Using Campus-wide LiDAR to Map and Characterize Understory at the University of British Columbia Vancouver Campus

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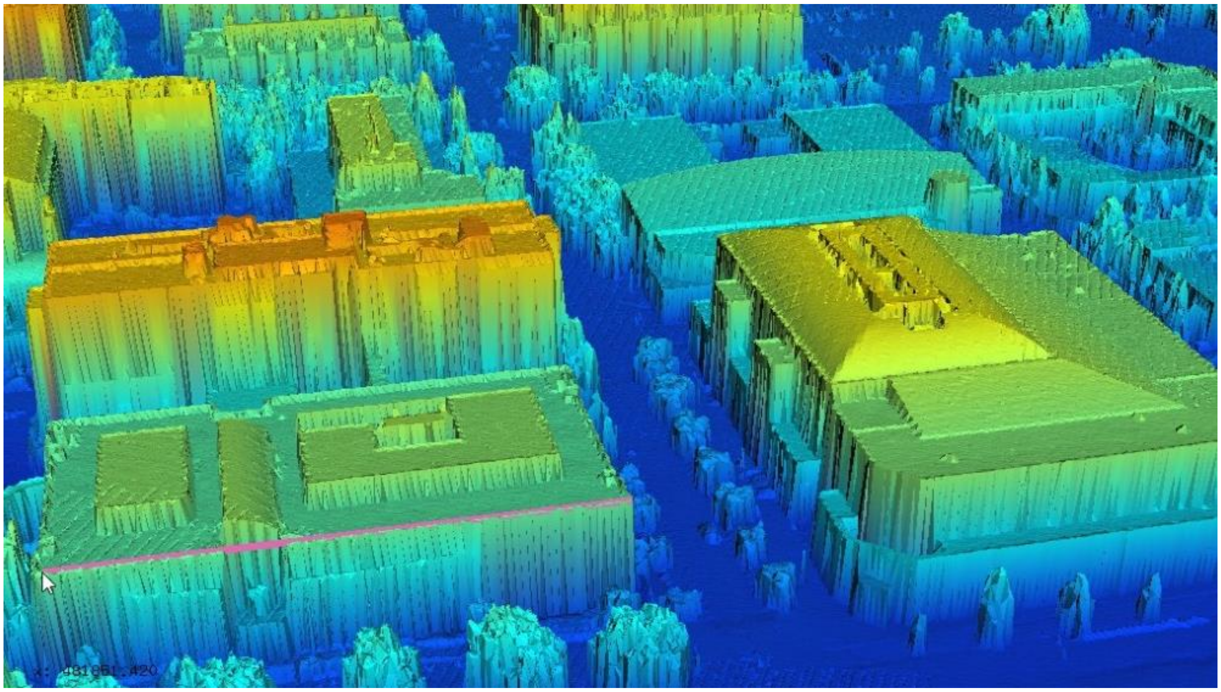

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Abstract

In response to the pressing need to address biodiversity loss and mitigate the impacts of climate change, recent studies have explored the role of understory vegetation in urban green spaces. Despite its importance, understory vegetation is often ignored in current inventories of urban green spaces. The University of British Columbia (UBC) seeks to characterize understory vegetation on campus and apply strategies for mitigating the climate change effect in specific hot spot areas. This study investigated the understory community of the UBC Vancouver campus by (1) mapping the height and height variation of the understory plant in the northern part of the UBC Vancouver campus by extracting campus-wide LiDAR data, and (2) generating complexity analysis near Saltwater residences based on field observation and height data retrieved from the LiDAR point cloud. Four metrics were identified to characterize understory structure complexity, including understory coverage, height variation, understory species diversity, and species rarity. Results indicate that over 50% of the understory in the study area was less than 0.8 meters in height. While understory plants grown near buildings showed relatively higher height variability (ranging from 0.35 to 0.69m), the distribution of understory height was not dependent on spatial location, and there was no clear pattern of similarity in the structural complexity between neighboring areas on the UBC campus. More species with a higher ecological value such as the Tall Oregon grape could be planted near saltwater residences to better combat climate change. Overall, this study demonstrates the potential of LiDAR to model and visualize understory vegetation structure and provides a methodology for conducting its structural analysis on the UBC Vancouver campus.

Keywords: understory vegetation, LiDAR, height, complexity analysis, climate change, UBC.

1 Introduction

1.1 Context

The understory plant community, composed of grasses, lichens, shrubs, mosses, and small trees, plays a critical role in both the above-ground and below-ground ecosystems (McIntosh et al., 2016). Understory vegetation is a crucial part of biodiversity, contributing significantly to biogeochemical cycles and plant community structure (Bartemucci et al., 2006). Nilsson & Wardle illustrate understory species as major drivers that facilitate tree seedling regeneration, nutrient cycling, microclimate building, ecosystem succession, as well as interact with fire regimes to affect vegetation composition in the long term (2015). Dirnböck et al. highlight the significance of understory in climate change mitigation potential as understory biomass contributes to carbon sequestration (2020). It is also an important part of the green space at the University of British Columbia (UBC) Vancouver campus, as such understory communities could provide food and habitat for various wildlife such as migratory birds and marine mammal species living on the UBC campus. However, understory vegetation is often disregarded because it has low economic value compared to trees and is hard to identify using remote sensing technology. Most of the studies conducted by the UBC Campus & Community Planning and UBC SEEDS (Social Ecological Economic Development Studies) Sustainability Program focus on the campus tree aspect. I have found two understory analyses conducted at UBC campus so far. One study aimed to digitize the social value map of the campus trees and shrubs (Lightfoot & Lin, 2020), while the other focused on building an inventory of understory plants along the proposed green corridor route between the forest of Pacific Spirit Park and the cliffs that overlook Wreck Beach at the UBC campus (Chan, 2016). Neither of these reports examined the understory species community on a campus-wide basis. Therefore, this study aims to map and characterize the understory community by its structural complexity in the major academic campus.

