Abstract

Modelling LiDAR metrics and land surface temperature to improve microclimate information in UBC Botanical Garden

Climate change is a key factor in how extreme weather events affect how ecosystems and species react to these changes in temperatures. UBC Botanical Garden is interested in improving microclimate information within the garden to understand how areas with shade create respite zones for species. Due to the recent extreme weather temperatures in Vancouver, the garden is interested in how to continue to adapt and mitigate to these extremes. Microclimates are important as they are cooler temperatures beneath the canopy. Looking at how canopy cover influences land surface temperature can give insight on microclimates. Using LiDAR metrics to calculate canopy cover and Landsat to calculate land surface temperature, a model was built to understand the significance of canopy cover and land surface temperature, with the addition of other LiDAR metrics. The model could only determine a 34% variation between the variables tested. Canopy cover showed to have a p-value of 0.0993 and maximum height had a p-value of 0.0034. To investigate the results further, an unpaired t-test was run to determine the relationship between areas with canopy cover and areas without canopy cover. The t-test showed there are significant differences as the p-value was 0.0035. With the results, they provide observations of how canopy cover currently influences microclimate within the garden. Areas found to have a high percentage of canopy cover reflected lower land surface temperatures. Currently, the model has the structure to predict canopy cover with LiDAR metrics. However, finer data is needed to accurately predict microclimate. Recommendations are provided to enhance the study area with future directions for research within UBC Botanical Garden to conduct a more intricate analysis.

Key words: Canopy cover, Landsat, land surface temperature, LiDAR, microclimate, multiple linear regression

1.0 Introduction: *How are microclimates influenced by canopy cover?*

Climate change is a key factor in how extreme weather events affect how ecosystems and species react to changes in temperatures (Harris et al., 2020). Urban green spaces are becoming more important in providing resilience to climate change as many tall broad trees provide shade through canopy cover in addition to other benefits (Cheng et al., 2021). This signifies how canopy cover is critical in providing recreational zones for all species as it provides shade and cooling effects. In UBC Botanical Garden (UBCBG), there are many native and non-native species that reside within the garden. The greatest challenge of unpredictable weather events is being proactive in establishing ecological restoration in areas needed that can aid in reducing the resiliency and resistance of these events. Depending on the amount of sunlight penetrating the canopy, microclimates differ widely among different landscapes (Chen et al., 1999). Acknowledging different microclimates is important in maintaining ecosystem services for species residing or passing through these areas. These respite zones can be essential during heatwaves and during migration or off-seasons, in letting species take comfort (Philpott & Bichier, 2012). In addition, with climate change altering many species and their ranges, range shifts may occur making these respite zones a new suitable habitat for them to occupy (Valladares et al., 2016).

1.1 Importance of canopy cover for species

Canopy cover influences the distribution of light, precipitation, and air movements which contribute to how air humidity, temperature, and moisture conditions are affected below the canopy (Jennings, 1999). Microclimate is defined as noticeable climatic conditions that differ from the temperatures outside of forests (De Frenne et al., 2021). Hence, canopy cover being able to create dynamic temperature differences inside the garden's microclimate to be different from outside the forest. Many organisms have different temperature thresholds and experience climate at different extents (Suggitt et al., 2011). This suggests that various species take advantage of these microclimates according to their thresholds. It is important to understand how canopy cover has changed and how these changes impact microclimates and conditions for species.

1.2 Remote sensing as tool for understanding microclimates produced from canopy cover

Remote sensing is greatly used in the study of canopy cover and the temperatures below the understory (Kašpar et al., 2021). One specific remote sensing tool is the use of Light Detection and Ranging (LiDAR) in studying canopy cover (Ma et al., 2017). Since it can penetrate forest canopy, it is beneficial in this project to understand areas without shade (canopy cover) and how microclimates are altered or changed. LiDAR's ability as an active remote sensing tool is advantageous in studying forested areas as it can estimate tree and stand heights, while characterizing the volume and biomass of the specific area of interest (Wulder et al., 2008). The use of remote sensing in the forestry industry is growing and that includes understanding how extreme weather will alter ecosystems and how species interact with them. However, the limitations in using remote sensing for fine-scale applications is the financial cost and availability of data. High resolution imagery is expensive and generally unavailable to the public. Turning to microclimates, with Landsat-8's thermal infrared bands, temperature data can be derived as land surface temperature (LST) to understand microclimates in the UBCBG. LST at a 30m spatial resolution can be valuable in understanding which areas in the UBCBG may be beneficial to species during extreme weather events. Both LiDAR and Landsat are beneficial in understanding how microclimate can be advantageous in proactiveness of reducing the perceived effects of climate change for species.

1.3 Research Gap

UBCBG is one of the oldest operating university botanic gardens in Canada (*About Us*, n.d.). The goal of the garden is to conduct: "education, research, conservation, community outreach, and public display of temperate plants from around the world" (*About Us*, n.d.). Within these goals, UBCBG will need to understand how they can continue to monitor microclimates from canopy cover as heatwaves become more prominent. Remote sensing applications was one tool that would be pertinent in exploring potential monitoring of canopy cover in conjunction with temperature data. Local variation in temperature offsets between canopy cover areas with understory or treeless areas has been previously studied by Kašpar et al. (2021). In the study, the authors used active LiDAR sensors and found that microclimate can be modelled at fine resolutions and would be suitable in understanding species shift with warming temperatures. They found that canopy height and cover had amplified temperature differences in open areas and areas under the canopy. This addresses a small portion of the study but signifies that there is a gap in understanding how shade in microclimates will benefit species residing in the garden. Furthermore, as many studies consider different types of microclimates, little research has been done on urban microclimates due to the spatial scale being too small (Berger et al., 2015).

