Baselining UBC's Urban Forest: Vancouver Campus

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EXECUTIVE SUMMARY

The University of British Columbia (UBC) Vancouver campus houses a plethora of natural assets- most notably, its urban forest. UBC Campus is infamous for its coastal forest setting, which is arguably one of the most important factors in developing its identity and attracting its outstanding student body. While the urban forest supplies many benefits to the socio-ecological environment, it is still insufficiently recognized in urban planning and development. In the broader context of campus, the City of Vancouver has developed an Urban Forest Strategy and associated targets and, as a separate entity, UBC needs to follow suit. An emerging campus Urban Forest Management Plan (UFMP) is in its beginning phases, however in order to produce a valuable mechanism for management and decision-making, there is an urgent need for more information and research to sufficiently recognize and baseline the campus urban forest to inform the future management and monitoring of UBC's most prominent natural asset.

This study aims to inform the development of the UBC Urban Forest Management Plan by further exploring the status of the campus urban forest, associated ecosystem services, and providing recommendations for planting locations and species selection to maximize value. Specific project objectives are to:

1. Represent the current status of the campus urban forest given pre-existing and derived data;
2. Identify and quantify namely the environmental benefits associated with the campus urban forest; *and*
3. Develop recommendations and priorities for campus urban forest management.

Collectively these objectives seek to increase the vigour, resiliency, and functionality of the campus urban forest, enhancing its full suite of associated socio-ecological benefits, in addition to its mitigation and adaptive capacity.

TABLE OF CONTENTS

1. INTRODUCTION

Trees and forests are the most prominent elements of urban nature (Tyrväinen et al., 2005). Over 80% of Canada's population lives in urban areas (Frank et al., 2014), 65% of which have favourable opinions associated with urban forests and greenspace (World Health Organization, 2015). Beyond contributions to wellbeing and local aesthetics, urban forests provide an extremely valuable and comprehensive range of ecosystem services to our communities and the broader environment. In the face of the uncertainty provoked by climate change, maintaining a thriving urban forest is critical for mitigation and adaptation efforts, in addition to ensuring the functionality of associated environmental, aesthetic, and economic benefits.

The University of British Columbia (UBC) Vancouver Campus houses a plethora of natural assets- most notably, its urban forest. UBC Campus is infamous for its coastal forest setting, which is arguably one of the most important factors in developing its identity and attracting its outstanding student body. While the urban forest supplies many benefits to the socio-ecological environment, it is still insufficiently recognized in urban planning and development (Tyrväinen et al., 2005). In the broader context of campus, the City of Vancouver has developed an Urban Forest Strategy (City of Vancouver, 2014) and associated targets and, as a separate entity, UBC should consider following suit. An emerging campus Urban Forest Management Plan (UFMP) is in its beginning phases, however in order to produce a valuable mechanism for management and decision-making, there is an urgent need for more information and research to sufficiently recognize and baseline the campus urban forest to inform the future management and monitoring of UBC's most prominent natural asset.

1.1 What is an Urban Forest?

Urban forestry can be defined as the science and art of managing trees, forests, and natural ecosystems in and around urban communities to maximize the physical, social, economic, and aesthetic benefits the urban forest provides to society (Helms, 1998). Unlike arboriculture and horticulture, urban forestry looks at the broader picture and considers cumulative effects and benefits of an entire tree population (Schwab, 2009), adapting a holistic approach to managing and balancing a variety of values and objectives. The University of British Columbia's urban forest comprises all of the trees and other vegetation found on campus. The urban forest incorporates both natural and planted vegetation found in gardens, plazas, streets, roofs, and forest periphery found on campus.

1.2 The Role of Urban Forests

Urban forestry has "transcended its original niche function in public policy as an aesthetic amenity to soften the urban landscape" to being increasingly perceived as a solution to pressing urban environmental problems (Schwab, 2009). The urban forest provides a variety of ecosystem services that enhance and promote a healthy, thriving environment. The benefits of the urban forest span environment, economic, cultural, and political domains (City of Melbourne, 2014). All interrelated, feedbacks between these domains collectively contribute to the creation of resilient and sustainable urban landscapes.

Environmental Benefits

Although it is difficult to place a monetary value on the suite of ecosystem services that the urban forest provides, there is a growing awareness of the intrinsic and monetary value of the ecosystem services that urban forests can provide (Livesley et al., 2016). Urban forests, for example, provide benefits such as promoting air quality, absorbing carbon dioxide, managing stormwater, providing wildlife habitat, and providing shelter from wind and noise (Ponce-Donoso et al., 2017; City of Vancouver, 2014; Roy et al., 2012; Tyrväinen et al., 2005; Konijnendijk et al., 2004).

The role and associated benefits of urban forests is scalable, providing substantial benefits at even the tree-level and accumulating to greater benefits at the street- and city- levels (Livesley et al., 2016; Tyrväinen et al., 2005). Individually, urban trees provide shade cooling, soil and water uptake, particle deposition, irradiance reflected, and rainfall interception and evaporation (Livesley et al., 2016). At the street-level, the urban forest facilitates pedestrian human thermal comfort, supports complex habitat and biodiversity, increases energy savings, and reduces runoff and improves water quality (Livesley et al., 2016). When extrapolated to an entire city, the urban forest is capable of reducing heat island effects, pollution, and runoff, and increases filtration (Livesley et al., 2016).

The urban forest provides a comprehensive suite of environmental benefits, however, there are several ecological benefits that may be of particular interest to UBC as it considers the benefits provided by its own urban canopy, including:

- **Stormwater Management.** The ability of the urban forest to reduce stormwater flows and aid in urban hydrological processes is especially critical. In conjunction with their root systems and surrounding soils, tree canopy intercepts and retains the flow of precipitation, ultimately reducing the rate the rate and volume of stormwater runoff, flood damage, stormwater treatment costs, and other problems related to water quality (Nowak & Dwyer, 2007).

- **Shading & Cooling Effects**. The addition and expansion of the urban forest also provides shade and cooling benefits to the urban environment. Through processes of transpiration and shade provision, trees help reduce surrounding surface temperatures- particularly in highly impervious environments (City of Melbourne, 2014).

- **Air Filtration & Carbon Sequestration**. The urban forest additionally ameliorates air pollution and reduces the presence of greenhouse gases (GHGs) in the atmosphere through photosynthetic processes, which removes carbon dioxide, nitrous oxides, sulphur dioxide, carbon monoxide and ozone from the atmosphere (Yin et al., 2011). Additionally the urban forest can filter dust and other fine particulate matter in the air by processes of absorption, detoxification, accumulation, and metabolization (Naik & Somashekar, 1970). Trees provide climate change mitigation measures through sequestering carbon dioxide, the main driver of climate change, which is an invaluable mitigation strategy for reducing atmospheric levels.

- **Enhancing & Promoting Biodiversity.** A healthy, thriving urban forest contributes to local habitat provision and biodiversity. Urban forests around the world have been shown to support a wide range of species, and provide habitat to a variety of common and endangered species of high conservation value. By planting and managing for species diversity, and a variety of age and size classes, species biodiversity and wildlife habitat values can be enhanced.

Socio-Cultural Benefits

Beyond ecological benefits, urban forests have many positive feedbacks on the socio-cultural aspects of a community. The urban forest and landscape helps contribute to an attractive townscape and communicates the image of a nature-oriented city, helping establish a local identity and character. Trees and green spaces provide aesthetic enjoyment and help create a pleasant outdoor environment (Tyrväinen et al., 2005), and play a significant role in making our towns and cities more livable and better adapted in the face of climate change. Defined green spaces and urban forest features help improve community cohesion, and encourages outdoor recreation and activity opportunities (City of Melbourne, 2014). Collectively, access to nature and views of green space and trees have positive effects on wellbeing, as studies have shown that both mental and physical disease rates were less prevalent in areas with higher percentage of green space (Maas et al, 2005). Although the socio-cultural benefits of the urban forest is difficult to measure, they are highly valuable and reflect the important contributions of trees and forests to the quality of life for urban communities.

Economic Benefits

Urban forests benefits that stem from both ecological and socio-cultural dimensions can be quantified in dollar terms and span across many industries, including sustainability, health, engineering, and real estate. The economic benefits of the urban forest helps form a strong, founded business case for urban forest expansion and protection, as often competing interests exist between the urban forest and other entities, including scenic viewsheds, sunlight, development, pests and allergies (City of Vancouver, 2014). Trees and urban greenspace have been associated with increases in nearby residential property values (Nowak & Dwyer, 2007), wherein homes adjacent to parks and open spaces are appraised 8-20% higher than comparable homes elsewhere (Crompton, 2001). Increased real estate values subsequently promotes local economies and tourism (Tyrväinen et al., 2005) by ensuring access to nature and healthy communities and enhancing local aesthetics. Features such as attractiveness, design, and other aesthetic elements of the urban environment have become central to branding and marketing in many urban areas (Erickson & Roberts, 1997), which can serve as a catalyst to local economic growth.

1.3 Climate Change: Adaptation and Mitigation through Urban Forests

Climate change refers to long-term shifts in weather conditions and may be measured by changes in a variety of climate indicators such as temperature and precipitation (Easterling et al., 2000). Climate change affects both average and extreme conditions globally, and is largely a function of human activity (Easterling et al., 2000). As some level of climate change is already underway, responding involves two approaches: mitigation and adaptation. Mitigating, or reducing, the effects of climate change requires the reduction of GHGs in the atmosphere. Means by which global citizens can mitigate further climate change is either by reducing sources of greenhouse gas emissions such as the burning of fossil fuels, or by enhancing existing carbon sinks that accumulate and store GHGs, such as forests and soils. Mitigation strategies seeks to stabilize GHGs in the atmosphere in a “timeframe sufficient to allow ecosystems to adapt naturally to climate change” (Hannah, 2015). Adapting, on the other hand, in a changing climate involves adjusting to actual or expected future climate. By learning to best manage lands and forests, we can promote climate change adaptation and promote the future resiliency of our campus urban forest despite a changing climate.

Climate change poses a threat to the conditions of urban forests, however, also presents an opportunity for UBC to adapt to and mitigate future change by enhancing the resiliency of the campus urban forest. The potential effects on the condition of the urban forest and its associated benefits are relatively understudied, and as a result many cities and municipalities do not know what actions to take to preserve the health of their urban forest and adapt and mitigate future change. As a leader in campus sustainability, this confluence of events provides UBC an opportunity to create a more resilient urban forest and to provide urban forest adaptation and mitigation strategies to universities worldwide.

1.4 Project Purpose

The development of an Urban Forest Management Plan will be critical to ensuring the consideration of the campus urban forest and associated suite of environmental, social, and economic values as UBC continues to develop over the coming years. The protection and enhancement of the urban forest and associated suite of ecosystem services will help respond to developmental and climate change pressures, reduce environmental costs of grey infrastructure, and improve the quality of the urban environment.

In order to develop a useful mechanism for management and decision-making in the future, and a means by which to monitor the health and status of UBC's urban forest assets in subsequent periods, information on the current urban forest must first be explored. This study aims to inform the development of the UBC Urban Forest Management Plan by further exploring the current status of the campus urban forest, associated ecosystem services, and providing recommendations for planting locations and species selection to maximize value.

Specific project objectives include:

1. Represent the current status of the campus urban forest given pre-existing and derived data;
2. Identify and quantify namely the environmental benefits associated with the campus urban forest; *and*
3. Develop recommendations and priorities for campus urban forest management.

Collectively these objectives seek to increase the vigour and resiliency of the campus urban forest, while enhancing its full suite of associated socio-ecological benefits, in addition to its mitigation and adaptive capacity.

2. METHODS

Mixed-methods research data and geospatial analyses were conducted to provide useful insight into the status and valuation of the campus urban forest. The amalgamation of these products have informed a meaningful baseline of this natural asset on UBC Vancouver campus.