Remote sensing technology has revolutionized the field of environmental research. It is a powerful tool for monitoring the presence, biophysical properties, and seasonal dynamics of vegetation (Frappart et al., 2020). By utilizing satellite imagery and proper image analysis methods, the production and maintenance of vegetation inventories can more practical and economical, especially over large areas (Xie et al., 2008). However, techniques for mapping understory occurrence using satellite imagery are limited, as the understory plants are obscured by tree canopies. Recent research has shown the potential of LiDAR (light detection and ranging) in modeling understory vegetation communities (Campbell et al., 2018; Korpela et al., 2012; Venier et al., 2019). LiDAR is unique in its ability to examine understory structure at high spatial resolution (Campbell et al., 2018). Korpela et al. examined the potential of LiDAR in mapping understory trees in pine stands and concluded that area-based LiDAR height metrics could be used for understory detection and assessment (2012). The working principle of LiDAR involves measuring the return time of a laser light pulse reflecting off solid objects and generating a three-dimensional representation based on the laser returns (Venier et al., 2019). The solid object could be vegetation, buildings, or the ground. By analyzing LiDAR data, estimation of height variation, canopy cover, crown closure, and average aboveground biomass could be generated (Thomas et al., 2006). A particular challenge in using LiDAR is that this three-dimensional (3D) data does not measure understory structure directly. Therefore, selecting a suitable ground reference to link the ground conditions with different understory structural metrics is crucial (Campbell et al., 2018).

1.2 Objectives

The objective of this project is to use Campus-wide LiDAR data to map and characterize the current distributions of understory vegetation communities on the UBC Vancouver campus. Rather than identifying the location of specific species on campus, the purpose of this study is to analyze the height variation and complexity of understory. The study area for the complexity structure analysis was confined to the Saltwater residences section of the UBC campus, utilizing four metrics: understory coverage, height variation, the number of species, and species rarity. This report also discussed the possible climate adaptation strategy of understory community on campus, based on the understory structure analysis. I hypothesize there will be a spatial pattern between height variations within the study area and the height variation will be higher in area far from buildings. I also expect high understory complexity will occur far from buildings and in larger patches because areas near buildings have more disturbance and habitat fragmentation reduces understory abundance (Aguirre& Dirzo, 2008).

This research aims to fill the knowledge gap regarding the current state of the understory vegetation on the UBC Vancouver campus. Additionally, the results of this study will serve as a resource for the UBC SEEDS Sustainability Program to analyze the impact of climate change on understory plant communities.

2 Data and Site Summary

2.1 Study area

The University of British Columbia Vancouver Campus (49.2606° N, 123.2460° W) is situated on the westernmost side of Point Grey Peninsula in Vancouver, British Columbia, Canada (Figure 1). The entire campus area is about 402 hectares and it is surrounded by forest on three sides and ocean on the fourth (UBC, 2022). The campus was established in 1908 and has established land use plans since 1997 to set the long-term direction which includes expanding its urban coverage, protecting green areas, and managing transportation (UBC Land Use Plan, 2015; UBC Campus & Community Planning, 2015). The campus is located in the Coastal Western Hemlock zone, CWHxm1 subzone (B.C. Government, 2022). Oregon grape, salal, red huckleberry, bracken fern, and Oregon-beaked moss are the common understory species in this biogeoclimatic zone (Doll, 2022).

The understory height analysis of this study was focused on the northern part of the academic campus (Figure 1). This area is managed by UBC Operations and was picked by the SEEDS's (Social Ecological Economic Development Studies) needs for understanding the campus understory structure in such area. The understory complexity evaluation was focused on the Saltwater residences within UBC campus, which is located at the north-east of the UBC campus in Vancouver, BC. This residence community is consisted of 5 independent buildings that constructed and opened between September 2021 to April 2022 (UBC, 2022). Evaluating this recently disturbed site could help on understanding its general understory condition and providing management suggestions to combat climate change.

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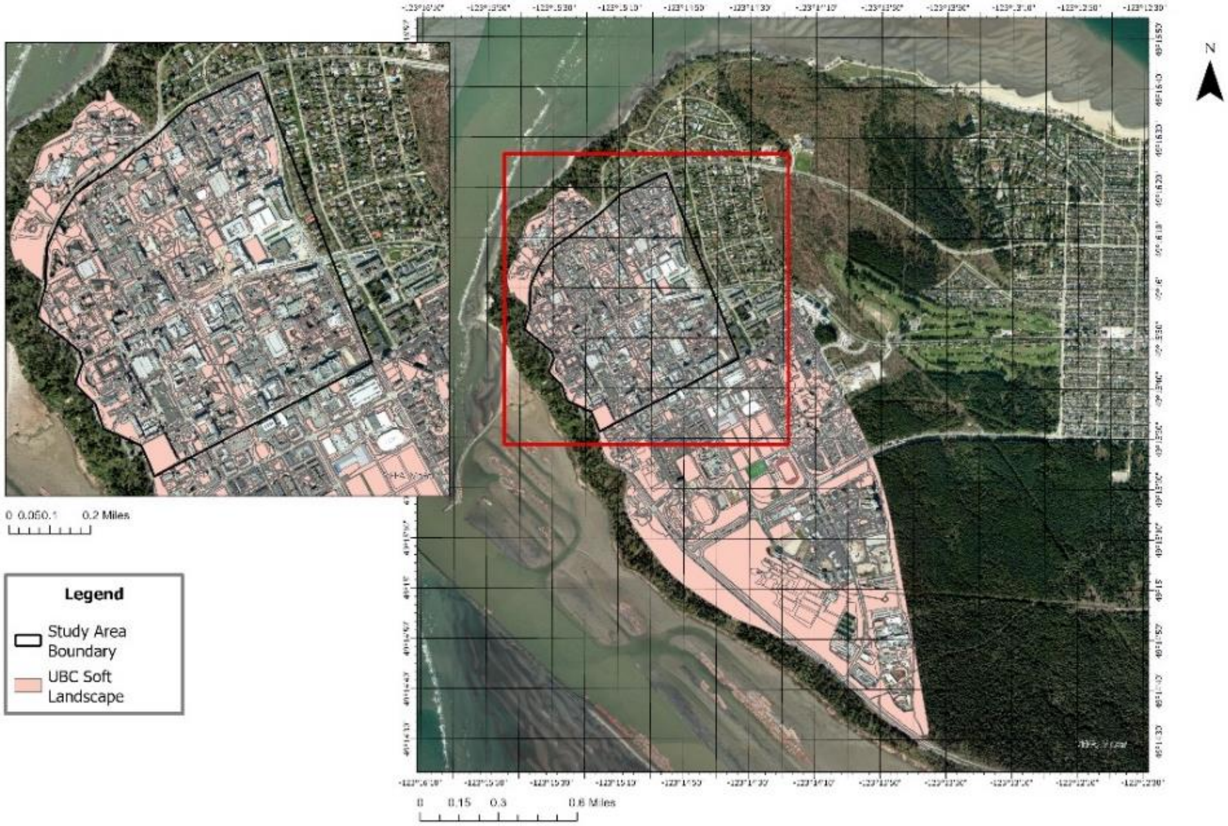

__Figure 1.__ Study area identification. The black boundary shows the study area for this project; the pink boundary illustrates the soil beds on camps and the understory plant grow in these soil beds will be measured in this research. Base imagery is projected in NAD 1983 UTM Zone 10N and sourced from ESRI (2022).