1.4 Research Aims and Objectives

This research aims to understand how tree canopy cover influences microclimates with the following research question: How has canopy cover altered microclimate at UBCBG?
By using Landsat-8 and LiDAR data to look at canopy cover, the project utilized a multiple linear regression derived from both datasets to analyze the following objectives:

1. Identifying trends in microclimate in the understory across the garden;
2. Comparing temperatures between areas with larger canopy cover between different garden area zones; and,

3. Providing additional resources that can give insight on how the garden can increase shade zones for resting species.

This research will aim to answer the hypotheses that if canopy cover encloses an extensive area, then microclimate in the understory will provide maximum shade and comfort for species under heat stress in the UBCBG. Furthermore, this study will ideally be the foundation for future use in the UBCBGs in utilizing remote sensing to assess and monitor microclimates affected by canopy cover. Thus, it will be an applicable tool in how the UBCBG will continue their monitoring and understanding the impact of microclimates on the collections and species within the Garden.

2. Study site and data description

2.1 Study site

UBCBG is located on the University of British Columbia (UBC) Vancouver Campus at latitude 49.25 decimal degrees and -123.25 decimal degrees on the traditional, ancestral, and unceded territory of the xwməθkwəy̓əm (Musqueam) People (see Fig. 1) . The campus is located in the Moist Maritime Coastal Douglas-fir Subzone (CDFmm) (*BEC WEB*, n.d.; *CDFmm.Pdf*, n.d.). It is one of the oldest university botanic gardens and sits at 37 hectares (*About Us*, n.d.). It was originally established in 1916 at a different location on the UBC campus and today hosts many native and non-native cultivated plants. In 1933, it became a separate non-academic service department and also included the Nitobe Memorial Garden and Rose Garden (*Historical Timeline*, n.d.). In UBCBG, there are 15 different cultivated and curated areas in the garden, however the study will be focusing on the Asian Garden.

Figure 1. Study area of the UBC Botanical Gardens in Vancouver, British Columbia. This map is projected on the NAD 1983 UTM Zone 10N. The study focuses on the Asian Garden represented in pink.

Each garden in the UBCBG represents the plant biodiversity of native and exotic temperate ecosystems. Throughout the collections, there are around 120,000 recorded plants that represent 6000 taxa (*Vision & Mission*, n.d.). The UBCBG aligns its goals with the United Nation Sustainable Development Goals (UN-SDGs) in order to advance and develop their programs and projects towards sustainable development (*Local Gardens Growing Global Goals*, n.d.).

2.2 Data summary: UBCBG Shapefile, LiDAR imagery, Landsat-8 tile

2.2.1 UBC Botanical Garden Shapefile

UBC Botanical Garden provided a shapefile that delineates the entire area of the Asian garden and the different beds that the native and non-native plants reside in. The garden is a total of 37 hectares. However, for this study, it will be focusing on the Asian Garden which is a total of 21 hectares–seen in Fig. 1. This gives a generous study area to understand microclimates below the canopy.

2.2.3 Landsat-8 Tile

Landsat-8 data was retrieved from the USGS EarthExplorer. The specific tile used for analysis was flown on June 30, 2021. The tile was already pre-processed by the USGS for improved geometric accuracy and improved digital elevation modeling (Masek et al., 2020).

2.2.4 LiDAR Imagery

LiDAR data was flown on June 23, 2021 over the UBC Campus. It is found in the UBC Abacus Library (https://abacus.library.ubc.ca/). Imagery tiles were selected under the criteria that it intersected with the boundary shapefile of the garden. The LiDAR data was collected under 30 pulses/m^2 and an altitude of 1400 m. The data has been processed to be positioned with a horizontal accuracy of ± 0.30m and vertical accuracy of ± 0.15m due to the flight acquisition (University of British Columbia. Campus and Community Planning, 2021).

Table 1. This table summarizes the relevant datasets used in the study. UBCBG stands for the UBC Botanical Garden which is the study area. LiDAR is the Light Detection and Ranging used as the remote sensing tool to analyze canopy cover. From LiDAR, data is presented in the LAZ format which is a compressed version of an LAS file that comes originally from LASer data. A Landsat-8 tile was retrieved from the USGS Earth Explorer Landsat Collection 2 Level 2.

Dataset	Resolution (m)	Date	Raw Data	Derived Data	Source
UBCBG Shapefile	n/a	2020	Shapefile of study of interest	Garden beds	UBCBG
UBC LiDAR Data	30 pulses/m^2	2021	LAZ	Canopy cover	UBC Abacus
Landsat-8 Tile	30m x 30m	2021	Landsat Collection 2 Level-2	LST	USGS Scene ID: LC08_L2SP_047026_20210630_20210708_02_T1

3.0 Methods

3.1 Overview of identifying canopy cover trends via microclimate dynamics at UBC Botanical Gardens

To analyze canopy cover and microclimate at the UBCBG, LST and canopy cover must be derived from the data collected. Using Landsat-8 data retrieved on June 30, 2021, it will be used to calculate daytime maximum temperatures in degrees Celsius and converted to a raster. Then, canopy cover will be calculated from LiDAR data on first returns only. Using the derived data, it can help identify canopy cover trends in the garden alongside microclimate. Together, with the use of modelling, understanding the relationship between these different spots in the garden to canopy cover can help identify trends in UBCBG.

3.1.1 Data pre-processing and preparation

LiDAR data is already cleaned and pre-processed by Forsite Consultant Ltd. Three tiles were shown to be surrounding the UBCBG. Using RStudio (RStudio Team, 2021) and the lidR package (Roussel, 2021), LiDAR data can be filtered for any duplicates from the tiles retrieved and also normalized to ensure outliers do not skew our data. The Landsat-8 data was retrieved from a Collection 2 Level-2 archive where it is already pre-processed.

3.1.2 Estimating canopy cover

Pre-processed LiDAR data was downloaded as three separate tiles with a 41ppm average point density. The data was filtered for duplicates using the lidR package (Roussel, 2021). A DEM was created using the grid_terrain function at a resolution of 2m. The DEM was used to normalize the data using the normalize_height function. Data was filtered to include first returns only using the opt_filter function on the catalog to ensure only points that hit the canopy were used. Finally, the percentage of points above 2 meters (pzabove2) was calculated using the grid_metrics function. The grid_metrics function also provided several other LiDAR metrics that could be used in the analysis. These included the maximum height (zmax), kurtosis (zkurtvalue), and skew (zskew).

