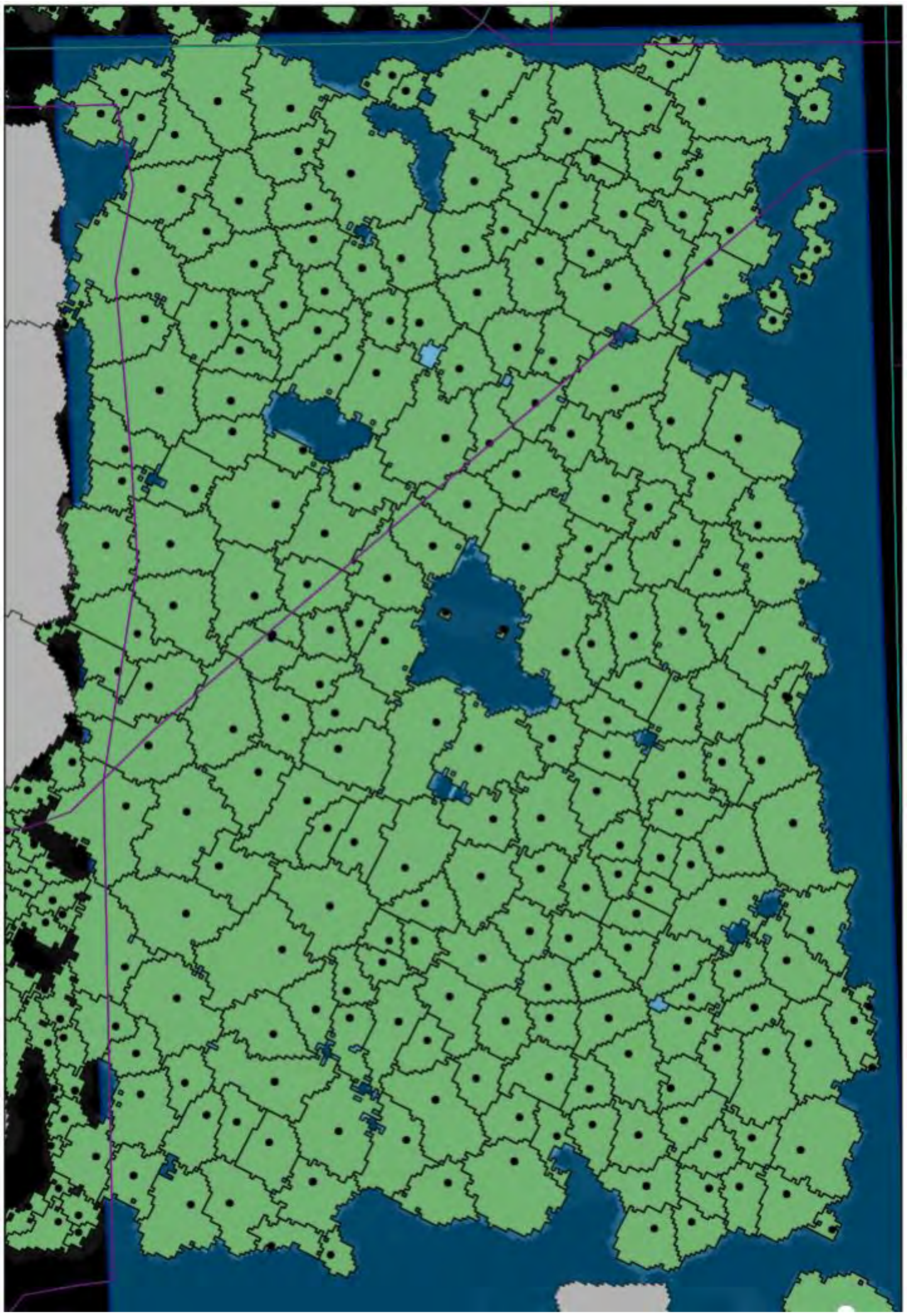
Sutherland, I. (2012). UBC's *Urban Tree Canopy: Growing Towards Sustainability or a Declining Resource?* (Rep.). Vancouver, BC: SEEDS.

University of Kentucky Department of Horticulture. (n.d.). Flowering Dogwood. Retrieved August 28, 2017, from http://www.uky.edu/hort/Flowering-Dogwood