2.2 Data summary

<u>University of British Columbia Vancouver Campus Lidar</u>

Estimate of understory height variation on campus was based on Campus LiDAR data retrieved from Campus and Community Planning of UBC (2021). This data was collected on June 23, 2021 with 30 laser pulses per square meter. The aircraft used for data acquisition is PA31 Piper Navajo with a 800 kHz scan rate sensor fly over 16 square kilometer areas at 1400m above ground level. According to Eagle Mappings Ltd, the data collector, the delivered dataset is positioned with a horizontal accuracy of ± 0.30m and vertical accruacy of ± 0.15m. Lidar data in the following four areas will be used for the understory height analysis: area number 481-5456, 481-5457, and 482-5456, 482-5457 (Figure 2). All the technical information is shown in Table 1.

Figure 2. *Range of LiDAR data for UBC Vancouver campus with specific area number. Data covers the geographic bounding between -123.261 º W to -123.191 º W and 49.2793 º N to 49.2328 º N. This LiDAR coverage map is projected in NAD 1983 UTM Zone 10N and sourced from Campus and Community Planning (2015).*

<u>University of British Columbia Vancouver Campus soft landscape</u>

Soil bed information at the University of British Columbia (UBC) Vancouver campus were downloaded as a geoJSON dataset from the UBC open geospatial repository on Abacus Data Network (Burton & Wiersma, 2016). Data are collected in 2016 in the WGS84 coordinate system by the UBC Campus and Community Planning program. The data is recorded in shapefile that includes three types of soft landscape: lawn, planting bed, and wild areas. The total number of polygons in this dataset is 2000. This data is a reference to see where the understory should be located.

<u>University of British Columbia Vancouver Campus Understory Species observation</u>

Understory occurrence data at the species level is retrieved from iNaturalist (Figure 3, 2022) and provided by the SEEDS Sustainable program (Davis, 2022). "iNaturlist" is a free platform that allows citizens to record observations of plants and animals using photographs and location information. This platform could help on evaluating understory species diversity at the UBC campus. All records after 2020 in iNaturalist within UBC are selected. And the point occurrence data is stored in csv format with latitude, longitude, and observation date columns. The number of observations vary widely between species and more observations was occurred in the summer months. Another understory data is collected by Davis. There is total 169 observations with species name, soil bed ID that find the species, and observation date recorded in csv format. I will join these shrub data to the soft landscape dataset. And this soil-bed-based occurrence would be supplementary dataset for understory complexity analysis.

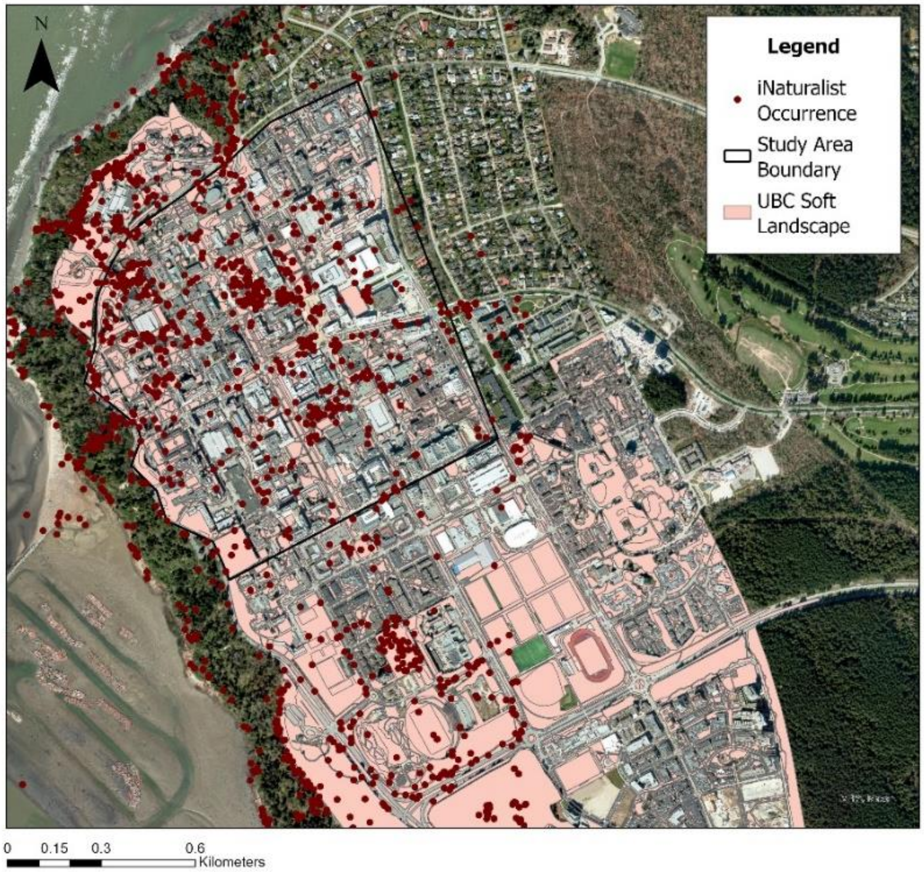

Figure 3. *Example of understory occurrence map at UBC Vancouver campus. The red points illustrate plan species occurrence recorded in iNaturalist Research-grade Observations (iNaturalist contributors, 2022).*

Table 1. Data Summary table of data collected for this project.