3.1.3 Calculating land surface temperature to analyze microclimates

LST was calculated in ArcGIS Pro using the Raster Calculator function (*Raster Calculator (Spatial Analyst)—ArcGIS Pro | Documentation*, n.d.). This method used Landsat's thermal band 10 to first calculate the Top of Atmospheric (TOA) spectral radiance. Then a conversion was done on the TOA to calculate Brightness Temperature and then converted to degrees Celsius.

Using a normalized difference vegetation index (NDVI) it was used to calculate the emissivity to then be used to calculate the proportion of vegetation. Finally, all the variables needed to calculate LST were derived–see Fig 2.

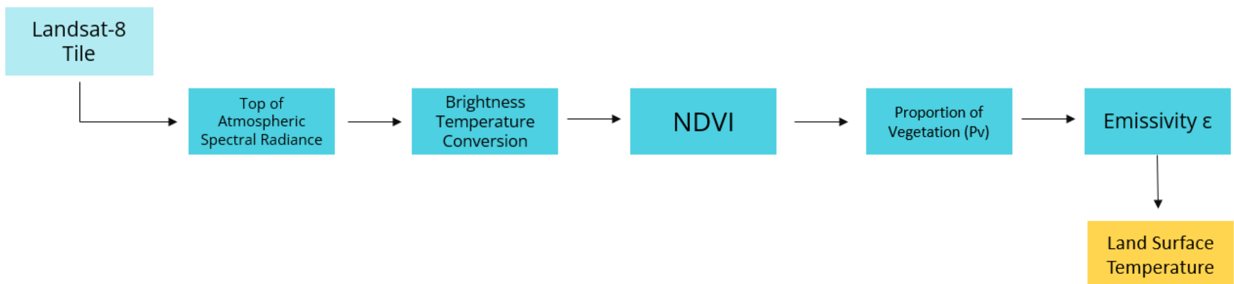

Figure 2. This is a workflow showing the five steps to calculating Land Surface Temperature (LST). First, the input data represented in light blue. The input data is a Landsat-8 tile retrieved on June 30, 2021. The next five steps to calculating LST are shown in dark blue. It starts with calculating the top of atmospheric (TOA) spectral radiance. Then, you convert TOA to brightness temperature and convert the units to degrees celsius. Next, is the calculation of NDVI. Then, you calculate the proportion of vegetation Pv. Afterwards, emissivity ε is calculated. Finally, you calculate LST with all four values from the previous steps. The final product is LST as a continuous raster.

3.1.4 Modelling Using Statistical Analyses

A multiple linear regression (MLR) was used to help analyze different explanatory variables to predict the outcome of the response variable canopy cover. To run the MLR, 100 random points were first generated using the ArcGIS tool *Create Random Points (Data Management)* (Create Random Points (Data Management)—ArcGIS Pro | Documentation, n.d.). The LST raster values and canopy cover raster values were extracted to the random points using the ArcGIS tool *Extract Values to Points (Spatial Analyst)* (Extract Values to Points (Spatial Analyst)—ArcGIS Pro | Documentation, n.d.). Additionally, three other LiDAR metrics were then extracted to our random points. These metrics were zskew, zkurt, and zmax. Finally, a Join (Join Features—ArcGIS Online Help | Documentation, n.d.) was done on all raster values attached to the points into one attribute table. The attribute table was then exported as a .shp feature class.

Using RStudio (RStudio Team, 2021), the exported attribute table was read in as a .shp file using the st_read function in the sf package (Pebesma, 2022). An empty model was created using the imported shapefile with 100 random points and raster values attached. LST was used as the intercept and the empty model was used to show which of the LiDAR metrics were significant when paired together. The grid metric pzabove2 and zmax were shown to be significant when paired with LST– where pzabove2 is the canopy cover percentage and zmax is the maximum height of trees (Stdmetrics · R-Lidar/LidR Wiki, n.d.). These two metrics were then included in the model. An unpaired t-test was then run to understand if the two groups: areas with canopy cover and areas without canopy cover, would show a difference between the two averages.