A. Appendix

**For access to the GIS files created in this project, please contact UBC Campus and Community Planning.*

A.1 Avenza Maps™ Example



A.2 Measurement Attributes and Criteria

ATTRIBUTE NAME	ATTRIBUTE DESCRIPTION
OBJECTID *	Auto generated ID
SHAPE *	Shape file type
FID_ZONE_TREE_CRWNS_SPATIALJOIN1	Foreign ID from spatial join between target feature: Zone_Treetops and join feature: Zone_Tree_Crwns. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
JOIN_COUNT	Join count from spatial join between target feature: Zone_Treetops and join feature: Zone_Tree_Crwns. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
TARGET_FID	Same as FID_Zone_Tree_Crwns_SpatialJoin1
ID	LiDAR ID number for each polygon from feature class Zone_Tree_Crwns. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
CROWNAREA	Crown area (m) as determined by LiDAR, taken from Zone_Tree_Crwns feature class. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
POINT_X	X coordinate (in meters) for each point taken from Zone_Treetops feature class. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
POINT_Y	Y coordinate (in meters) for each point taken from Zone_Treetops feature class. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
FID_ADJ_PTS_TREE_DATA_TABLE_	Foreign ID from join between resulting feature class from spatial join between Zone_Treetops and Zone_Tree_Crwns (Shared_Tree_Crwn_Index) and Tree_data_table. Several data points have null values because they do not overlap with any polygons from the Zone_Tree_Crwns feature class
FOLDERPATH	Folder path attribute from Orig_pts feature class created by Avenza Maps™

SYMBOLID	Symbol ID attribute from Orig_pts feature class created by Avenza Maps™
AVENZA_ID	ID number assigned to each tree identified in the field (from Adj_pts feature class, originally "Name" attribute from Orig_pts feature class renamed as "Avenza_ID")
TREE_DATA_TABLE__TREE_ID	Tree ID number continuing from old tree inventory (i.e. start at 11037)
TREE_DATA_TABLE__AVENZA_ID	Same as Avenza_ID
TREE_DATA_TABLE__LATIN	Latin name for species of each tree. Identified in field. Three points given the attribute "maple" because the species for these trees was unable to be identified
TREE_DATA_TABLE__DC	Binary code determined in the field identifying whether tree is deciduous or coniferous: 0 = Deciduous, 1 = Coniferous
TREE_DATA_TABLE__CMN	Common name for species of each tree. Identified in field. Three points given the attribute "maple" because the species for these trees was unable to be identified
TREE_DATA_TABLE__LIDAR_ACC	Coded attribute indicating accuracy of LiDAR in identifying tree. 0 = 1:1 (Tree identified by LiDAR matches reality), 1 = 1:0 (Tree identified by LiDAR, does not exist in reality), 2 = 0:1 (Tree not identified by LiDAR, but exists in reality), 3 = multiple tree tops in one canopy
TREE_DATA_TABLE__AD	Binary code determined in the field identifying whether tree is alive or dead: 0 = dead, 1 = alive
TREE_DATA_TABLE__DBH_MM	Diameter (mm) at Breast Height measured in field
HEIGHT	Height (m) of tree top determined from LiDAR data
TREE_DATA_TABLE__HT	Height (m) of tree top measured in field. Some data points have null values because it was not possible to accurately measure height in the field.
TREE_DATA_TABLE__CRWN_WIDTH	Crown width (m) measured in field by measuring the longest crown axis and crown axis perpendicular to it, adding the two together and then, finally, dividing by 2. Some data points have null values because it was not possible to accurately measure crown width in the field.
TREE_DATA_TABLE__P_F	Coded attribute indicating the Probability of Failure for each tree, determined in field. 1 being least likely to fail and 5 being the most likely

TREE_DATA_TABLE__P_T	Coded attribute indicating the Probability of Target for each tree, determined in field. 1 being occasional target, 3 being frequent target (i.e. there is frequently a target for the tree to potentially harm)
ID_DETECT	Coded attribute indicating if a GPS point fell within a polygon from Zone_Tree_Crwns: 0 = did not fall within polygon, 1 = did fall within a polygon
CLUSTER_INDEX	Coded attribute indicating if tree is a part of cluster of trees: 0 = no cluster, 1 = cluster
SUBZONE	Coded attribute indicating which location category the tree belongs to. 1 = Area in Rhododendron Woods where every tree found was measured and given an GPS point, 2 = All street trees whose GPS points overlap with a polygon from feature class Zone_Tree_Crwns, 3 = trees in both Rhododendron Woods and Botanical Gardens where only the tallest trees were measured and given GPS points, 4 = trees that were measured in field whose GPS point did not overlap with a polygon from feature class Zone_Tree_Crwns
H_ALS	Height (m) measurement taken from overlapping polygon from feature class Zone_Tree_Crwns. Several points share overlapping polygons and thus share height measurements
H_FIELD	Height (m) of tree measured in field using clinometer. When unable to measure in field, given height measurement from overlapping polygon from Zone_Tree_Crwns.
H_MEASURED	Coded attribute indicating if attributes H_ALS and H_field are reliable measurements or if copied over erroneously from a different attribute (i.e. several trees under the canopy of a large tree sharing the LiDAR height measurement of the tallest tree or the LiDAR height measurement being used as the measurement for the clinometer attribute. 0 = at least one of the attributes H_ALS or H_field is inaccurate and unreliable, 1 = both attributes H_ALS and H_field are reliable and accurate

Note: This table of attributes was taken from the metadata of the GIS data files created during this project. Some attributes were deleted and may no longer exists on the shape files. Please contact the UBC SEEDS Biodiversity Coordinator more for information.