ID	Category	Name of data	Author	Date of last update	Conditions of use	Limitation
1	LiDAR	E481_N5456.laz	UBC. Campus and Community Planning	Dec 3, 2021	Public	none
2	LiDAR	E481_N5457.laz				
3	LiDAR	E482_N5456.laz				
4	LiDAR	E482_N5457.laz				
5	SHP	ubcv_softlandscape.geojson	UBC. Campus and Community Planning	Feb 12, 2021	Public	No specific species information within each soil bed polygon.
6	CSV	ubcv_shrub_species	Egan Davis	Unknown	Private	Limited data with only 169 observation
7	CSV	iNaturalist Research-grade Observations	iNaturalist contributors	October 27, 2022	Public	none

3 Methods

3.1 Overview

The methodology of this project was separated into three main components which include (1) acquisition of understory field data, (2) processing of campus-wide LiDAR data, and (3) analysis of understory structure. To conduct the understory structure analysis, LiDAR data of the entire study area and field observation data within Saltwater residences were processed in R Studio and ArcGIS Pro. The lidR package, which is a point-cloud oriented R package, was utilized to manipulate and visualize airborne laser scanning (ALS) data (Roussel et al., 2020). Specifically, R Studio and the lidR package enabled the extraction and analysis of height variation from the campus-wide LiDAR data. ArcGIS Pro was employed to perform structure complexity analysis and to export this information graphically. An overview of the workflow implemented in this study is presented in Figure 4.

3.2 Understory Field Data Acquisition

In order to analyze the understory vegetation complexity at the Saltwater residences on the UBC campus, additional field study data is needed to supplement the existing datasets. To accomplish this, 11 random points were selected from each soil bed within the Saltwater residents to serve as the plot centers for the 5m x 5m plots. On each of these sample plots, the understory plant

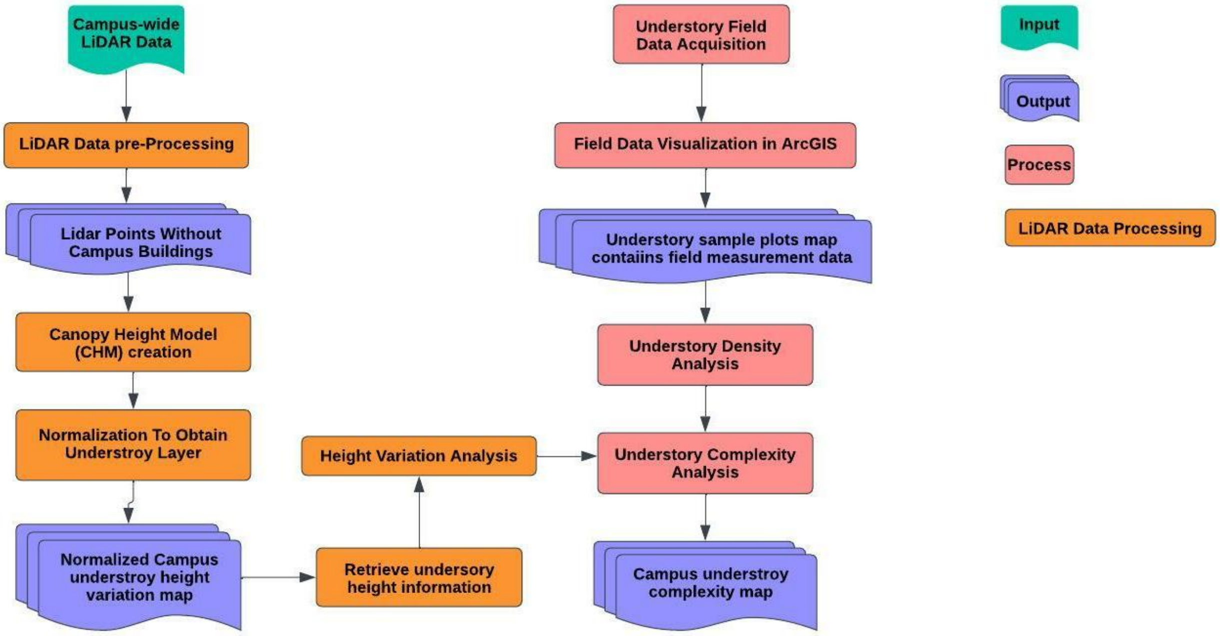

Figure 4. *Flow chart for Process overview. The input data is campus-wide LiDAR data. The final outputs are the campus understory height variation map within the study area and the campus understory complexity map that illustrates the sample plot with specific complexity value.*

coverage (%) and species diversity were measured and recorded. Identification of unique species that are uncommon within the current Biogeoclimatic Ecosystem Classification (BEC) zone, or species of high ecological or conservation importance, could serve as an indicator of greater complexity. To determine a species' conservation value, the "Field Guide to Species at Risk in the Coast Forest Region of British Columbia" (Proulx et al., 2003) was utilized, and species listed in this guidebook were identified as having high conservation importance. The species observation data from iNaturlist (iNaturalist contributors, 2022) was combined with field observation data to measure the species diversity at each plot. Google Earth imagery from Landsat 8 was utilized as a reference map to conduct this field measurement (Perez, 2016).

3.3 Campus-wide LiDAR Data Processing

LiDAR Data pre-Processing

This project will focus on the area that could grow plant at the northern part of UBC campus, so LiDAR point cloud data will be extracted within each soil bed shown in the soft landscape shapefile. Before clipping the LiDAR points with the UBC soft landscape data, it is essential to ensure that all .laz files and shapefiles are in the same coordinate system. Following the common classifications for understory and overstory layers in forestry (Pisek et al., 2010), the understory layer falls under the overstory layer and is defined by a height range of 0 to 2 meters. In accordance with this category, normalization techniques are employed to extract the LiDAR point cloud data below 2 meters in height from the campus soft landscape .laz files.