3.1.5 Workflow

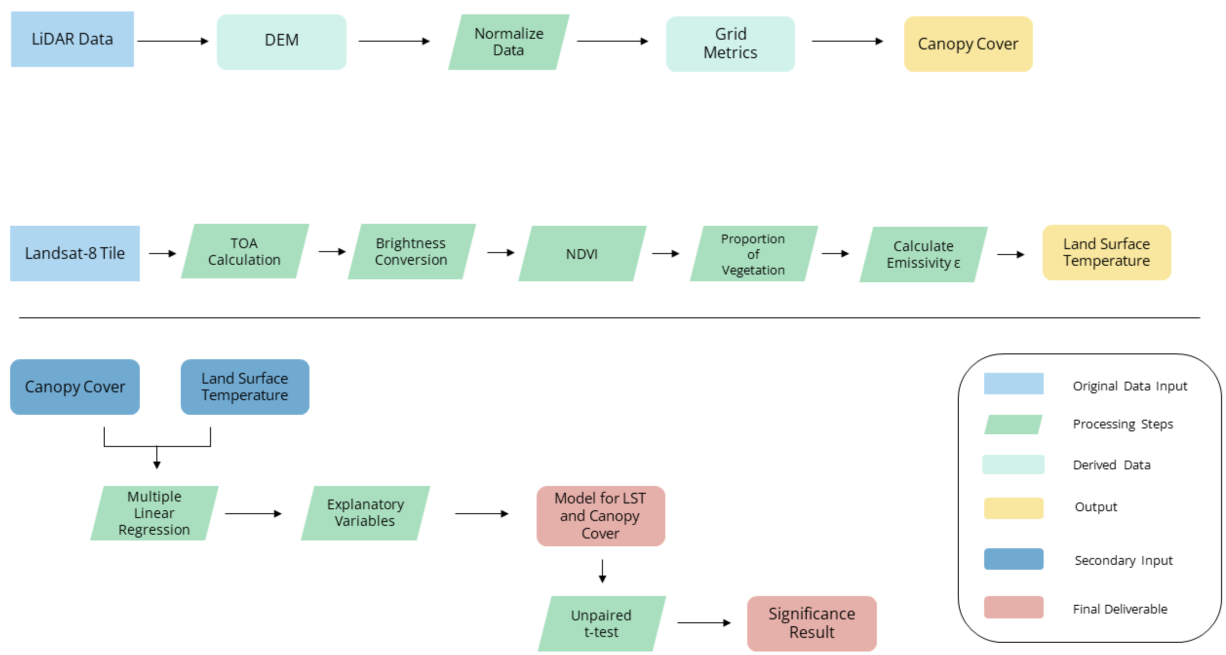

Figure 3. The study's workflow diagram on canopy cover and microclimate in UBCBG. This is based on using LiDAR and Landsat-8 data. To run the multiple linear regression, first canopy cover must be derived and then LST data as seen in yellow. With these two outputs, they can then be input as a secondary input into running a multiple linear regression that can produce a model for canopy cover, maximum height, and LST—as seen in red. An unpaired t-test is done to further investigate the results from the model to give a significance result.

4.0 Results

4.1 Using land surface temperature to assess microclimate

A land surface temperature calculation was done to understand the range of temperatures in different parts of the city. As seen in Fig 4., calculations ranged from the low of 58.6 °C shown in blue and highs of 64.2 °C shown in red. Areas that had lower temperatures were generally areas with canopy cover as seen in Fig 5. In the UBCBG, a large portion of the area had relative average temperatures shown in yellow–see Fig 2. It is important to note that LST is different from ambient temperature; where ambient temperature is the temperature of the environment

(*Land Surface Temperature*, 2021). Therefore our lowest and highest values seem abnormal. Canopy cover is evident in the UBCBG due to cultivated areas of the garden and old growth trees. The hypothesis, “if canopy cover exists, then LST will be cooler beneath the canopy than in other areas without canopy cover” can be visually seen in the LST calculations but further investigation with statistical tests is needed. Areas in UBCBG, where buildings exist, emitted higher daytime maximum temperatures and were represented in red orange colours. Comparing UBCBG buildings to forested areas show that canopy cover can play a significant part in cooling temperatures down while extreme temperatures occur.

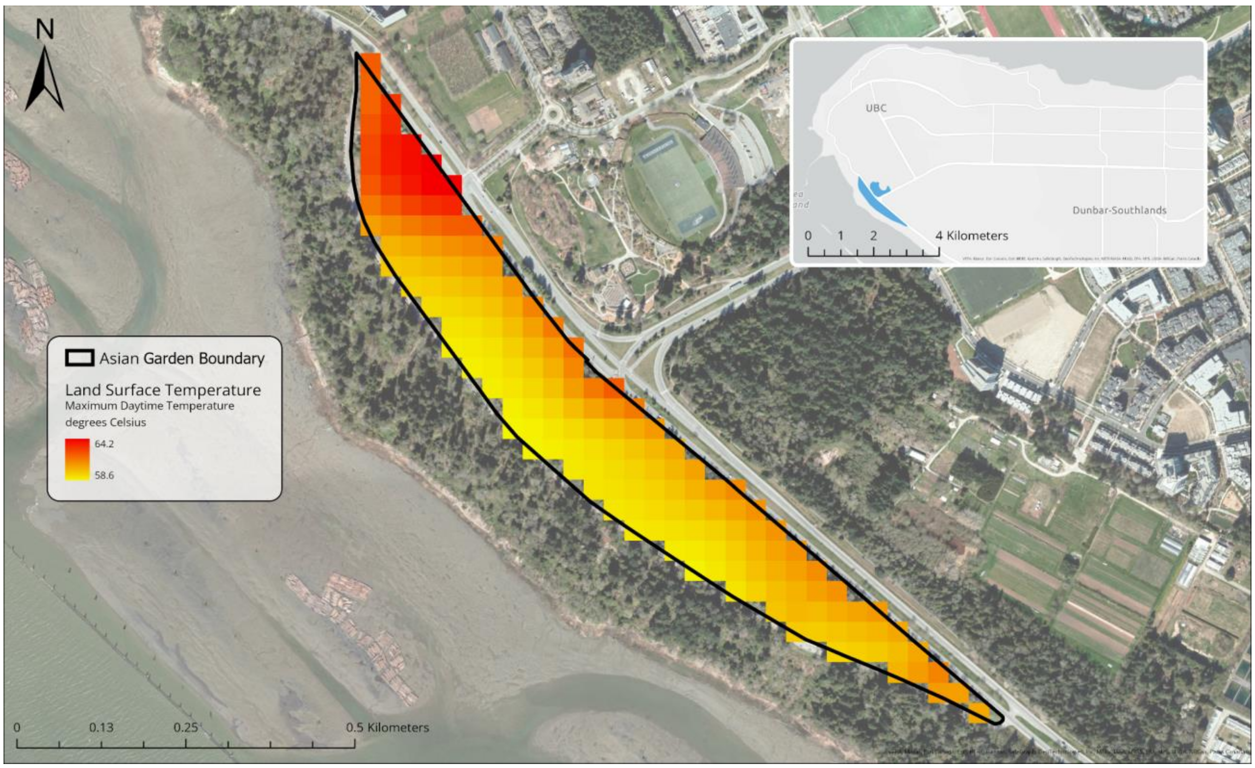

Figure 4. This is a land surface temperature map of UBCBG using Landsat-8 data retrieved on June 30, 2021. On this day, a heat dome extreme weather event was occurring causing extreme high temperatures. You can see the yellow-orange areas reflect cooler temperatures. In areas that have high temperatures, those are reflected in bright red, and they look to be correlated with buildings in UBCBG.

4.2 Canopy cover as the driving variable

Canopy cover percentage is important when used in analyzing microclimate. In Fig 5., areas with canopy cover are represented in dark green and areas with no canopy cover are shown in white– these areas in white are generally buildings and roads. When reviewing our second hypothesis: “if canopy cover is broad and covers an expansive area, temperatures below the canopy will be cooler than the temperature outside the forest due to shading effects", inferences can be made from our LST calculations and to canopy cover percentage generated. There is an abundance of canopy cover within the UBCBG and looking at Fig 4., the LST map, temperatures are cooler in the UBCBG boundary than outside of the garden where buildings exist.