2.1 Tree Canopy Cover

As a means of estimating tree canopy and other land cover types on UBC Vancouver campus, the i-Tree Canopy v6.1 tool was used. i-Tree is a peer reviewed software suite from the USDA Forest Service that provides urban forestry analysis and benefits assessment tools. This tool allows the user to draw an area of interest or upload a GIS shapefile of their study location. Land cover types of interest are defined by the user, wherein i-Tree Canopy generates random sample points. Per point land cover classes are defined by the user as per the categories of interest previously defined. As the number of sample points across the area of interest increases, the standard error associated with each land cover type decreases.

Land cover classes were defined into three broad categories, including tree cover, artificial/impervious surfaces, and soft landscape. Points were classified as tree cover if the randomly generated point occurred over tree or tree canopy. Artificial/impervious surfaces include surfaces such as buildings, roads, walkways, and other concrete or artificial structures such as cars on campus. Finally, soft landscape includes randomly generated points include shrub, grass, or agricultural fields. Collectively, these land cover types broadly encompass the university and provide insight into the tree canopy cover, impervious- or impenetrable surfaces- and, soft landscape.

For the purpose of this study, the university's legal boundary and academic core have been observed separately in various applications. While UBC is responsible for managing the campus urban forest in its entirety, a substantial portion of the periphery of campus is does not receive any regular and significant human intervention. The majority of planting operations and management are centralized towards the core of the academic portion of campus, which excludes residential neighbourhoods and special zoning areas. As the campus' most central and highly trafficked area, the academic core should receive special consideration in future planting operations and tree replacement activities. For this purpose, both the academic core and greater UBC campus will be referred to throughout this study.

UBC Legal Boundary

The UBC Vancouver campus legal boundary was obtained from the UBC Dataverse ABACUS Public Data Collection, produced by Campus and Community Planning (Burton & Wiersma, 2016) (Figure 1). This geospatial data was stored as a GIS shapefile and inputted into the i-Tree Canopy v6.1 interface. Aforementioned land cover types were manually defined, including tree cover, artificial/impervious surfaces, and soft landscape. A total of 1,000 points were randomly generated within the UBC legal boundary to estimate the relative proportions of tree cover, artificial/impervious surfaces, and soft landscape across the campus. 2018 Google Maps Products were used in the i-Tree Canopy interface (i-Tree, 2018).

Academic Core

To provide meaningful statistics exclusive to the academic core and planting operations, excluding the majority of neighbourhood housing and special zoning constraints, the academic core of campus was manually delineated according to other Campus & Community Planning documents (University of British Columbia, 2010) (Figure 1). Aforementioned methods for estimating land cover type within the campus legal boundary were similarly applied to the academic core study area, however only 500 points were randomly generated to represent the study site due to its smaller area.

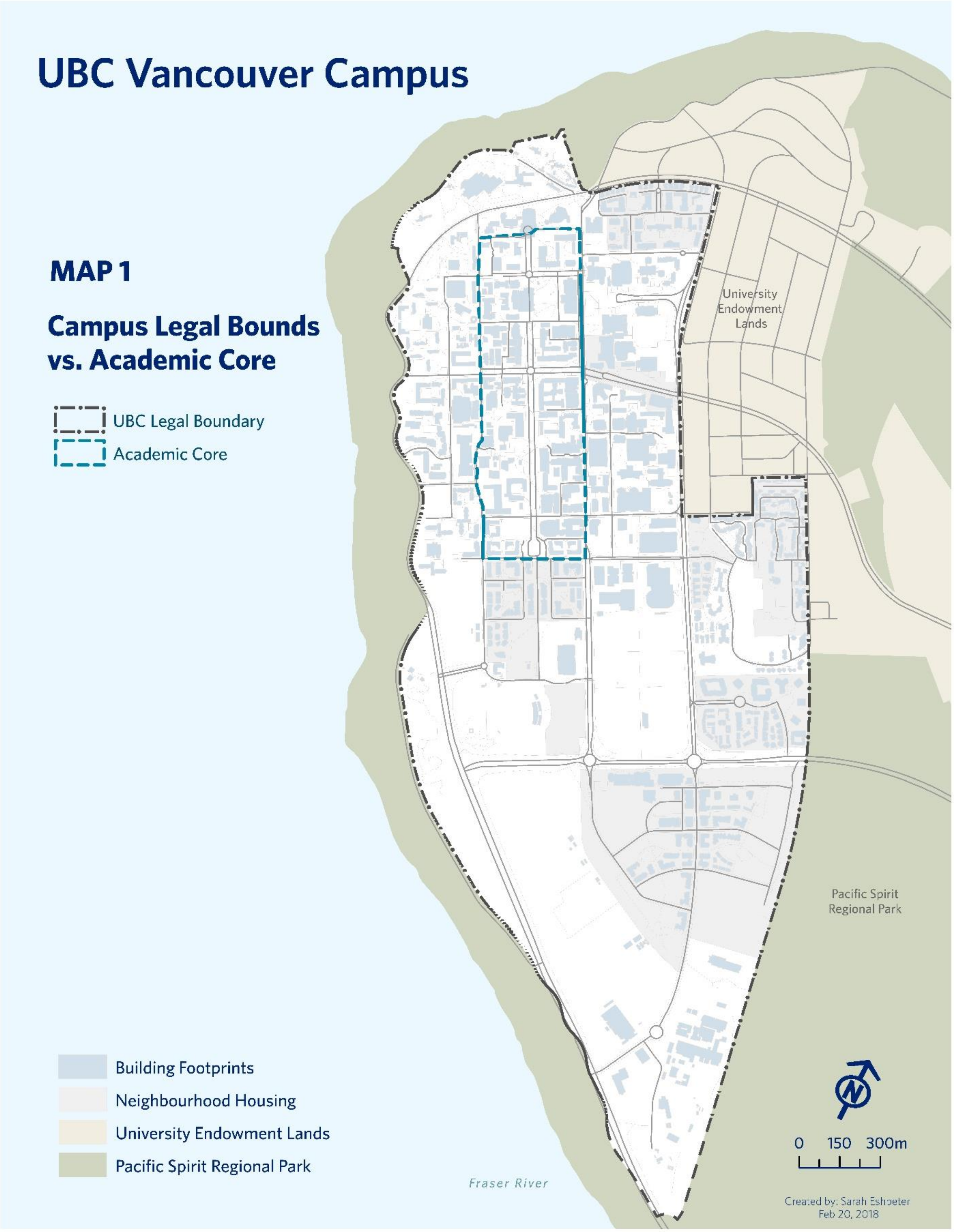


Figure 1. UBC Vancouver campus legal boundary and academic core, as defined for the purpose of this study.

2.2 Grey-Green Mapping

Previously used in the tree cover analysis, three broad land cover types encompass the campus ecosystem, including artificial or impervious surfaces, soft landscape (i.e. grass and shrubs) and tree canopy. While land cover types were estimated on campus using the i-Tree Canopy tool, the spatial mapping of these surfaces allows for the prioritization of management activities based on objectives such as adding additional green spaces or stormwater irrigation.

The 2017 orthophoto dataset of campus produced by McElhanney Consulting Services Ltd. and distributed by the University of British Columbia (McElhanney Consulting Services Ltd., 2017) was obtained from the UBC Dataverse ABACUS Public Data Collection. This dataset includes georectified orthophotos of the UBC Vancouver campus as taken in July 2017, with a 10 cm spatial resolution. Orthophotos were pre-processed using ENVI remote sensing software and ArcMap v10.5 from the ESRI software suite. Orthophotos were clipped to the legal campus boundary, and training samples were collected for the aforementioned land cover types in addition to a shadow class for each image that comprised the UBC campus, as previous studies suggest that individual as opposed to composite classification may be used to increase accuracy (Shao & Lunetta, 2011). The addition of a shadow land cover class was necessary to maintain classification integrity, as the weather conditions and time of day during image collection resulted in a significant amount of shadow, which is spectrally differentiated from all other land cover types.

Training samples were collected manually in areas with pure pixel composition in ArcMap v10.5 to promote image classification quality. Training samples were gathered for each class, ensuring a minimum of 25% of pixels within an individual image represented either shadow, impervious surfaces, soft landscape, or tree canopy cover types. Signature files were created from the training samples for each orthophoto. Maximum Likelihood supervised classification was performed on each image in ArcMap. This classification method is based on the theory of maximum probability, wherein each pixel is assigned to one of the various classes based on the means and variances of the class spectral signatures. The statistical probability for each class is calculated to determine the membership of pixels to a land cover types, assigning pixels to classes based on a priori probability weighting (ESRI, 2017).

2.3 Tree Species Composition & Diversity

Knowledge of tree species composition in an urban forest allows land managers to assess vulnerabilities and enhance the ecological capacity of the urban forest, while minimizing replacement costs over time (Vander Vecht & Conway, 2015). An important element of effective strategic management is accounting for diversity, the composition of the urban forest at UBC will influence associated services and disservices (Vander Vecht & Conway, 2015) and is an invaluable baseline to inform urban forest management strategies and inform future planting efforts.

Data was extracted from the UBC 2010 Tree Inventory (Burton & Wiersma, 2016) obtained from the UBC Dataverse ABACUS Public Data Collection. This inventory contains spatial and botanical information, such as species, genus, and diameter at breast height (DBH). Species abundance and location was analyzed using ArcMap v10.5 from the ESRI software suite. For both the campus boundary and academic core, total number of inventoried trees, genera, and species abundance and composition was recorded. Relative genera and species abundance and composition were calculated for both the campus and academic core.

The diversity of the composition of trees included in the inventory was assessed by calculating the inverse of Simpson's Diversity Index (inverse SDI). Inverse SDI gives a measure of diversity, wherein the greater the SDI value the higher than diversity level (Sun, 1992). This value elicits the direct comparison of species diversity levels between any urban tree populations (Sun, 1992). The formula for the inverse SDI is:

$$[\sum Ni \bullet (\sum Ni - 1)] / [\sum Ni\,(Ni - 1)]$$

where N_i is the number of individuals in the i^{th} group (species or genus) (Sun, 1992).

The existing campus tree inventory, however, has not been updated in its entirety for over well over a decade and does not accurately reflect the status of the UBC Vancouver Campus urban forest. UBC lacks any other tree inventory data of campus, and despite its limitations, this dataset provides valuable insight into the previous planting choices, species composition, and density of areas on campus, and is generally representative given the long-lived nature of tree species.

2.4 Solar Radiation

Solar radiation maps reveal the geographic distribution of solar energy across a specific region, which can be modelled for various times of the year to inform management activities, or even the development of solar energy utilization via technologies such as solar panels. Topography is a key factor that determines the spatial distribution of solar radiation, including features such as aspect, orientation, and shadows cast by topographic features, such as trees (Gastli & Charabi, 2010). This variability also changes throughout time of day and year due to shifts in the sun angle and differing effects of shadow casted resultantly (Gastli & Charabi, 2010). Incoming solar radiation is modified as it passes through the atmosphere, hitting the Earth's surface as direct or diffuse radiation- the sum of which is the total radiation a surface receives (Gastli & Charabi, 2010). An annual solar radiation analysis was conducted for the UBC Vancouver campus using a GIS-based analysis outlined in Gastli & Charabi (2010).

A Digital Elevation Model (DEM) was first produced for the Vancouver Campus by implementing Light Detection and Ranging (LiDAR) data collected in 2015 (University of British Columbia, 2015b) produced by Campus and Community Planning. LiDAR data was downloaded from the Abacus Dataverse Network. LiDAR data depicts three-dimensional information about the Earth and its surface characteristics. This data collection therefore provides 3D information about the campus surface, including heights of features such as buildings and tree canopy. As these characteristics inform shadows and solar radiation levels, the derived DEM is an input requirement to the ArcGIS Spatial Analyst Solar Radiation Tool. This tool takes into account the latitude and longitude of a DEM raster and heights of features, such that the angle of the sun hitting the surface throughout various times of day and seasons are reflected in addition to the integration of surface features.

The Solar Radiation tool was used to calculate the total solar radiation received across the UBC Vancouver campus on an annual basis in ArcMap v10.5. Solar radiation was evaluated on a weekly interval in the 365 day calendar year occurring in 2017, approximating the amount of incoming solar radiation received across an a 30-minute time interval within each 24-hour day. In total, solar radiation based on the regional hemispherical viewshed, sunmap, and skymap were calculated for 52 days at 48 time intervals per day to represent summer solar radiation values in watt hours per squared meters (WH/m^2) across campus.