A.3 Species Frequency

Species (Latin Name, Common Name)	Frequency (# of trees)
Acer ginnala, Amur Maple	10
Abies balsamea, Balsam Fir	1
Populus balsamifera, Balsam Poplar	1
Prunus serotina, Black Cherry	18
Populus trichocarpa, Black Cottonwood	9
Quercus macrocarpa, Burr Oak	2
Pseudotsuga menziesii, Douglas-fir	219
Quercus robur, English Oak	7
Cornus florida, Flowering Dogwood	3
Styrax japonicus, Japanese Snowbell	1
Fagus sylvatica 'Asplenifolia', Cut-leaf Beech	1
Platanus x acerifolia, London Plane	2
Abies procera, Noble Fir	2
Acer platanoides, Norway Maple	18
Holodiscus discolor, Ocean Spray	1
Arbutus menziesii, Pacific Madrone	1
Betula papyrifera, Paper Birch	1
Quercus palustris, Pin Oak	4
Pinus ponderosa, Ponderosa Pine	1
Alnus rubra, Red Alder	55
Acer rubrum, Red Maple	2
Quercus rubra, Red Oak	3
Picea sitchensis, Sitka Spruce	3
Acer saccharum, Sugar Maple	6
Tsuga heterophylla, Western Hemlock	3
Thuja plicata, Western Red cedar	151

A.4 Lidar Tree Crown Identification Accuracy Analysis

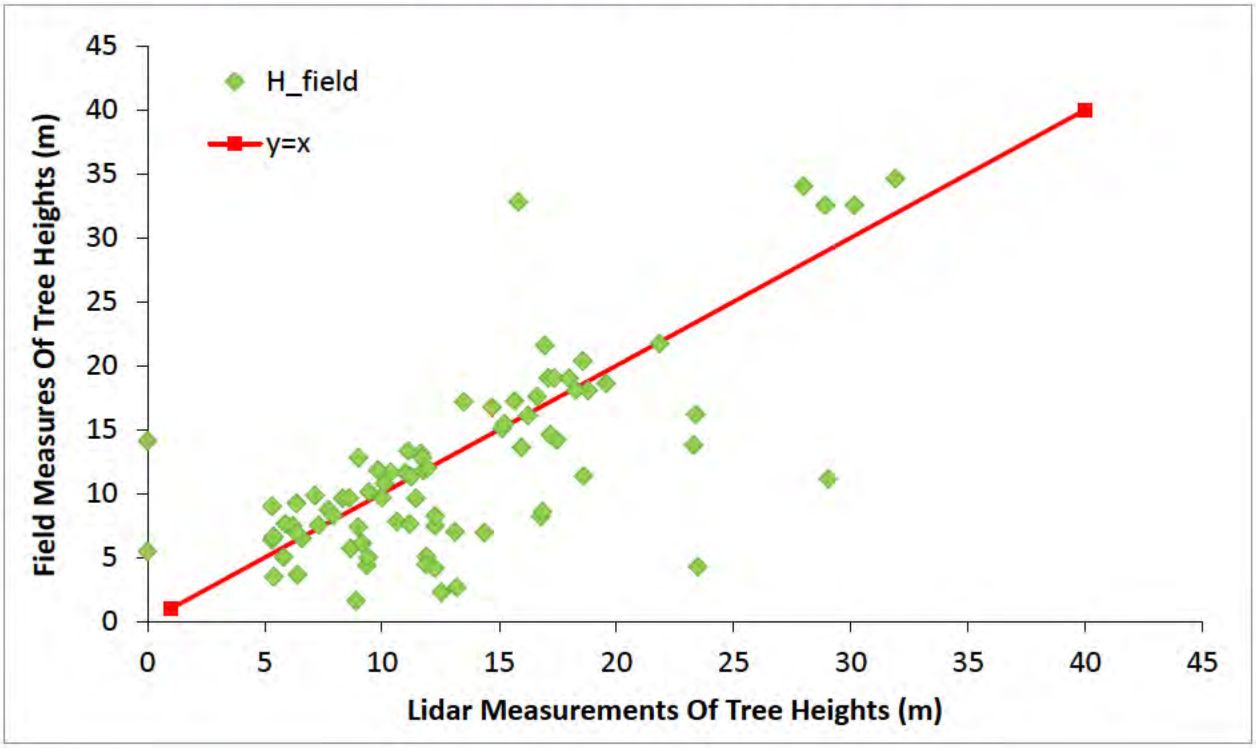


Figure A-1: The graph above shows a comparison of trees where we had both a lidar measurements and field measurements. (H_Measured = 1 in the GIS file). This scatter plot has a standard deviation of 2.7 m compared to the linear regression line.