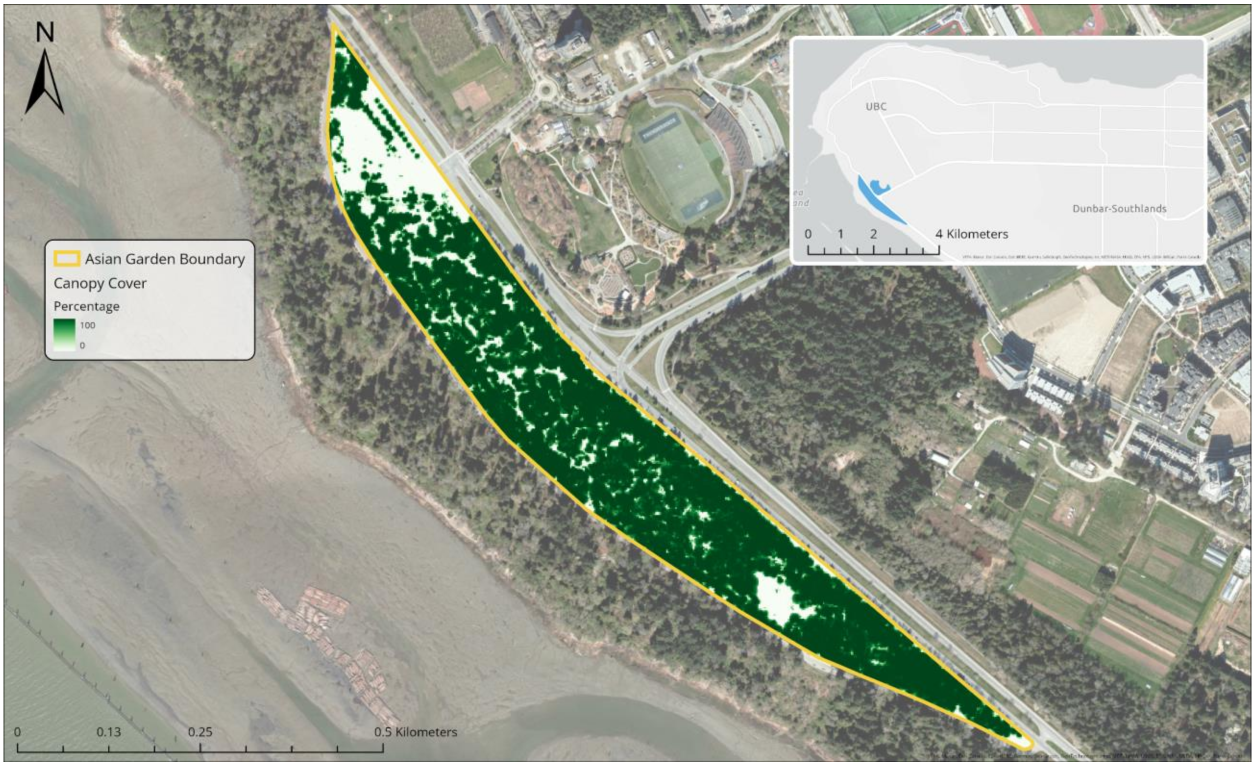

Figure 5. Canopy cover in UBC Botanical Garden is a large factor in creating respite zones for species. Areas with high canopy cover are represented with a deep dark green and areas without canopy cover are represented in white. Vegetation that has little to no canopy cover is shown in light green. Canopy cover was calculated from LiDAR data flown in 2021.

4.3 Land surface temperature and LiDAR metrics statistical analyses

100 random points were derived from LST as explanatory variables in the UBCBG to understand how microclimates in different areas of the garden are affected by the response variable canopy cover. Two additional LiDAR metrics, pzabove2va and zmax, were found to have high correlation with LST. These represent canopy cover and maximum height. They were included in the model to understand how different metrics of LiDAR would affect statistical modelling. Using statistical inferences of multiple linear regression, the hypotheses: "if canopy cover encloses an extensive area, microclimate in the understory will provide maximum shade and comfort for species under heat stress in the UBCBG" could then be answered with our derived data.