2.5 Ecosystem Services by Species

Ecosystem services provided by significant species on campus were estimated to inform and provide valuable management and planting recommendations to enhance ecosystem services received on campus and aid in local climate change mitigation.

The i-Tree MyTree v1.2 application was used in order to calculate the monetary ecosystem service benefits derived from the species, average diameter at breast height (DBH), health, sun exposure, and proximity/direction to a building. This tool allows for a simple estimation of benefits provided by individual trees, related to GHG mitigation, air quality improvements, building energy use, and stormwater interception (i-Tree, 2017). Future benefits are forecasted using a model that calculates species-specific tree height for each consecutive year the model is run (i-Tree, 2017). The ecosystem services values derived in the i-Tree Design application are based on the following sources (i-Tree, 2017):

- **Stormwater.** Stormwater values are based on the methods and models derived from the i-Tree Streets application.

- **Carbon**. Carbon dioxide sequestration values are derived from species-specific biomass equations.

- **Energy**. Tree effects on energy are calculated using methods detailed in the USDA Forest Service publication. Trees effect on building shade, evapotranspiration, and wind speed reduction are calculated using an applied reduction factor based on tree type, height, azimuth, and distance from the building.

- **Air Quality**. Air pollutant deposition resource unit values are based on methods and models derived from the i-Tree Streets application.

For the purpose of comparison, selected tree species were located in front of the Forest Sciences Centre in order to directly compare differences in energy, stormwater mitigation, air quality, and carbon sequestration. Tree benefits were estimated for a year. Selected tree species for analysis include: *Acer rubrum* (Red maple), *Quercus rubra* (Red Oak), Prunus *cerasifera* (Cherry plum) and *Thuja plicata* (Western red cedar), all of which are iconic species on UBC Vancouver campus. *Prunus cerasifera* was selected as a species for analysis, as this tree represents perhaps the most notable ornamental, flowering tree species on campus. *Acer rubrum* was selected, as it is the most abundant nonnative species on campus, and often lines streets across campus. *Quercus rubra*, on the other hand, is most well-known on UBC campus for lining the Main Mall pedestrian corridor which is the artery in the academic core. Lastly, *Thuja* *plicata* was selected to represent one of the dominant native species, which is highly valued ecologically, financially, and culturally in BC.

As the current campus inventory has null DBH values for virtually inventoried species, a DBH value of 15 cm was kept constant to remove bias in tree diameter size differences. Further, the health of the all selected species were assumed to be 'fair' in order to provide a more conservative ecosystem service benefit estimate, and in partial shade conditions.

2.6 Predicting the Effects of Climate Change

While climate change is a largely accepted phenomenon affecting ecosystems globally, the regionalized effects of climate change are relatively understudied. To increase the resiliency and viability of UBC's urban forest into the future, further information regarding the locally specific effects of climate change will help provide insight into future conditions and management.

Climate

Future climate projections from general circulation models (GCMs) can be used to predict the potential impact of climate change and provide information for developing adaptive management strategies (Wang et al., 2016). A tool developed at the University of British Columbia, ClimateBC (Wang et al., 2016), provides locally specific climate modelling and projections of a variety of climate variables under different GCMs and Representative Concentration Pathways (RCPs). To predict the locally specific impacts of climate change on the UBC Vancouver campus, ClimateBC was used to model historical climate norms and project climate variables into the future.

The UBC Legal Boundary was inputted into the ClimateBC software, and both historical and future climate variables were estimated under the second generation Canadian Earth System Model (CanESM2), a coupled global climate model developed by the Canadian Centre for Climate Modelling and Analysis of Environment and Climate Change Canada. CanESM2 represents the Canadian contribution to the IPCC Fifth Assessment Report (Chylek et al., 2011). The model combines an atmosphere-ocean CGM, a land-vegetation model, and an interactive ocean and terrestrial carbon cycle (Chylek et al., 2011), and represents a nationally specific and high accuracy model for projecting the effects of climate change. RCP scenario 4.5, a scenario of long-term global greenhouse gas (GHG) emissions with peak emissions at 2040 followed by a steady decline (International Panel on Climate Change, 2015), was used in conjunction with CanESM2 to model the local effects of climate change on UBC campus.

Average climate conditions and measurements for the period 2000-2010 were used to represent a historical baseline. Climate variables were modeled at 30-year intervals from 2025-2085, estimating seasonal and annual precipitation levels.

Tree Species Suitability

Shifts in climate envelops affect tree species suitability given changing conditions. The Biogeoclimatic Ecosystem Classification (BEC) system groups ecosystems based on three levels of integration, including regional, local, and chronological that considers feature such as vegetation, soils, topography and site sequences that are used to infer the regional climate can identify geographic areas with relatively uniform features (MacKillop & Ehman, 2016). The BEC system delineates ecological zones that are commonly used in forestry and conservation that classifies ecosystem based on the potential of the site at climax or mature successional stages (MacKillop & Ehman, 2016).

UBC Vancouver campus is situated in the Coastal Western Hemlock (CWH) biogeoclimatic (BEC) zone, Very Dry Maritime subzone, Eastern variant (xm1). However, as climate change threatens the campus, it can be expected that regional climate variables and the associated BEC classification will change in light of a changing climate. In order to assess future site conditions and suitability under these conditions, projected BEC zones and species suitability forecasts were modelled using the Tree Species Selection Tool (TSST) [beta version] developed by the Ministry of Forests, Lands and Natural Resource Operations and Rural Development's (FLNROD) (FLNROD, 2018). This tool provides forest practitioners with the best available science-based information to inform tree species selection decision-making in the context of a changing climate (FLNROD, 2018).

Several supporting elements inform this model (adapted from FLNROD, 2018):

1. **BEC Framework**. Including tree species silvics and ecology.

2. **Ecological Factors.** Information on ecological factors to determines risks to tree species ecological suitability.

3. **Species Information for Management Objectives & Values**. Information to assist in evaluating tree species in the context of management objectives/values.

4. **Climate Change Adaptation.** Climate science and tree species information to consider in developing adaptation strategies.

Using the TSST, the UBC Vancouver campus was identified and climate conditions for the given area were projected forward. The TSST models BEC subzones and implicates the consensus of 31 climate futures that are used to estimate tree species suitability in future time periods based on ecologically suitable species by BEC subzone and variant (FLNROD, 2018). Campus location, elevation, latitude and longitude, as well as BEC subzone and site series was identified to configure the model. Reports were generated for years 2025, 2055, and 2085. Tree species suitability is assessed only for species that naturally occur across this range, as conventionally the TSST is used for traditional practitioners at the stand- and landscape- levels (FLNROD, 2018). Management intervention, however, is prominent in campus planning and operations and historically occurred at a large scale for UBC Vancouver campus' initial development. Nonetheless species suitability still provides insight into the viability and suitability of native and natural species on campus, as well as to what species would be naturally dominating the landscape if development had not occurred.

3. RESULTS

3.1 Tree Canopy Cover

The i-Tree land cover analysis successfully quantified proportions of artificial/impervious surfaces, soft landscape, and tree canopy cover for the academic core and the broader campus. Results indicate that the largest surface cover across the UBC Vancouver campus is impervious, comprising roughly 45% of the total landscape (Figure 2). Soft landscape features such as shrubs and grass represent 25$^{\%}$ of the campus surface, while tree canopy occupies nearly 30% (Figure 2).

The academic core, however, exhibited a different surface cover composure with an estimated 60% classified as artificial or impervious surfaces (Figure 3), representing the greatest change in comparison to the composition of the greater campus bounds. Soft landscape in the academic core of campus represented 16% of surface cover, representing nearly 65% less surface cover than across the campus (Figure 2 and 3). Tree canopy in the academic core exhibited the smallest fluctuation in composition in the two areas of study, comprising 22% of surface cover (Figure 3). The standard error associated with these estimates is less than 2%.

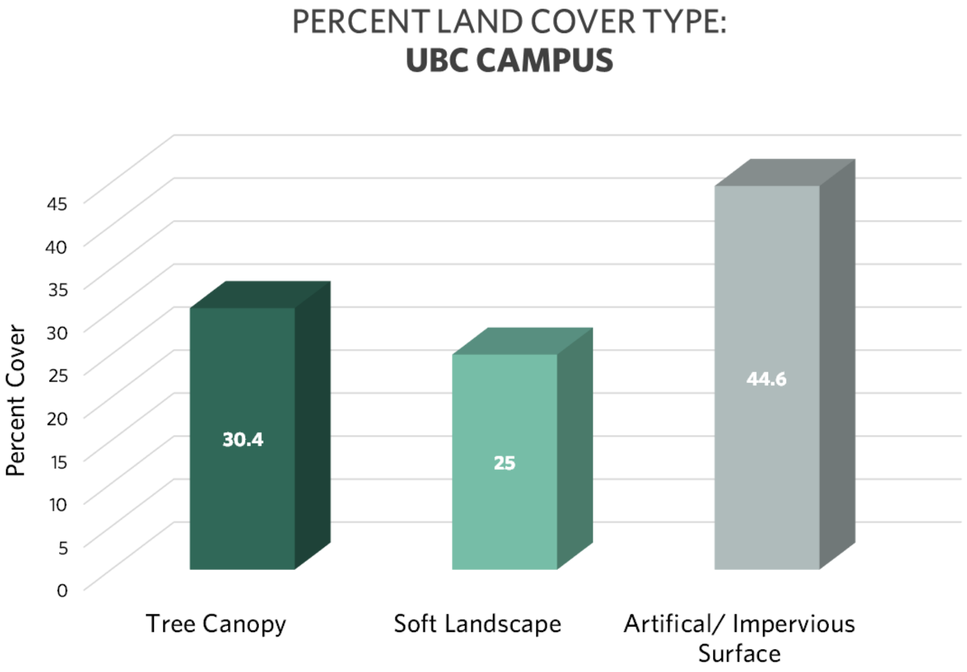


Figure 2. Percent land cover type across UBC Vancouver campus.

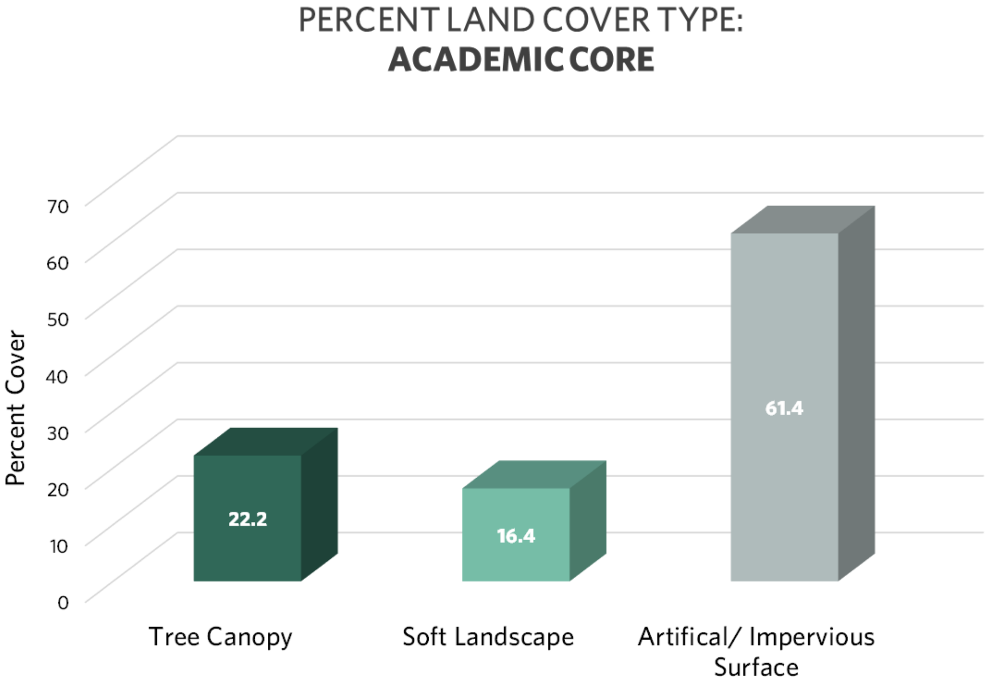


Figure 3. Percent land cover type across the UBC academic core.