Canopy Height Model creation

A Digital Terrain Model (DTM) that represent the ground surface and Digital Surface Model (DSM) that represents heights of objects above the ground surface was generated by using R studio (White et al., 2013). It is crucial to ensure the accuracy of these models since any errors will propagate to future height estimations (Roussel et al., 2022). In previous studies, a continuous LiDAR raster DTM or DSM was created by assigning each cell the Z-value of the first return that had fallen within it (Sadeghi et al., 2016). Following this procedure, we generated DTM and DSM models in this study. A Canopy Height Model (CHM) represents the height of the canopy above ground level. To evaluate the height of the understory vegetation, we generated a Canopy Height Model (CHM) by subtracting the DTM from the DSM, with a spatial resolution of 5 m. The standard deviation of height in each 5m x 5m cell was then calculated using R studio, as higher standard deviations suggest greater height variation within the understory vegetation (Stepper et al., 2015). It is important to note that generating accurate DTM, DSM, and CHM models is critical for ensuring the reliability and validity of our findings. The basic formular to calculate average height and height variation in each 5m x 5m pixel is listed below:

Mean of top height: $X_{bar} = \frac{\sum_{i}^{n} Xi}{n}$

Standard variation of top height: $\mathrm{SD} = \frac{\sum_{i}^{n}(xi - x_{bar})^2}{n-1}$

3.4 Understory Structure Analysis

To analyze the complexity of the understory structure at the Saltwater residences, four metrics were identified, three of which have been used in previous research: understory coverage (Sullivan et al., 2001; Willim et al., 2019), understory height (Feldmann et al., 2018), and understory diversity (Paulson et al., 2021). Additionally, a fourth metric, species rarity, was considered, including unique and ecologically or conservationally important species explained in section 3.2.

The complexity analysis of area near Saltwater residences was conducted in ArcGIS Pro based on the data collected from the 11 sample plots. Each metric was evaluated separately using the expression [F/Fmax], where F represents the value of the metric and Fmax is the maximum value of the metric. For understory coverage (Coverage), the higher the percentage of coverage, the higher the complexity score. For the number of species (n_species), the higher the number of species, the higher the complexity score. For Height variation (Height_va), the larger the standard deviation, the higher the complexity score. For Species rarity (Rarity), the higher the number of unique and ecologically or conservationally important species, the higher the complexity score.

Finally, a weighted complexity calculation was applied to obtain the final complexity index with the expression: Coverage0.2 + n_species0.3 + Height_va0.3 + Rarity0.2.

4 Results

4.1 Understory height & height variation analysis

The canopy height model (CHM) that only contains the first returns of LiDAR point data was created for the overview of understory condition at the northern part of UBC academic campus In general, there is no significant pattern in height distribution for shrubs on campus. The rectangular, empty locations in the canopy height model (CHM) are areas with no data (Figure 5). These areas refer to the buildings on campus. The heights of understory plants measured in every 5m*5m pixel in the study area range from 0 to 2m. More than 50% of the study area has a height that less than 0.8 meters. Though the understory plants grown near buildings have relatively higher heights (from 1.66 to 2m), it is hard to say an obvious spatial correlation between the understory height and geospatial location on campus. The standard deviation of understory height is low on main roads (e.g. Main Mall, E Mall) on campus (Figure 6), indicating less variability in height. In contrast, the understory grown at the north edge of the study area has higher height variation. Unexpectedly, greater height variability (ranging from 0.35 to 0.69m) was observed for understory planted near buildings, which is not aligned with the original hypothesis. Only a few pixels have identified with standard deviation of height range from 1.04 to 1.386 m, indicating limited areas of significant variation. These findings provide insight into the understory condition and can inform landscape management practices on campus.

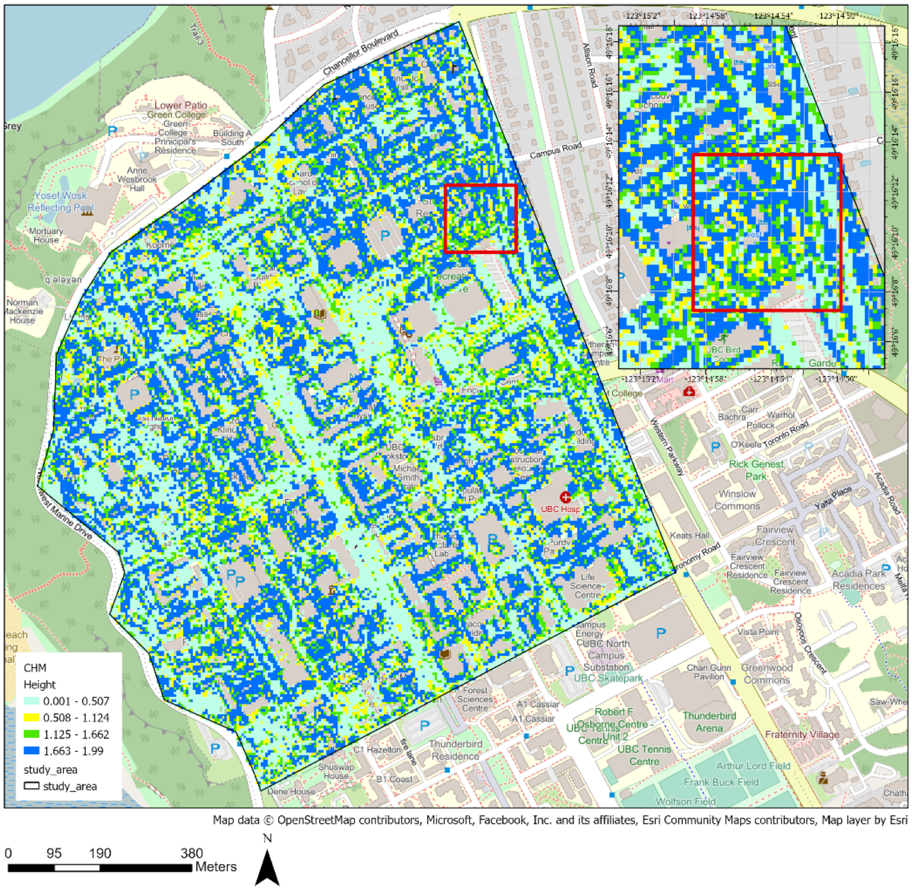

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Figure 5. *Canopy height model (CHM) of the understory plant in the northern part of UBC academic campus in Vancouver, BC. The red rectangular on the inset illustrate the general location of Saltwater residences. Base imagery is projected in NAD 1983 UTM Zone 10N and sourced from ESRI, OpenStreetMap contributors and the GIS User Community.*