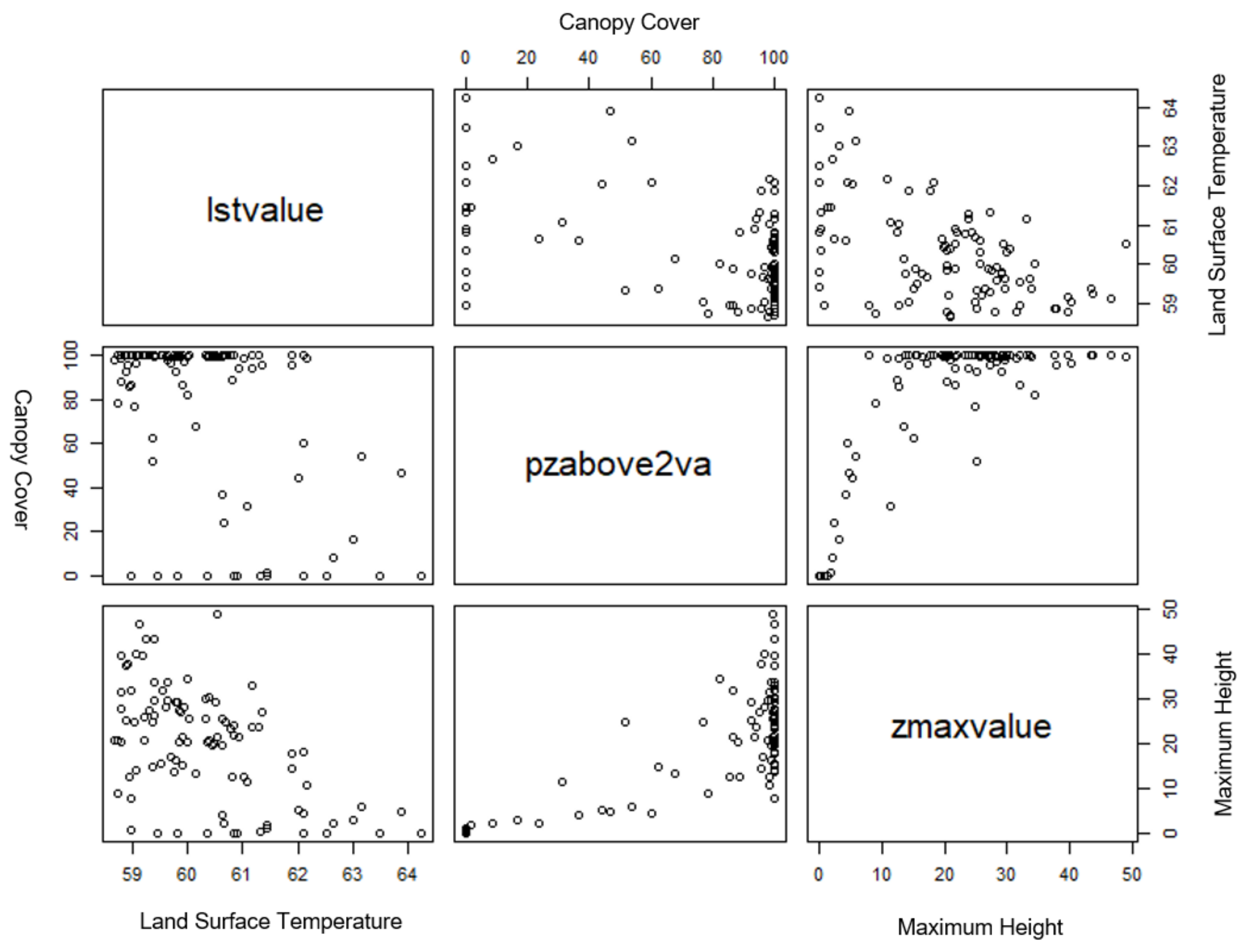

Figure 6. This is the distribution of the pairs of canopy cover and maximum height when paired with land surface temperature. pzabove2va is the LiDAR metric for canopy cover and zmaxvalue is the metric for maximum height. Values ranging from 0-100 on axis represent canopy cover. The maximum height ranges from 0-50 and LST ranges from 58-65.

Looking at Fig 6., the pairs between LST, canopy cover, and maximum height have a strong relationship when first viewing the pairs. After running the MLR with both variables, the correlation between LST and canopy cover is not significant. The p-value for canopy cover is at a value of 0.0993 as seen in Table 2. However, the maximum height of trees has a significance with LST at a p-value of 0.0034. The overall R^2 value of the model was 0.3409 signifying there is not a strong relationship between the two variables and LST–Fig 7., shows the predicted vs. measured graph. The model for coefficients from LST, canopy cover, and maximum height is seen below. Further investigations can be done to understand the significance of areas with and without canopy cover.

$$(-0.007739 * \text{canopy cover}) + (-0.042072 * \text{maximum height}) + 61.78942 \quad (1)$$

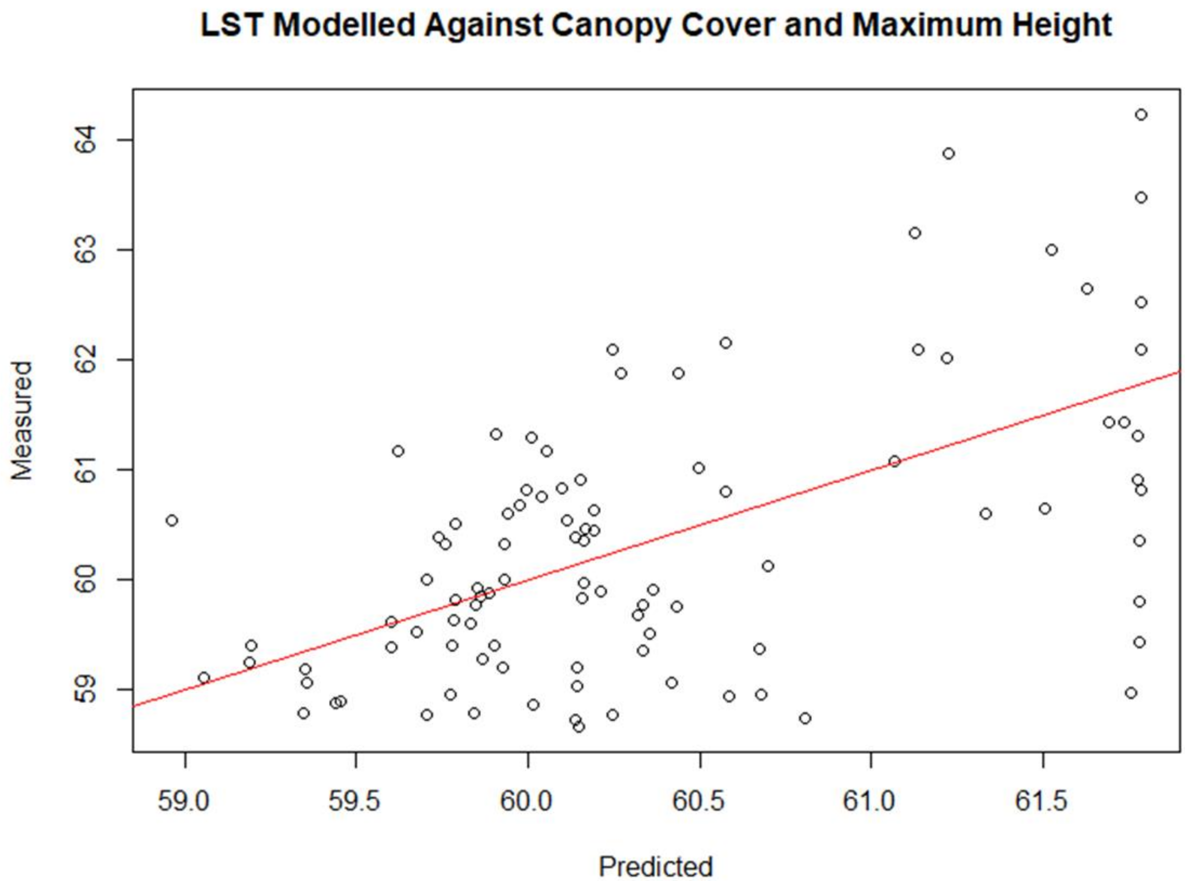

Figure 7. This is the predicted vs. measured plot produced from the model. The closer points are along the fitted line, the stronger the relationship. Since the R^2 value is 0.3409, the model can only explain a 34% variation between the variables tested.