3.2 Grey-Green Mapping

The effective mapping of ‘grey’ and ‘green’ infrastructure effectively necessitates the ability to characterize land cover (form) and land use (function) simultaneously (Liquete et al., 2015). As a result of mapping grey and the various forms of green infrastructure across campus, these assets on campus were spatially mapped and identified. The initial grey-green mapping demonstrated satisfactory levels of accuracy, although classification confusion exists intermittently- particularly in the sports fields and research ponds on campus. The dataset resulting from this initial spatial classification is presented in Figure 4.

The map demonstrates the different associations that can be observed between the discrete landscape features across campus. As previously established in the quantification of surface cover, the academic core houses the highest concentration of grey infrastructure (Figure 4), although the highest density of grey infrastructure, or artificial/impervious surface, is located along Wesbrook Mall from the Doug Mitchell Thunderbird Sports Centre to the bus loop and Aquatic Centre. While the academic core is highly comprised of artificial surface types, a substantial amount of tree canopy exists lining the Main Mall pedestrian walkway (Figure 4).

South Campus houses the majority of UBC’s urban forest assets, including forested areas along Southwest Marine Drive that are the periphery of Pacific Spirit Regional Park (Figure 4). Similarly, the greatest presence and highest concentration of soft landscape features are situated in South Campus, including notable features such as the sport fields located along Wesbrook Mall across from Hampton Place, as well as the UBC Farm (Figure 4).

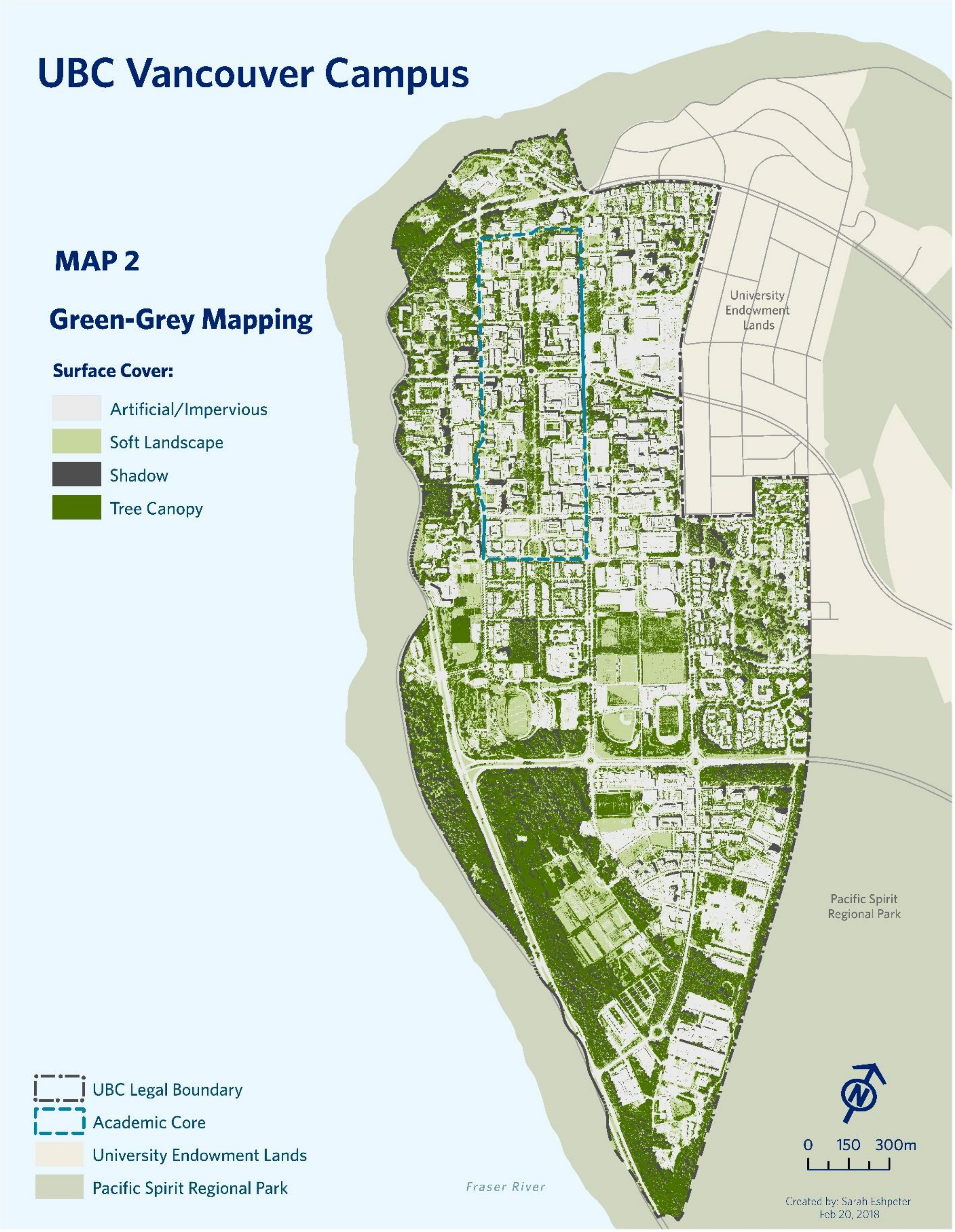


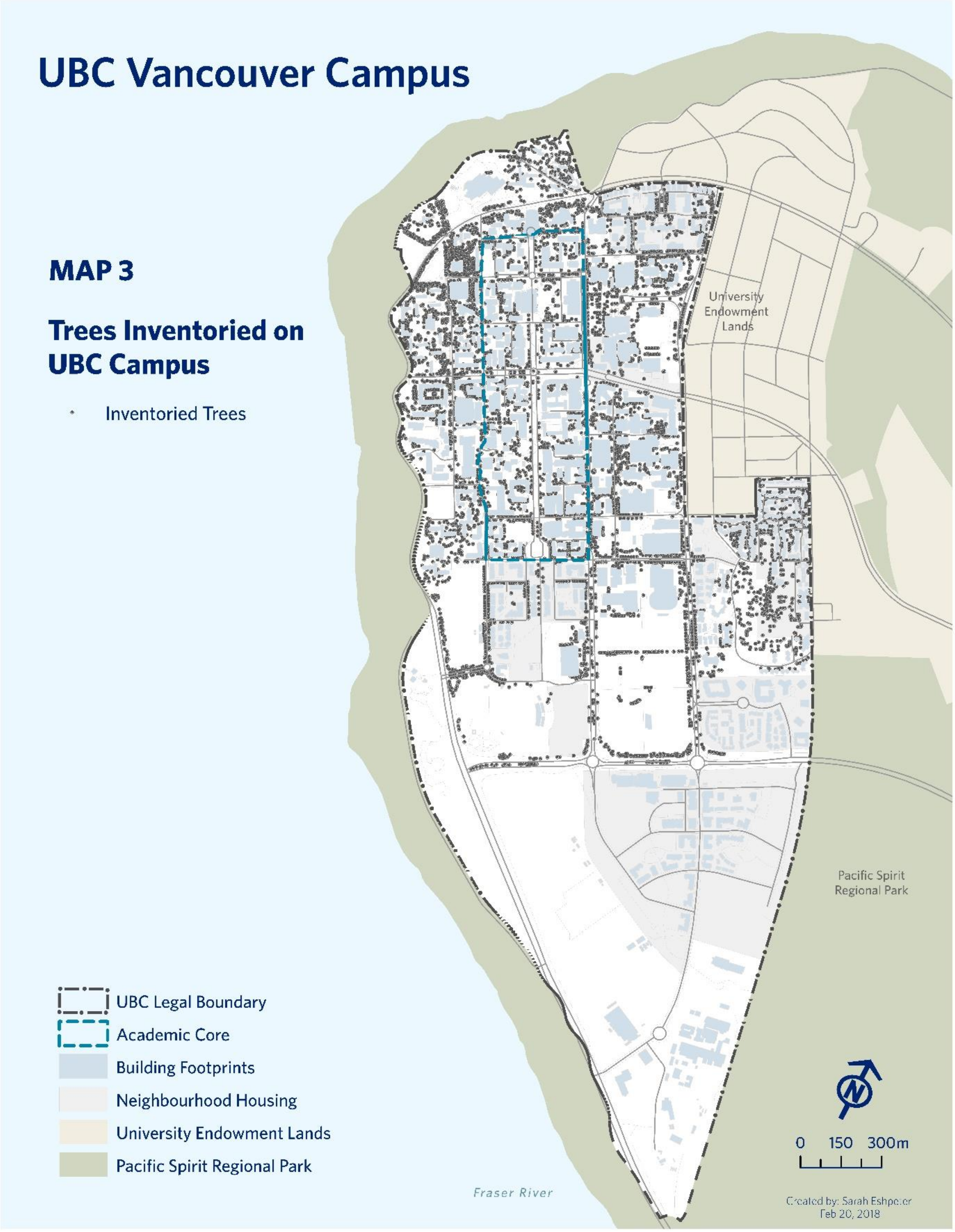
Figure 4. The result of grey-green mapping of the UBC Vancouver Campus.

3.3 Tree Species Composition

The campus tree population at the University of British Columbia Vancouver Campus has relatively limited diversity, with 53% of 6,068 trees in the database represented by five common genera (Table 1). *Acer* is the most common genus by far on campus, representing over 20% of all trees on campus. This is the only genus that exceeds a 20% threshold, with *Thuja, Pinus, Quercus, and Pseudotsuga* all representing between 5% and 15% of the campus tree population. In total, 84 genera and 173 species make up the existing campus inventory of campus trees within the legal campus bounds. The academic core, on the other hand, is composed of a different species composition and exhibits slightly higher species diversity than the broader UBC campus, with 42% of 1,092 inventoried trees represented by five genera (Table 2). *Acer* is also the most common genera in the academic core, representing nearly 12% of trees, while *Pinus, Fagus, Quercus,* and *Chamaecyparis* represent between 5% and 10% of the tree population in the core (Table 2).

Inverse SDI values less than 10 for any given genus suggest that the species diversity is insufficient (Sun, 1992), which can help inform future planting and planning efforts. In urban forestry, a 10-20-30 rule for tree species diversity is commonly used, which suggests that no more than 10% of any one species, 20% of any one genus, or 30% of any one family should exist across an urban forest to ensure species diversity (Santamour, 2004). Observing the entire tree population across UBC campus included in the campus Tree Inventory (Burton & Wiersma, 2016), *Acer* and *Thuja* genera resulted in inverse SDI values of 4.5 and 9.0, respectively (Table 1). In the academic core, however only the *Acer* genus exhibited a resultant value of less than 10, with an inverse SDI value of 8.6 (Table 2).

Tree species included in the campus inventory were cross-referenced with the native plant species in British Columbia (BC Nature, 2002) to assess the proportion of native species across campus. A total of 21% of inventoried species on campus are native growing species in the province, however only 6% of species in the academic core are of native origin. Nearly 50% of all tree species on campus native to BC are *Thuja Plicata* (Western red cedar) followed by *Psuedotsuga menziessi* (Douglas-fir) representing nearly 25%, and *Acer macrophyllum* (Big-leaf maple) and *Quercus garryana* (Garry oak) representing about 10% (Figure 9).



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Feb 20, 2018

Figure 5. All trees inventoried in the UBC Vancouver Campus as per the Campus Tree Inventory.

Table 1. Genus composition of trees inventoried in the UBC Vancouver campus and their relative inverse SDI value.