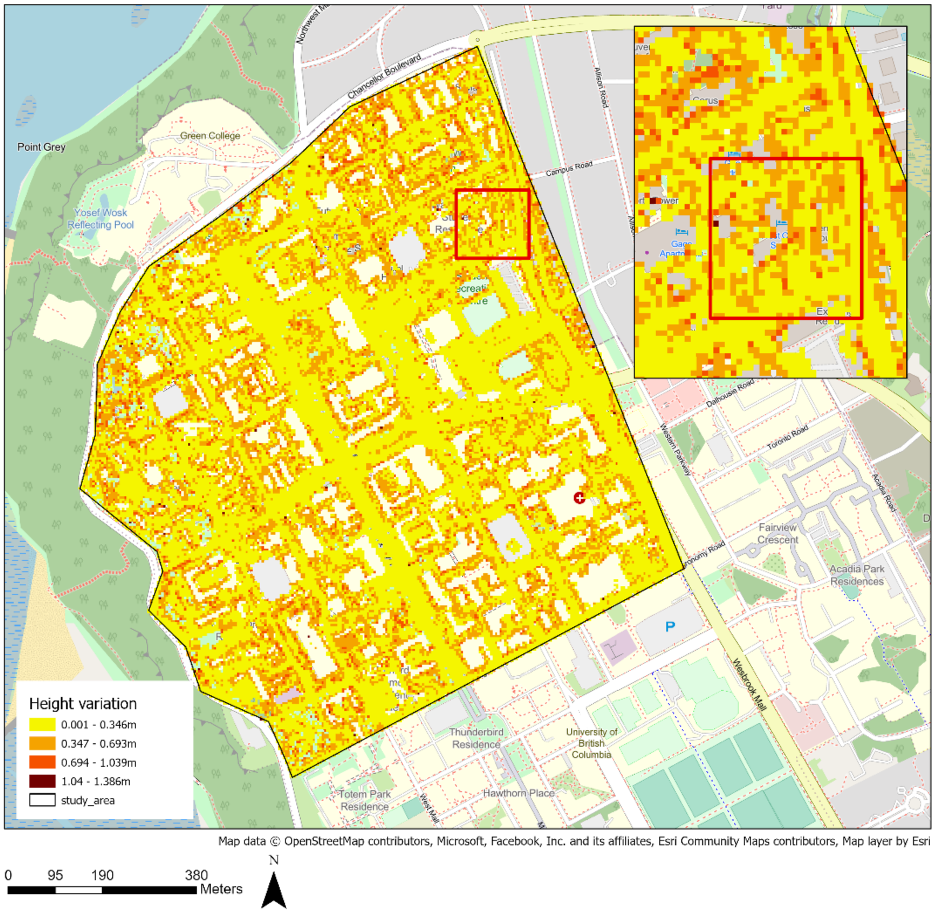

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Figure 6. *Standard deviation of height for the understory plant in the northern part of UBC academic campus in Vancouver, BC. The red rectangular on the inset illustrate the general location of Saltwater residences. Base imagery is projected in NAD 1983 UTM Zone 10N and sourced from ESRI, OpenStreetMap contributors and the GIS User Community*

4.2 Understory structure complexity analysis at Saltwater residence

This research presents findings based on a field study conducted on eleven soil beds near the Saltwater residences (Table 2). The majority of the soil beds are structured man-planted beds with an average coverage of less than 50% (Figure 7A) and contain four to seven species (Figure 7B). Four soil beds have been identified as having higher understory height variation (Figure

7C), while two soil beds have a height variation of less than 0.26. However, I found two species, the common snowberry (Symphoricarpos albus) and tall oregon grape (Berberis aquifolium), that have high ecological value for the UBC campus and are defined for species rarity identification (Figure 7D). The common snowberry is an important food source and cover for birds and small mammals (McWilliams, 2000). The tall Oregon grape is a common species on campus but it can make an attractive addition to the UBC landscape as a food source and cover for birds and deer. Invasive species like English holly and Himalayan blackberry are found within the Saltwater residences.

The understory structure complexity of all observed soil beds is generally low. However, the two soil beds in the northeast of the Saltwater resident community have the highest structure complexity compared to other soil beds (Figure 8). The two soil beds with the lowest coverage also have the lowest structure complexity. Results suggest that there is no spatial correlation between the understory complexity and geospatial location within the Saltwater residences. These findings can inform future landscape management practices for the Saltwater residences, and provide insight into the ecological value of certain species present in the area. Table 2 summarizes the characteristics of the eleven soil beds observed during the field research.

Table 2. *Field research record of the coverage, number of species, unique species, and invasive species in the soil beds near the Saltwater residences.*

Plot#	coverage	number of species	number of unique species	Invasive species
1	50%	5	0	Himalayan blackberry
2	35%	7	0	0
3	70%	4	1	0
4	10-15%	4	0	0
5	35%	4	0	0
6	50%	5	1	English holly
7	50%	5	1	0
8	50%	5	0	0
9	5%	4	0	0
10	30%	4	1	0
11	25%	4	1	0