Table 2. This is the summary of the model created using land surface temperature, canopy cover, and maximum height. Where pzabove2 is canopy cover and zmax is maximum height. The asterisks represent the most significant variables.

	Estimate	Standard Error	t value	Pr(>|t|)
(Intercept)	61.789420	0.238614	258.952	< 2e-16 ***
pzabove2	-0.007739	0.004651	-1.664	0.09938
zmax	-0.042072	0.014014	-3.002	0.00341 **

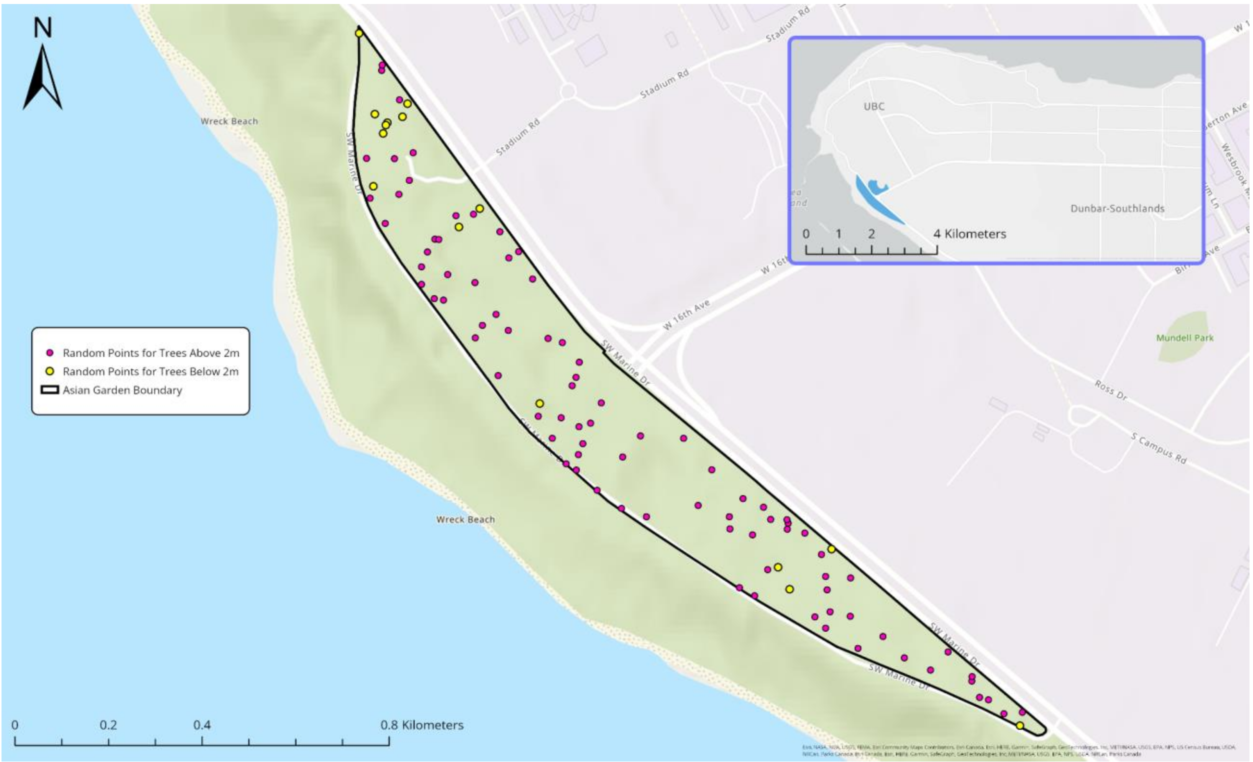

Figure 8. This map depicts 100 random points categorized into two types. The first are the pink points which have been filtered for trees above 2m. The yellow points are trees below 2m. These points were separated to run an unpaired t-test.

An unpaired t-test was run to compare the means of the two unrelated groups to determine if there was any difference between the two. Looking at Fig 8., the two groups were random points for trees above 2m and random points for trees below 2m within the garden. The t-test showed (see Table 3) that the two unrelated groups did have differences as the p-value was 0.0035 which is less than the alpha of 0.05. This means that areas with canopy cover were different from areas without canopy cover. We reject our null hypothesis as the true difference in means is not equal to 0.

Table 3. Welch Two sample t-test to determine if two unrelated groups have differences.

Welch Two Sample t-test		
t = -3.3943	df = 16.503	p-value = 0.003571

5.0 Discussion

Using standard LiDAR metrics and LST, a model was created to understand how both variables interact with each other to explain how canopy cover influences microclimate. An initial model showed that two LiDAR metrics, pzabove2 and zmax, would have a significant relationship between LST as seen in equation 1 and Fig 6. However, pzabove2, which is the canopy cover variable, was not significant after running the model at a p-value of 0.0993. Only zmax, maximum height, was significant at a 0.00341 p-value which is smaller than our alpha of 0.05. Furthermore, the overall model R^2 value was at 0.3409 meaning the model could only determine that 34% of variation of the dependent variable, LST, was explained by the independent variables pzabove2 and zmax. To continue investigating whether canopy cover influences microclimate, an unpaired t-test was run to compare the two unrelated groups to determine if there were differences in areas with canopy cover and areas without canopy cover. The t-test results had a p-value of 0.0035, signifying that the null hypothesis would be rejected as the true difference in means is not equal to 0. Yet, because our overall R^2 value has a confidence level of 34%, the model used is not the best in determining how canopy cover alters microclimate. There are several factors that could be contributing to low values in our model that will be explained further.