Genus	Count	Common Name	Percent of Inventoried Campus Trees*	Inverse SDI Value
Acer	1,362	Maple	**22.4%**	**4.5**
Thuja	676	Arborvitae	**11.1%**	**9.0**
Pinus	422	Pine	**7.0%**	**14.4**
Quercus	394	Oak	**6.5%**	**15.4**
Psuedotsuga	367	Douglas-fir	**6.0%**	**16.6**
Prunus	242	Prunus	**4.0%**	**25.2**
Chamaecyparis	219	False Cypress	**3.6%**	**27.8**
Platanus	183	Plane Trees	**3.0%**	**33.3**
Magnolia	179	Magnolia	**2.9%**	**34.1**
Other	2,024	-	**33.5%**	-
Total	**6,068**		**100.0%**	**-**

*Inventoried without an identified genus were excluded from this analysis.

Table 2. Genus composition of trees inventoried in the UBC academic core and their relative inverse SDI value.

Genus	Count	Common Name	Percent of Inventoried Academic Core Trees*	Inverse SDI Value
Acer	129	Maple	**11.7%**	**8.6**
Pinus	103	Pine	**9.4%**	**10.8**
Fagus	92	Beech	**8.4%**	**12.1**
Quercus	79	Oak	**7.2%**	**14.1**
Chamaecyparis	58	False Cypress	**5.3%**	**19.3**
Betula	43	Birch	**3.9%**	**26.1**
Liriodendron	43	Tulip Tree	**3.9%**	**26.1**
Magnolia	43	Magnolia	**3.9%**	**26.1**
Prunus	40	Prunus	**3.6%**	**28.2**
Other	469	-	**42.7%**	-
Total	**1,099**		**100.0%**	**-**

*Inventoried without an identified genus were excluded from this analysis.

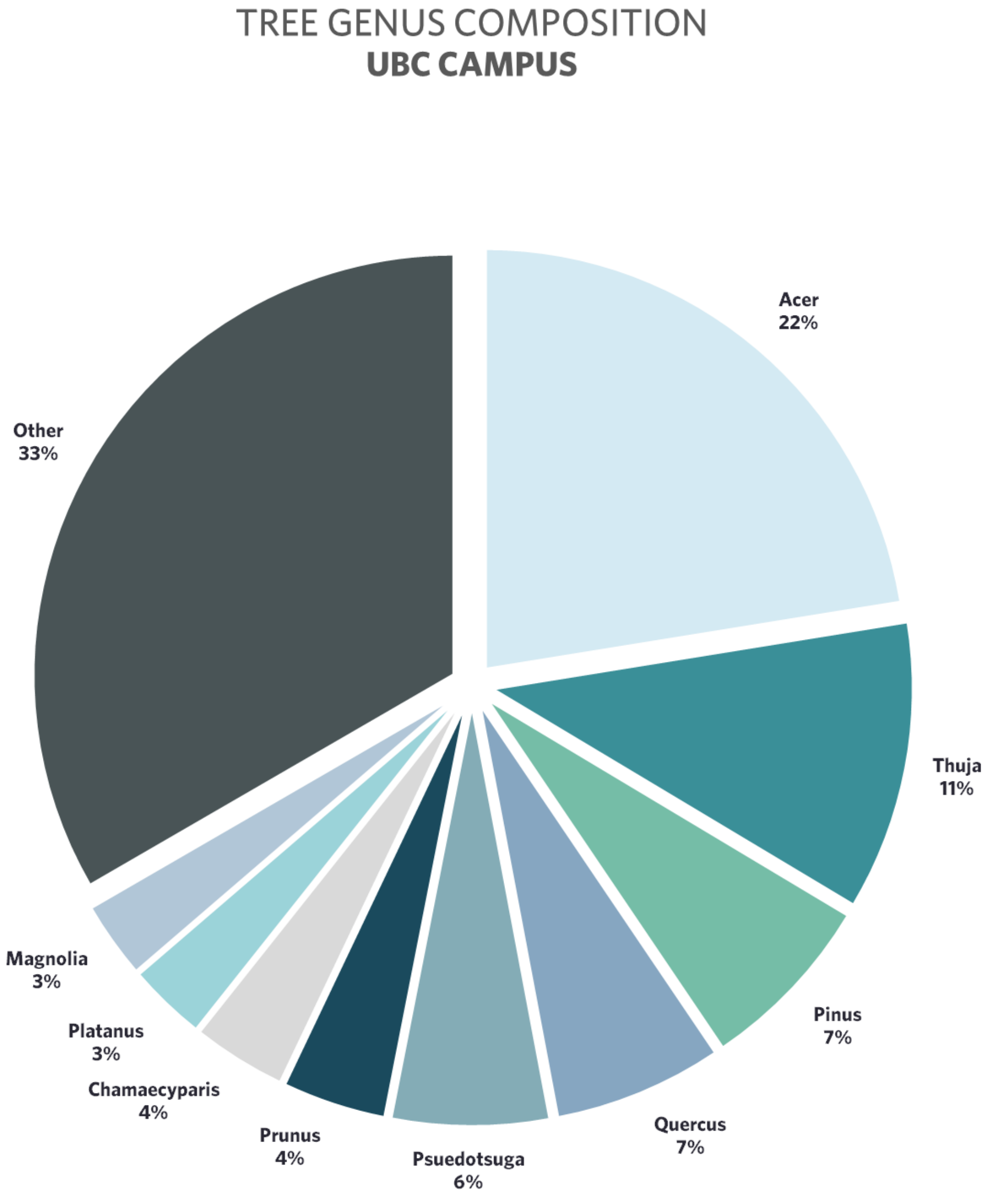


Figure 6. Tree genus composition of the tree population within the UBC legal campus boundary. Nine common genera represent 67% of all 6,121 trees included in the inventory with an identified genus. The remaining 33% of trees on campus are comprised of 76 genera, representing roughly 2,075 individual trees.

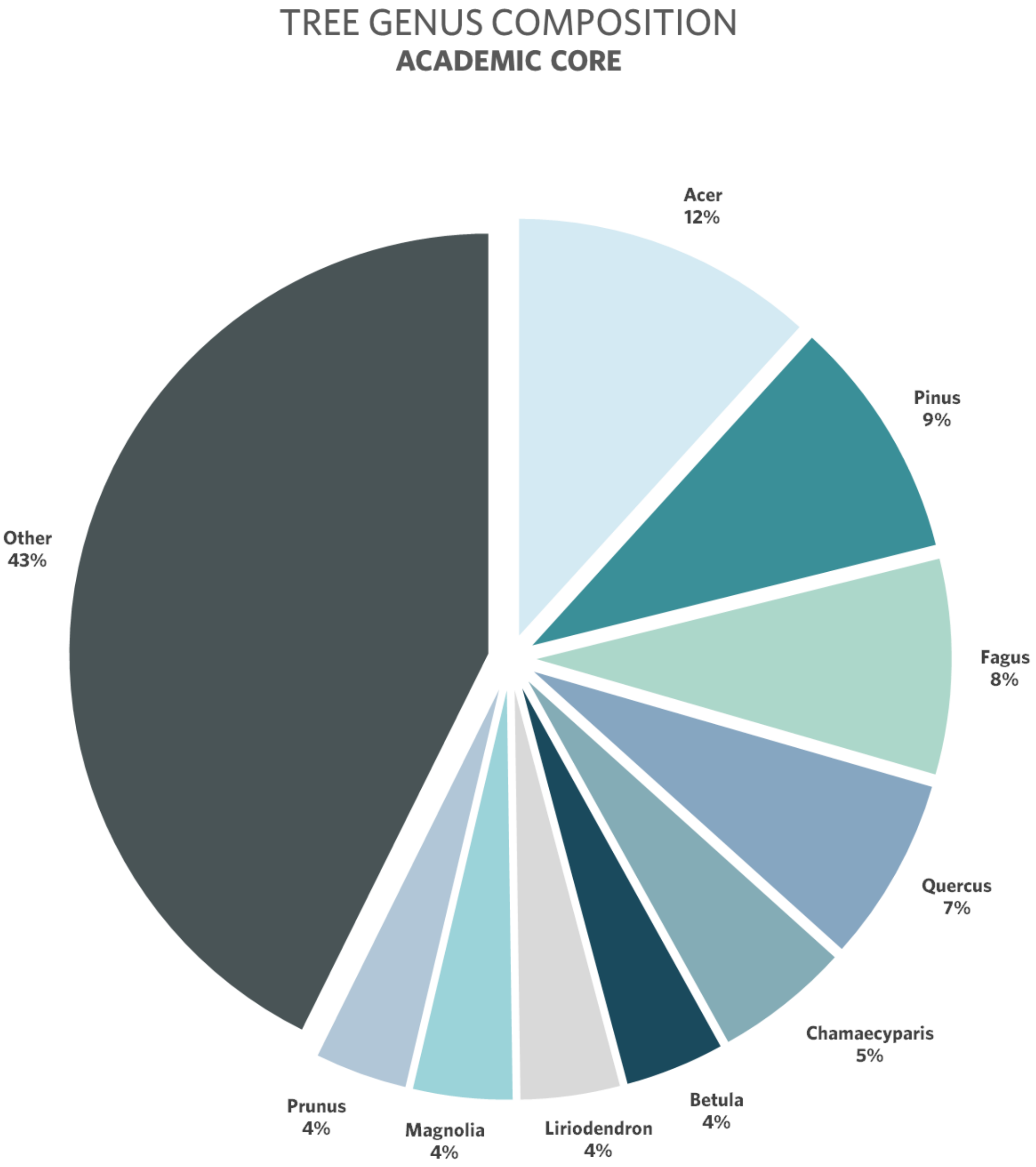


Figure 7. Tree genus composition of the tree population within the UBC academic core. Nine common genera represent 57% of all 1,099 trees included in the inventory with an identified genus. The remaining 43% of trees on campus are comprised of 63 genera, representing roughly 470 individual trees.

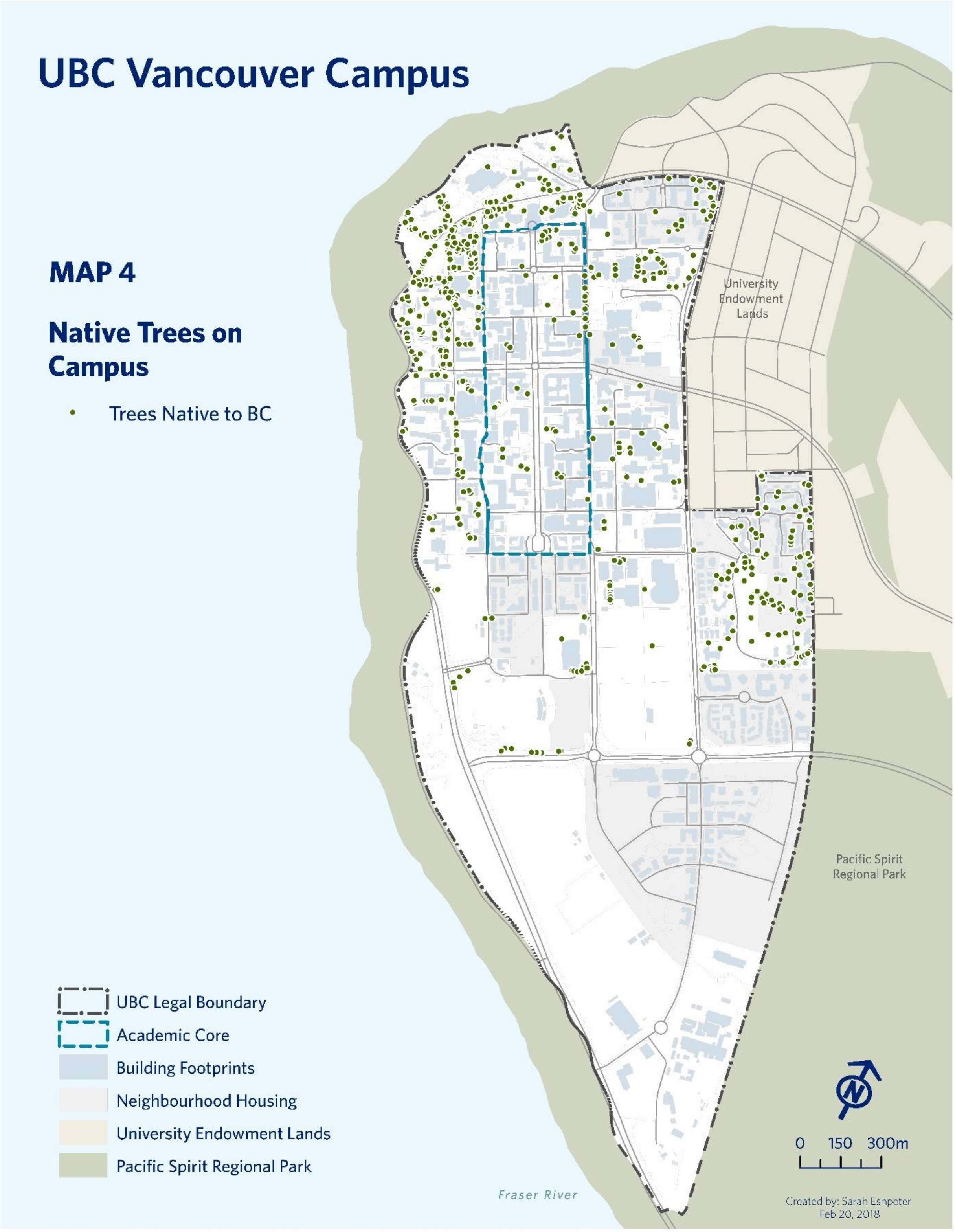


Figure 8. Tree genus composition of the tree population within the UBC academic core.