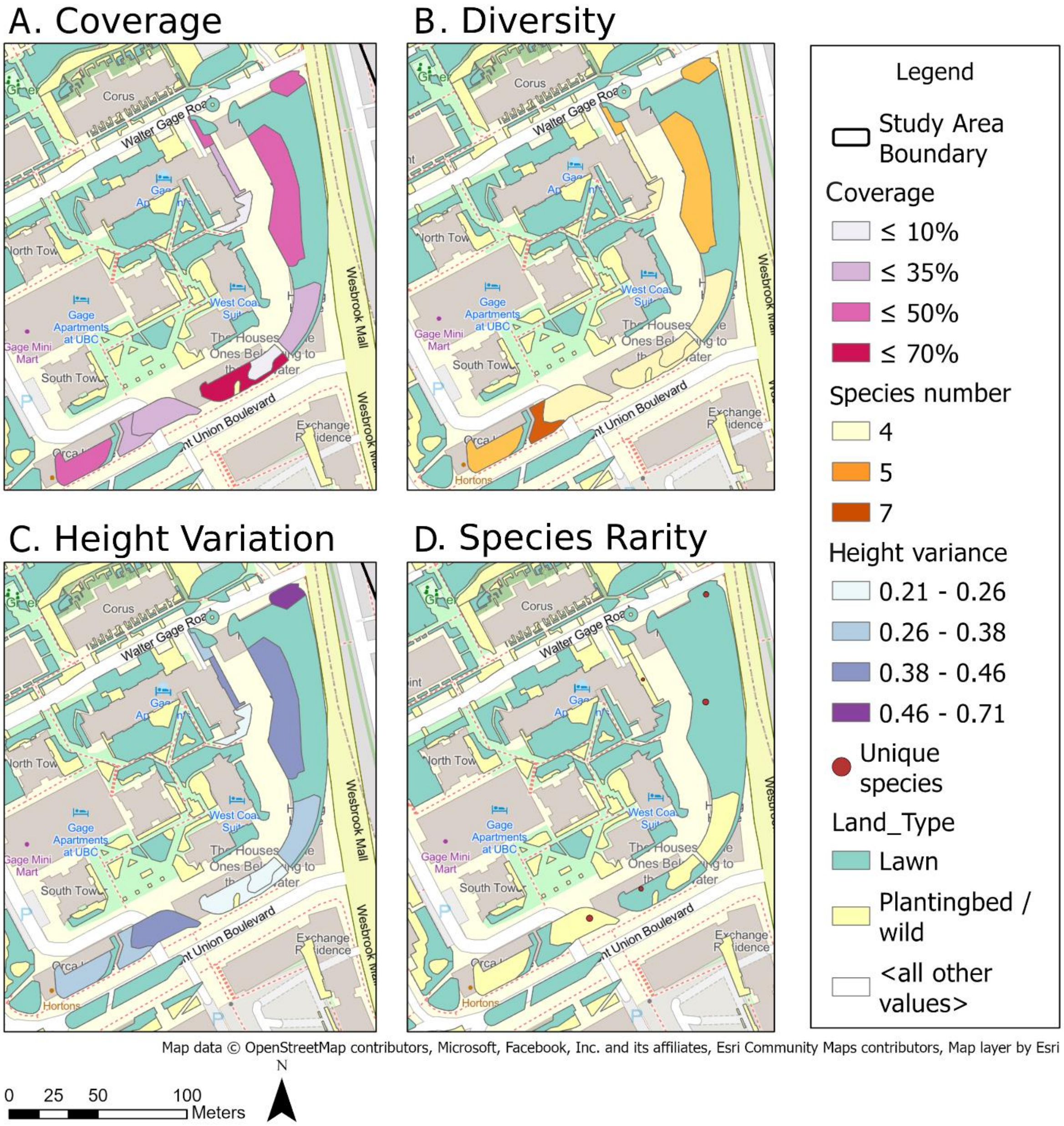

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Figure 7. *Map illustration of the understory coverage (Figure 7A), understory diversity (Figure 7B), height variation (Figure 7C), and species rarity (Figure 7D) in the Saltwater resident community, which located at the north-east of the UBC campus in Vancouver, BC. The darker color shown in graphs A to C means the area has a higher density/diversity/height variation score. The red points shown in graph D illustrate the unique species occurrence. The soil beds that are not analyzed in this study is shown as green or yellow color to represent different land type on the map. The soil bed in green is identified as Lawn, while soil bed in yellow is identified as planting bed or wild soil bed. Base imagery is projected in NAD 1983 UTM Zone 10N and sourced from ESRI, OpenStreetMap contributors and the GIS User Community.*