5.1 Canopy cover explains microclimate temperatures

LiDAR is an advancing tool to help characterize forest structure. Canopy cover is important in forests because it buffers understory temperatures in addition to a myriad of other ecosystem services (Kašpar et al., 2021). To assess how temperatures are being buffered below the understory, microclimate is an important variable in determining these differences. A study done by Kašpar et al (2021), found that although ground-measured canopy height and cover has been mostly studied, it is impossible to use these metrics in implementation in understanding microclimatic effects over a large spatially continuous area. The values pzabove2 and zmax from the model gave useful insights of how LST would be affected in areas with large canopy cover. However, it was only useful for obtaining structural drivers of understory microclimate (2021). This is why the overall R^2 value was 0.3409. Additionally, it can explain why pzabove2 was not significant whereas zmax showed to be significant at a p-value of 0.00341. Using LST derived from Landsat is an inferior choice as the resolution is very coarse compared to the study area. It is notable in the LST values derived, that initial insights to how canopy cover affected the areas within the study area had lower values than areas where buildings existed. However, due to the 30m coarse resolution of Landsat, it does not provide a good estimation of microclimate. Most studies using LST to study microclimate generally have a larger study area. A study by Ali et al. (2017), looked at microclimate land surface temperatures across urban parks in Bhopal city. The large study area of 463 km^2 is drastically different than UBCBG Asian Garden. The authors were able to assess a larger area with larger green spaces throughout the city. This provides good estimations on how LST can be used in analyzing microclimates on a larger spatial area. For the Asian Garden study area, finer scale temperature data is needed. Kašpar et al's (2021) study used microclimate loggers to measure in situ air temperature for their microclimate data. Using fine-scale ground measurements would be beneficial in small study areas as it can represent the area better. Although most studies use temperature loggers or finer scale microclimate data, LST in our study gives a good oversight to microclimates in UBCBG. This study on the Asian Garden is valuable in giving UBCBG a starting point to improve microclimate monitoring.

5.2 Modelling microclimate and canopy cover

Many components of the model showed that pzabove2 and zmax were significant to incorporate in the model against LST as seen in Fig 6. However, the final model showed that pzabove2 was not significant anymore and zmax was statistically significant when modelled against LST. Due to this, it was imperative to understand how these two distinguished areas differed. The t-test shows us that there is a difference between areas with and without canopy cover. However, because the model produced low R^2 values (see Fig. 7) and only showed zmax to be significant, this model is not accurate in assessing how canopy cover influences microclimate. An additional downfall of the model is the sampling of random points. Looking back at Fig 1. and 8., points were generated on buildings within the garden when using the tool on the study area boundary. This does not give a good variation of sampling within the study area as the study is focusing on canopy cover within the garden and not buildings. Yet, the statistical modelling on the variables still gives adequate surface level insight in understanding microclimate in UBCBG. Greiser et al. (2018), suggested that forest management and conservation is a key factor in being able to provide support from the effects of climate change and temperature below the canopy. Within the UBCBG the cultivated and non-cultivated areas have a variety of canopy cover structure that can explain the t-test results as areas with canopy cover and areas without canopy cover have statistically significant results. Greiser et al. (2018) found that microclimate modelling is still new and needs to be further assessed in managed forested landscapes. With climate changing brining more extreme weather temperatures, this study was important to understand microclimate in UBCBG (Harris et al., 2020). Urban green spaces are becoming highly coveted in urbanized areas as humans and all species enjoy the ecosystem services green spaces bring (Cheng et al., 2021).

5.3 Recommendation for future microclimate assessments

Many studies studying microclimate and remote sensing used temperature sensors to understand understory temperatures (Kaspar et al. 2021; Zellweger et. al. 2019). For future work in the UBCBG, installation of temperature loggers throughout garden beds can be beneficial in determining an accurate model between canopy cover and microclimate. The Temperature-Moisture-Sensor (TMS) is a new innovation designed for ecological applications (Wild et al., 2019). It has a large memory and long battery life making it a viable logger in the field. These temperature data loggers can gather microclimate information for years with little to no maintenance and facilitates long-term measurements in vast areas as it is similar in shape and height to a small plant (2019). As it measures temperature and soil moisture, acquiring the TMS in UBCBG would be valuable for prospective studies to come. It is an ideal data logger to acquire as it can monitor microclimates across different spatial scales and habitat types. With UBCBG having various garden beds, these sensors are suitable for all different types of beds within the garden. Additionally, to create a model for the UBCBG, sampling random points from the ground to specifically choose areas with canopy cover and areas without canopy cover may be able to show a better understanding of how canopy cover has altered microclimate in the UBCBG. This is due to the 100 random points chosen within the study area being generated on buildings. If field work is not feasible, a generated shapefile excluding buildings may be a solution when creating random sampling points in ArcGIS. As the study area is focused on the Asian Garden, it could be beneficial and interesting to increase the study area to the entire UBCBG. This can increase the random points to create a better sampling within the model and to see what areas are lacking canopy cover within the garden. This would be valuable in ecological restoration and creating new areas for species that reside within the UBCBG during extreme weather temperatures. Currently, the model provides a practical structure in future assessment of microclimate research within the UBCBG. With these recommendations, the model can be further used in a pragmatic approach in how plants are understood and valued alongside species that take refuge within the garden. As microclimate modelling is advancing, UBC Botanical Garden has potential to advance their understanding of finer resolution temperature scale below canopy in future studies.

Recommendations:

- Acquiring Temperature-Moisture-Sensors (TMS) would be beneficial for UBCBG to assess microclimate in future studies. These are viable in the field as they have long battery life and a large memory storage.
- Field work in ground sampling points can give larger spatial variance within the study area. As there are buildings within UBCBG, ground sampling can exclude these areas to provide better sampling points.
- With field work, ground samples can also be used in ground truthing data to provide validation and accuracy to test against models created. With a generated shapefile excluding buildings and structures, random points can be generated similarly to this study to create a model. Then, this data can be validated and tested for accuracy against a model using ground samples.

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