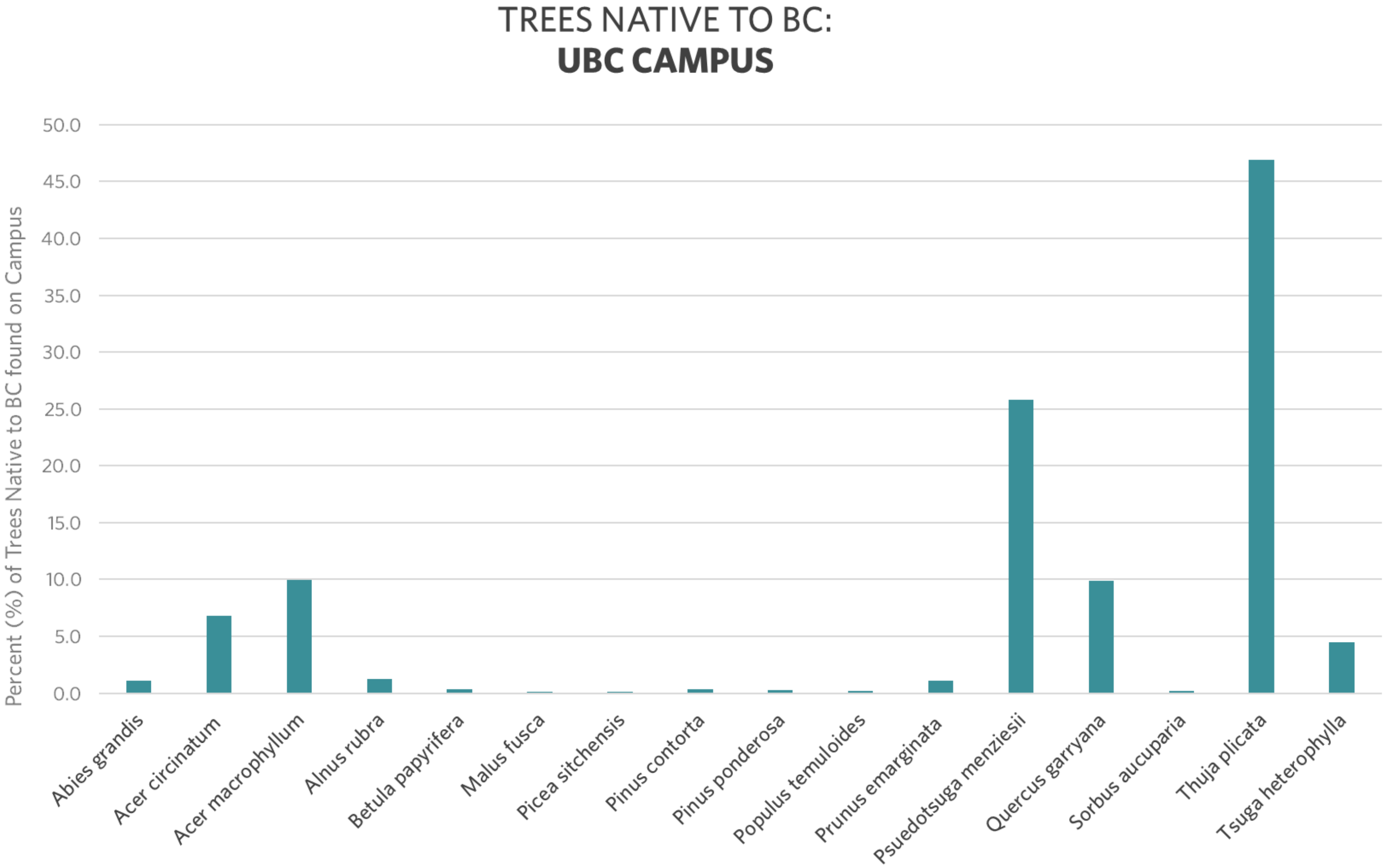
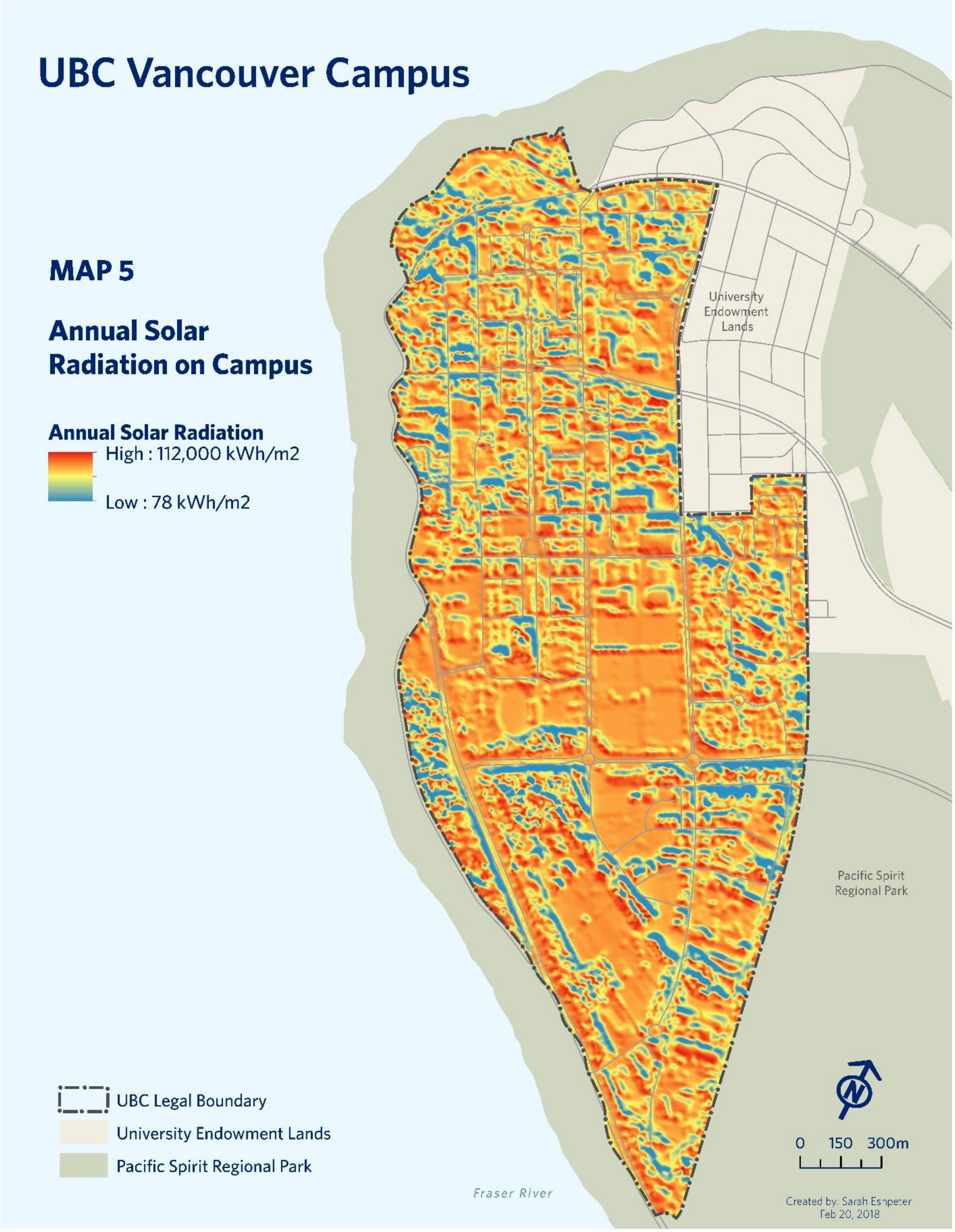


Figure 9. The composition of trees on campus native to BC.

3.4 Solar Radiation

Solar radiation on campus varies significantly across campus. Latitudinal and longitudinal effects are minimized across the campus landscape, as the study area is relatively small and does not significantly influence the angle of the sun. At the landscape-level, the topography is an important factor for the spatial radiation absorption. The amount of solar radiation depends on elevation, inclination, orientation, and shadows caused by topographical features. Inter-campus variation in total annual solar radiation is affected by namely the heights of surface features as these areas often receive the most direct radiation and provide shade to their peripheral surroundings. Considering UBC's unique features, tall trees and buildings appear to be the primary sources of shading on campus (Figure 10).

Figure 10 shows the results of the campus solar radiation analysis.



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Feb 20, 2018

Figure 10. Total annual solar radiance received on campus.