Table A-1: The table below shows the lidar tree crown location identification accuracy stratified by height classes for the street tree subzone.

	Street Tree Subzone Height Classes							Total
	1m-3m	3m-5m	5m-7m	7m-9m	9m-13m	13m-19m	>19m	
Tree number in each height class	16	29	32	29	27	25	29	187
Number of accurate trees	3	5	11	11	15	18	9	72
Number of not-accurate trees	13	24	21	18	12	7	20	115
% of accuracy	19%	17%	34%	38%	56%	72%	31%	39%

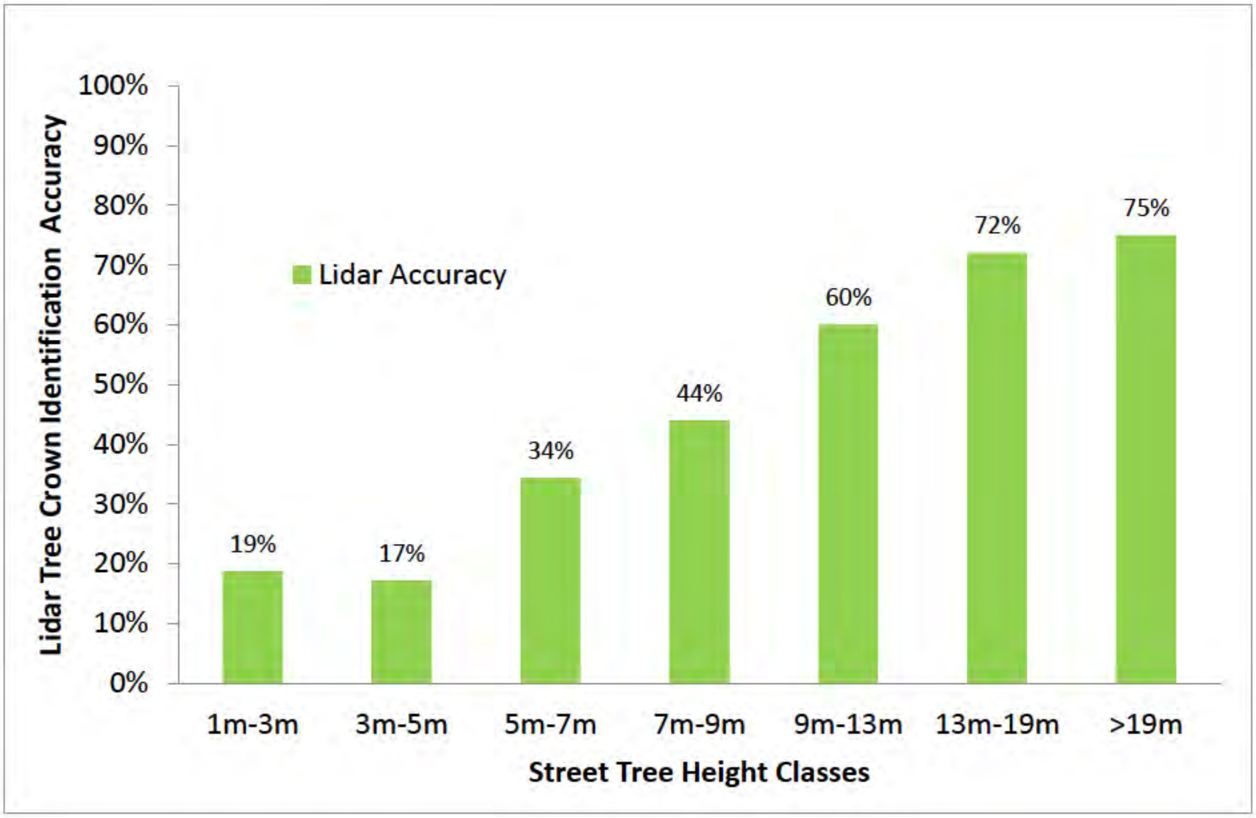


Figure A-2: Lidar tree crown identification accuracy omitting multi-stemmed trees for different tree height strata at the street tree subzone.

Table A-2: The table below shows the street tree subzone lidar tree crown location identification accuracy for trees without multi-stems stratified by height classes.

	Height Classes							Total
	1m-3m	3m-5m	5m-7m	7m-9m	9m-13m	13m-19m	>19m	
Tree number in each height class	16	29	32	25	25	25	12	164
Number of accurate trees	3	5	11	11	15	18	9	72
Number of not-accurate trees	13	24	21	14	10	7	3	92
% of accuracy	19%	17%	34%	44%	60%	72%	75%	44%

A.5 Project Zone Canopy Height Model