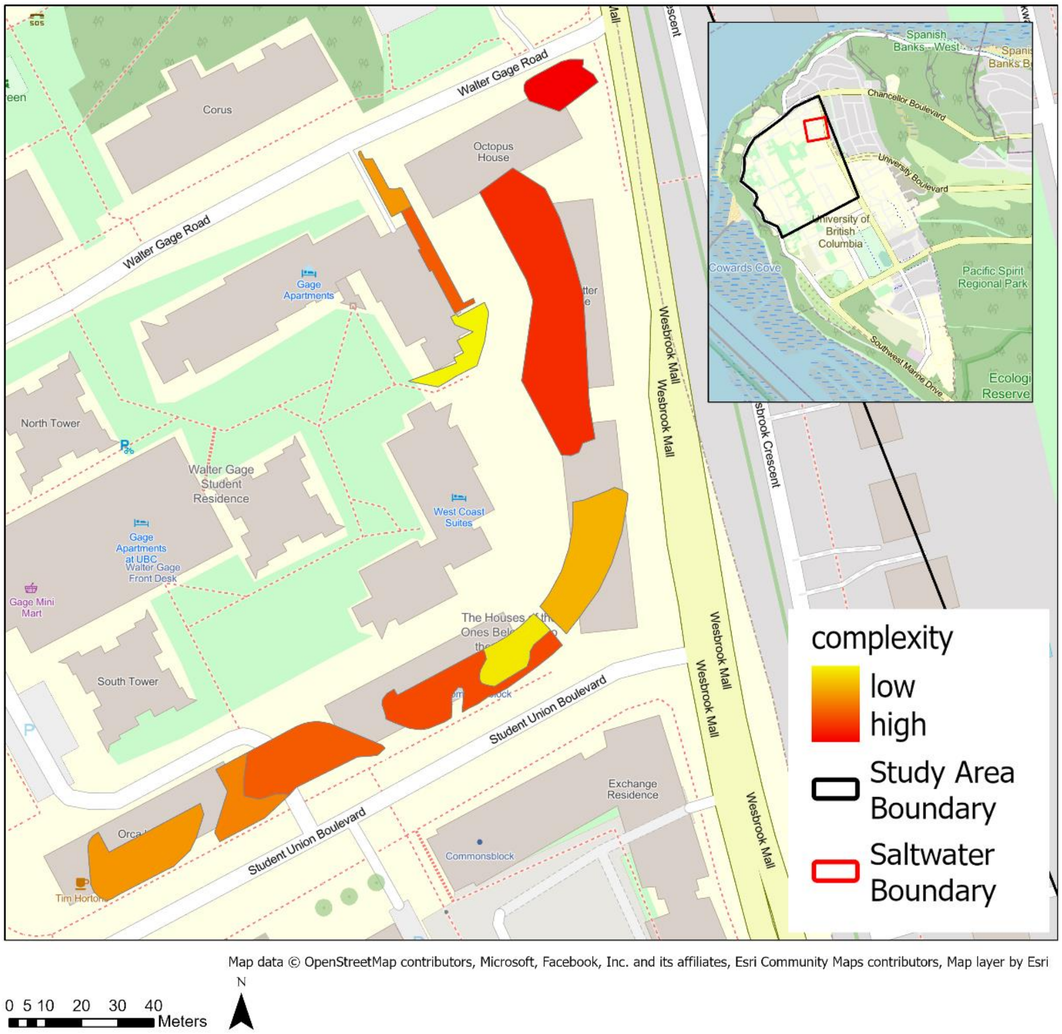

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Figure 8. *Map illustration of understory complexity in the Saltwater residences of UBC campus in Vancouver, BC. The darker color means the area has higher structural complexity. Two soil beds in the northeast of the Saltwater resident community have the relatively highest structure complexity. The inset shows the study area at University of British Columbia Vancouver campus, with a red rectangular illustrate the general location of the Saltwater residences, which is at the east of the study area. Base imagery is projected in NAD 1983 UTM Zone 10N and sourced from ESRI, OpenStreetMap contributors and the GIS User Community.*

5 Discussion

Prior studies have shown the ability of LiDAR to characterize understory structure at a high spatial resolution across broad areas (Campbell et al., 2018; Venier et al., 2019). This is the most powerful remote sensing technology applied in this study. The methodology introduced in this study provides a good example of how to conduct understory structural analysis and visualize understory data on the UBC Vancouver campus, though a larger field sample size and necessary data verification is needed in future application. To map and characterize the current understory vegetation communities on the UBC Vancouver campus, this study used campus-wide LiDAR data to analyze the height and height variation of the understory in the study area, and a complexity analysis is conducted near Saltwater residences based on field observation and height data retrieved from the LiDAR point cloud. I introduced four criteria of understory complexity to allow for an objective way of assessing understory complexity: understory coverage, the number of species, height variation, and species rarity. It was hypothesized that: (1) there will be a spatial pattern between height variations within the study area. (2) high understory complexity will occur far from buildings and in larger patches. Overall, the results do not support the first prediction and there is no sufficient evidence to support the second prediction. Since most of the soil beds on the UBC campus are man-planted, the distribution of and characterization of understory plants is deliberately varied, reducing the likelihood of spatial autocorrelation and promoting a diverse and healthy ecosystem.

5.1 LiDAR-derived height, height variation

The mapped canopy height model (CHM) of the northern part of the UBC academic campus indicates that the distribution of understory height is not dependent on its spatial location and that there is no clear pattern of similarity in the height values between neighboring areas on the UBC campus (Figure 5). Though the height variation map of the study area suggests that there is no significant spatial autocorrelation present (Figure 6), this study shows how LiDAR can be used to extract understory height data. This finding can serve as a guide for future analysis of understory data on the UBC campus and can be used as a methodological reference. These successfully generated results agree with Campbell et al. (2018) and Venier et al. (2019), which prove the ability of LiDAR analysis to model and visualize understory vegetation structure.

5.2 Understory complexity analysis

The complexity analysis is based on the general condition of 11 soil beds within the Saltwater residences (Table 2). Land use history could affect the understory condition (Svenning et al., 2008). The result of my field observation and structure analysis suggests that management practices could significantly impact the understory structure, for example, leading to a relatively high vegetation cover and high complexity in some soil beds though Saltwater residences are recently finished residences that experienced intense disturbance. However, the understory complexity analysis is only conducted near Saltwater residents and most soil beds are man planted, so drawing a conclusive preference for the occurrence of high understory complexity based on limited data is challenging. The outcomes of this study could not support Aguirre and Dirzo's (2008) findings that areas in close proximity to buildings have low structural complexity as these areas experience greater disturbance, and that understory abundance is reduced due to habitat fragmentation.

5.3 Possible climate adaptation strategy of understory community

The understory community is a vital component of ecosystems at the UBC Vancouver campus and plays a crucial role in climate change mitigation (Dirnböck et al., 2020). There are some management suggestions to enhance the resilience of the understory community to climate change based on the understory structure analysis. More species with the higher ecological value could be planted near saltwater residents to increase understory diversity and abundance. For example, the Tall Oregon grape, a native shrub in British Columbia is drought-tolerant and Pollinator friendly. Native species could better be adapted to local conditions and can provide better ecosystem services such as carbon sequestration and nutrient cycling (Hobbs et al., 2013). Planting these kinds of species could improve the ability of the understory community to cope with climate change. Invasive species could also be manually removed from the understory community. In general, invasive plant species are better competitors than native plant species. The presence of invasive species could have a negative effect on the understory by outcompeting native species and altering ecosystem processes.

5.4 Limitations of current understory analysis

While this study represents the first attempts at combining LiDAR and field observation to analyze the understory community structure at the UBC campus, there are still limitations that point out the future directions of the study. First, interpolation of understory complexity based on random sample data is not allowed as the soil beds are man-planted and there is no spatial autocorrelation presence for understory structure. There is no sufficient field observation to support complexity analysis in the whole study area, so the complexity calculation is limited to the Saltwater residence in this study. Second, noise in LiDAR data could reduce the accuracy of height and height variation analysis. The presence of a dense overstory canopy could also lead to shadowing effects, which may obscure the understory vegetation and lead to an underestimation of understory height. Third, the soft landscape shapefile used in this analysis is out of date as the data was collected in 2016 (Burton & Wiersma, 2016) while the Saltwater residences were finished construction and opened in 2022 (UBC, 2022).

5.5 Future directions

In future research, it would be beneficial to increase the sample number and widen the sample range for field observation. There is only part of the UBC campus area has been analyzed, and further canopy height model (CHM) could be built to help understand the understory structure of the whole campus. Further verification of this research is necessary to test the accuracy of the result. Additionally, recent research has successfully provided evidence for the potential of machine learning algorithms in the urban planting areas analysis (Chaturvedi, & de Vries, 2021; Cetin, & Yastikli, 2022). It would be valuable to investigate the potential use of machine learning algorithms to automatically classify different vegetation layers, which could help to improve the data accuracy.

Furthermore, there is no literature that applies a similar method I used for understory complexity analysis, the definition of understory complexity is based on my current knowledge and available data. Future studies could explore other relevant factors that might strengthen the capacity of the understory community to adapt to changing climatic conditions, such as understory density or carbon sequestration ability, to better understand and define the complexity understory community.

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