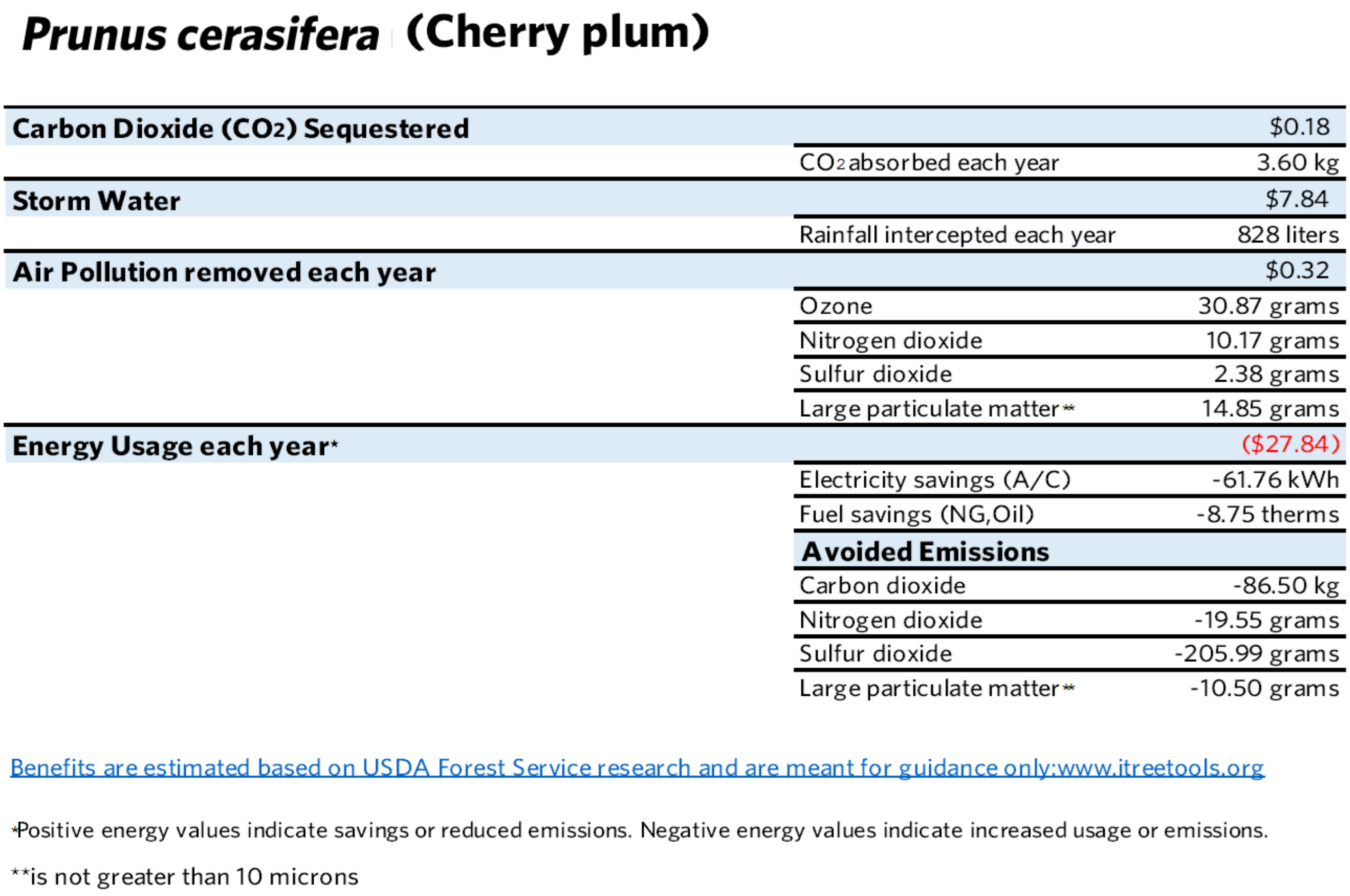
3.4 Ecosystem Services by Species

After performing an annual ecosystem assessment for several iconic species on campus, it is clear that regardless of variation in factors such as health, DBH, placement, and sun exposure, differences in ecosystem services provided by species are inherent (Table 3A-D).

Annual ecosystem services provided by a 15 cm DBH, fair health *Prunus cerasifera* (Cherry plum) were the least considerable as compared to the benefits of *Quercus rubra* (Red Oak), *Acer rubrum* (Red maple), and *Thuja plicata* (Western red cedar) with one exception. While the Cherry plum provides less stormwater interception and air filtration, it is in fact estimated to sequester more CO_2 than the native Western red cedar (Table 3A, 3D). Red maple and Western red cedar provided the most significant contributions to stormwater interception, interception 996 and 978 liters of stormwater per year, respectively (Table 3C, 3D). Additionally, Acer rubrum is estimated to store the greatest amount of CO_2 of all other species included in this analysis (Table 3C). *Thuja plicata* by far inflicted the lowest amount of energy costs associated with the planting near a building caused by increased heating needs (Table 3D), while *Prunus cerasifera* required the greatest increase in energy use for winter heating (Table 3A).

In combining the monetary totals for all ecosystem service aspects included in this analysis, direct comparisons can be made (given the same size, health status, sun exposure, and proximity to a building) in the annual services provided by each tree species. *Prunus cerasifera* ranked the lowest among all species, having a net ecosystem service value of - $19.50 given outstanding conditions (Table 3A). *Acer rubrum* ranked 3rd out of the four species, with an estimated annual value of - $3.54 (Table 3B), closely followed by *Quercus rubra* (Table 3C). *Thuja plicata* contributed the most substantial ecosystem service quantification, with an estimated annual value of $6.08 given current variables.

Table 3 (A). Annual ecosystem services provided by a single *Prunus cerasifera* tree with a DBH of 15cm, located in partial sun, in a fair health condition.



Prunus cerasifera (Cherry plum)

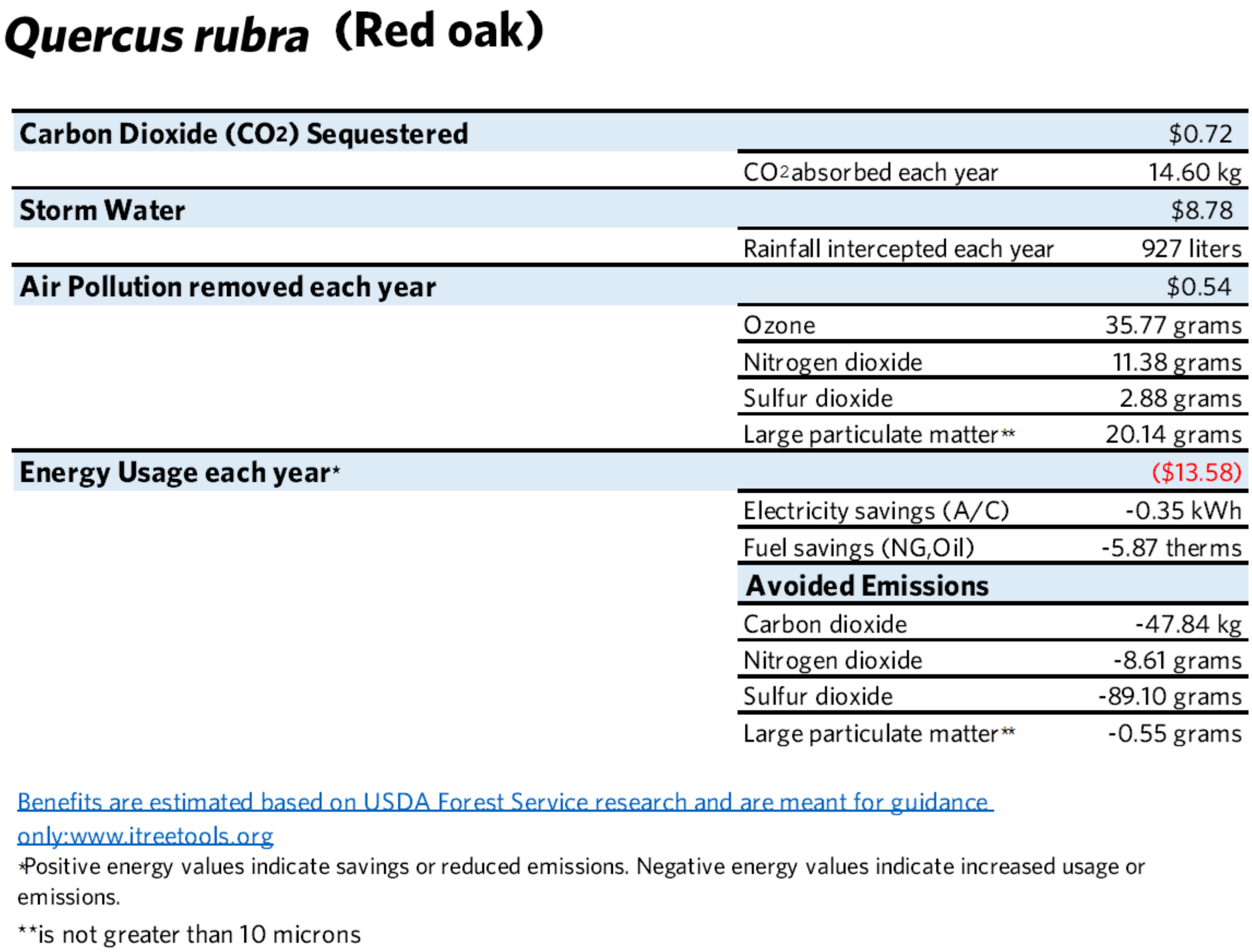
Carbon Dioxide (CO_2) Sequestered		$0.18
	CO_2 absorbed each year	3.60 kg
Storm Water		$7.84
	Rainfall intercepted each year	828 liters
Air Pollution removed each year		$0.32
	Ozone	30.87 grams
	Nitrogen dioxide	10.17 grams
	Sulfur dioxide	2.38 grams
	Large particulate matter**	14.85 grams
Energy Usage each year*		($27.84)
	Electricity savings (A/C)	-61.76 kWh
	Fuel savings (NG,Oil)	-8.75 therms
	Avoided Emissions	
	Carbon dioxide	-86.50 kg
	Nitrogen dioxide	-19.55 grams
	Sulfur dioxide	-205.99 grams
	Large particulate matter**	-10.50 grams

Benefits are estimated based on USDA Forest Service research and are meant for guidance only:www.itreetools.org

*Positive energy values indicate savings or reduced emissions. Negative energy values indicate increased usage or emissions.

**is not greater than 10 microns

Table 3(B). Annual ecosystem services provided by a single *Quercus rubra* tree with a DBH of 15cm, located in partial sun, in a fair health condition.



Quercus rubra (Red oak)

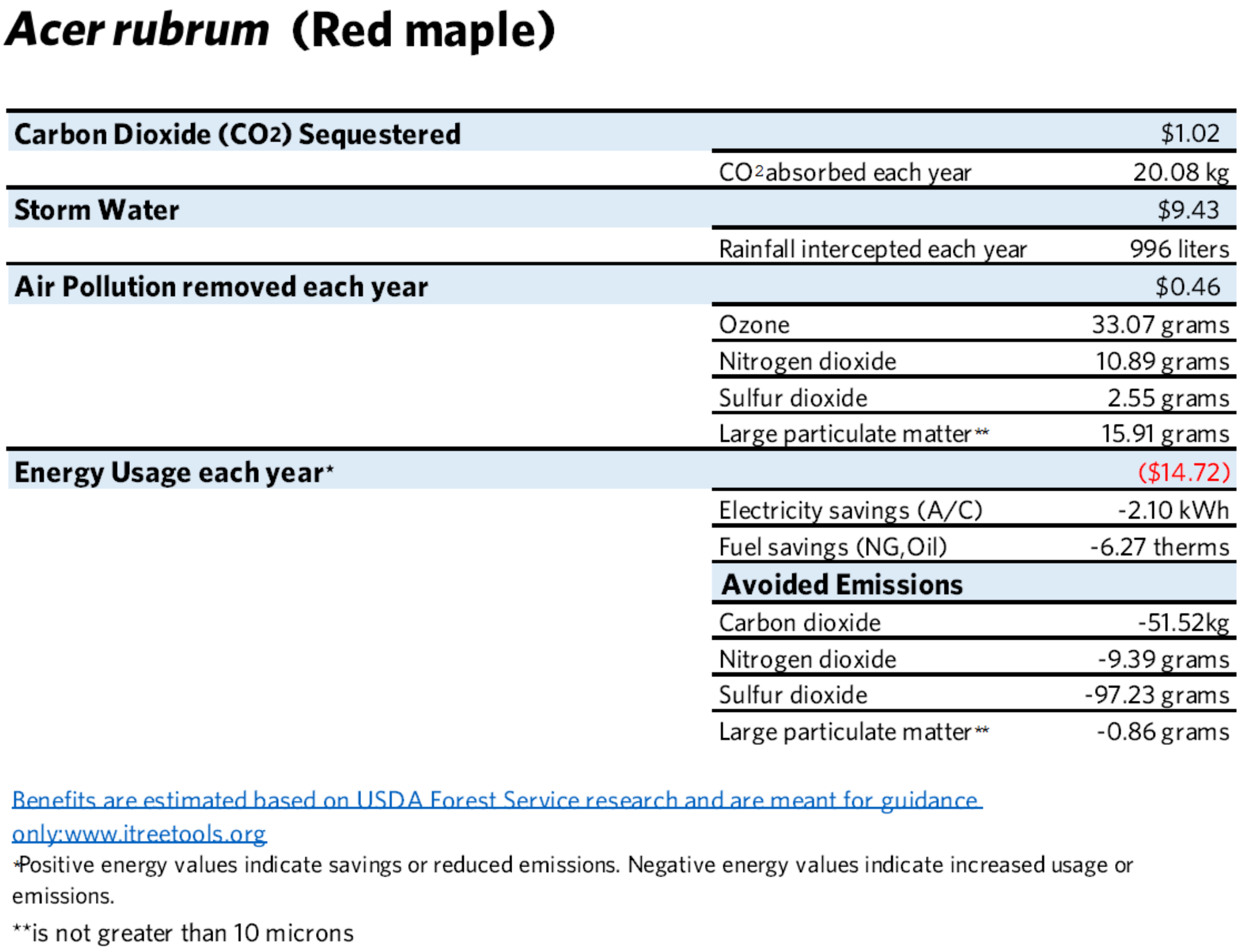
Carbon Dioxide (CO_2) Sequestered		$0.72
	CO_2 absorbed each year	14.60 kg
Storm Water		$8.78
	Rainfall intercepted each year	927 liters
Air Pollution removed each year		$0.54
	Ozone	35.77 grams
	Nitrogen dioxide	11.38 grams
	Sulfur dioxide	2.88 grams
	Large particulate matter**	20.14 grams
Energy Usage each year*		($13.58)
	Electricity savings (A/C)	-0.35 kWh
	Fuel savings (NG,Oil)	-5.87 therms
	Avoided Emissions	
	Carbon dioxide	-47.84 kg
	Nitrogen dioxide	-8.61 grams
	Sulfur dioxide	-89.10 grams
	Large particulate matter**	-0.55 grams

Benefits are estimated based on USDA Forest Service research and are meant for guidance only:www.itreetools.org

*Positive energy values indicate savings or reduced emissions. Negative energy values indicate increased usage or emissions.

**is not greater than 10 microns

Table 3 (C). Annual ecosystem services provided by a single *Acer rubrum* tree with a DBH of 15cm, located in partial sun, in a fair health condition.



***Acer rubrum* (Red maple)**

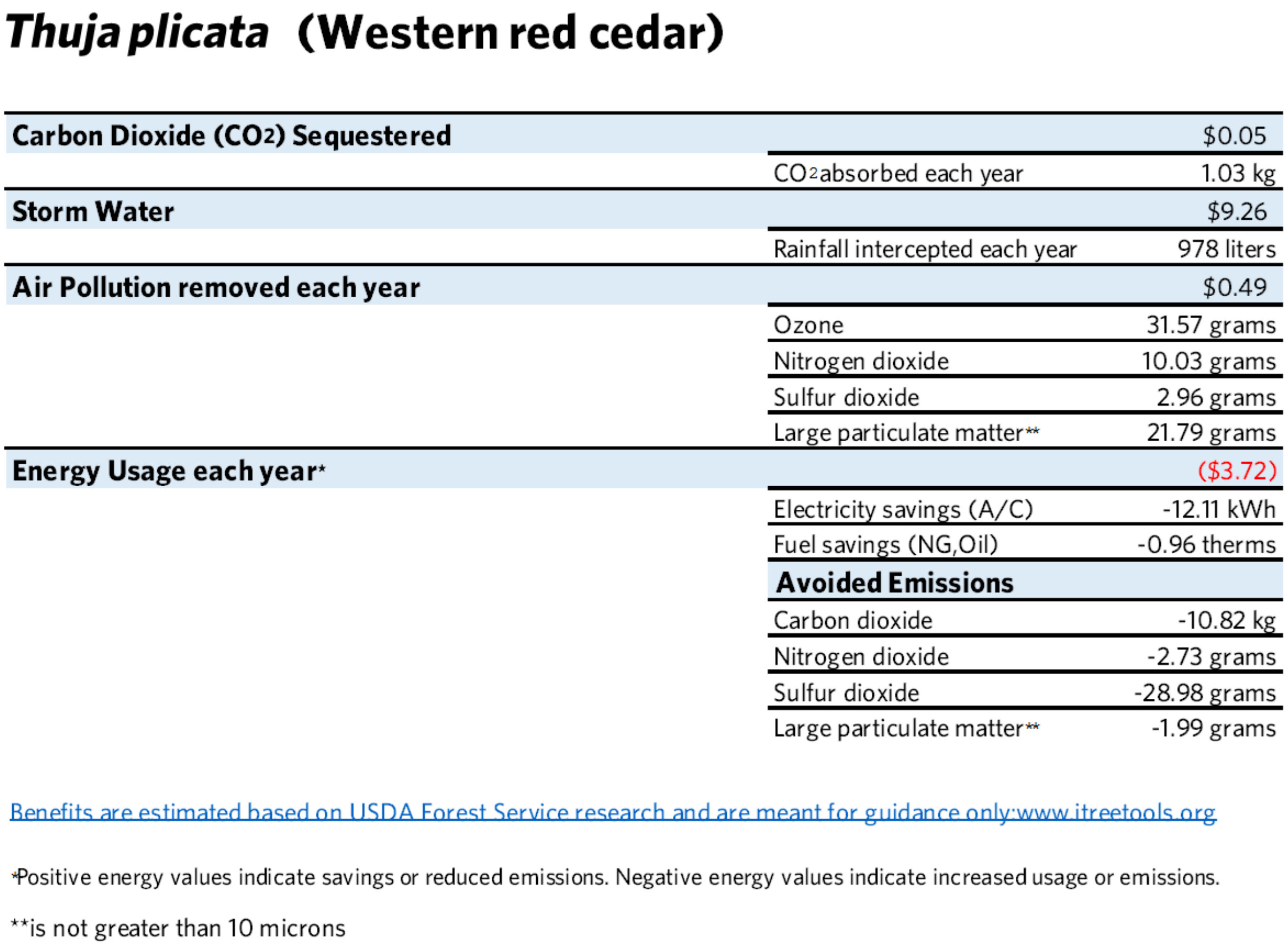
Carbon Dioxide (CO_2) Sequestered		$1.02
	CO_2 absorbed each year	20.08 kg
Storm Water		$9.43
	Rainfall intercepted each year	996 liters
Air Pollution removed each year		$0.46
	Ozone	33.07 grams
	Nitrogen dioxide	10.89 grams
	Sulfur dioxide	2.55 grams
	Large particulate matter**	15.91 grams
Energy Usage each year*		($14.72)
	Electricity savings (A/C)	-2.10 kWh
	Fuel savings (NG,Oil)	-6.27 therms
	Avoided Emissions	
	Carbon dioxide	-51.52kg
	Nitrogen dioxide	-9.39 grams
	Sulfur dioxide	-97.23 grams
	Large particulate matter**	-0.86 grams

Benefits are estimated based on USDA Forest Service research and are meant for guidance only:www.itreetools.org

*Positive energy values indicate savings or reduced emissions. Negative energy values indicate increased usage or emissions.

**is not greater than 10 microns

Table 3 (D). Annual ecosystem services provided by a single Thuja plicata tree with a DBH of 15cm, located in partial sun, in a fair health condition.



Thuja plicata (Western red cedar)

Carbon Dioxide (CO_2) Sequestered		$0.05
	CO_2 absorbed each year	1.03 kg
Storm Water		$9.26
	Rainfall intercepted each year	978 liters
Air Pollution removed each year		$0.49
	Ozone	31.57 grams
	Nitrogen dioxide	10.03 grams
	Sulfur dioxide	2.96 grams
	Large particulate matter**	21.79 grams
Energy Usage each year*		($3.72)
	Electricity savings (A/C)	-12.11 kWh
	Fuel savings (NG,Oil)	-0.96 therms
	Avoided Emissions	
	Carbon dioxide	-10.82 kg
	Nitrogen dioxide	-2.73 grams
	Sulfur dioxide	-28.98 grams
	Large particulate matter**	-1.99 grams

Benefits are estimated based on USDA Forest Service research and are meant for guidance only:www.itreetools.org

*Positive energy values indicate savings or reduced emissions. Negative energy values indicate increased usage or emissions.

**is not greater than 10 microns

3.5 Projected Effects of Climate Change

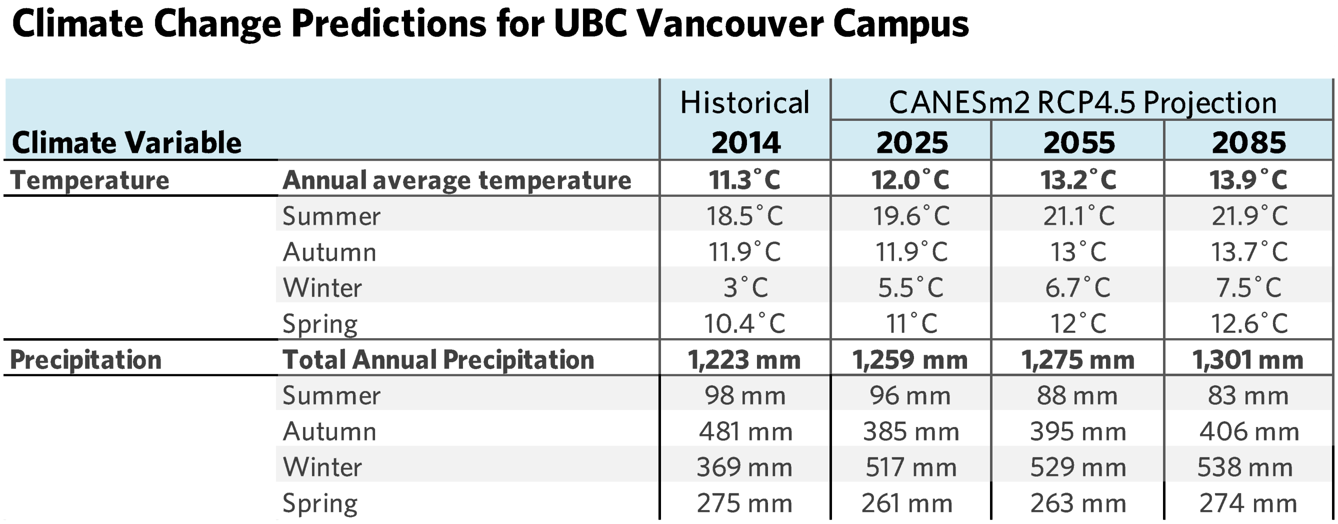
Climate change is expected to alter the local climate envelop, and resultantly influence native species suitability to the local environment and conditions.

Climate

Climate variables recorded in in 2014 represent a historical norm or baseline to which to compare future conditions. Currently, local annual average temperature measures 11.3˚C, with an average summer temperature of 18.5˚C and winter temperature of 3˚C (Table 3) (ClimateBC, 2017). Applying the aforementioned CanESm2 model with RCP 4.5, temperature and precipitation variables were estimated for 2025, 2055 and 2085 (Table 3). Local projections indicate that annual average temperature will continue to rise, and is estimated to increase by a total of 2.6˚C by 2085 (Table 3) (ClimateBC, 2017). On a seasonal basis, the average winter temperature is expected to exhibit the most drastic seasonal temperature increase compared to seasonal norms by 2085, which is projected to increase by 4.5˚C (ClimateBC, 2017). Autumn temperatures are forecasted to be the most stable in future periods despite climate change (ClimateBC, 2017).

Precipitation is another critical climate variable, particularly in the greater context of the Pacific Northwest. Although the climate is forecasted to incrementally warm, precipitation is also forecasted to increase. Collectively, total annual precipitation levels are forecasted to increase by just over 6% between now and 2085 (Table 3), assuming a moderate climate change scenario (RCP 4.5) (ClimateBC, 2017). Stark seasonal changes, however, exist in forecasted precipitation levels and provide greater insight into the future climate. Summers are expected to become drier, with only 83 mm of precipitation estimated in the summer season by 2085 (Table 3) (ClimateBC, 2017). Autumn similarly will experience less precipitation levels as climate change further influences local and regional weather patterns. On the other hand, precipitation in spring is not expected to experience any significant change against 2014 levels (Table 3) (ClimateBC, 2017). The greatest seasonal difference in precipitation levels will be seen during the winter months, wherein rainfall is expected to increase by approximately 40% (Table 3) (ClimateBC, 2017).

Table 4. Climate change climate variable predictions for the UBC Vancouver campus.



Climate Change Predictions for UBC Vancouver Campus

Climate Variable		Historical	CANESm2 RCP4.5 Projection		
		2014	**2025**	**2055**	**2085**
Temperature	**Annual average temperature**	**11.3°C**	**12.0°C**	**13.2°C**	**13.9°C**
	Summer	18.5°C	19.6°C	21.1°C	21.9°C
	Autumn	11.9°C	11.9°C	13°C	13.7°C
	Winter	3°C	5.5°C	6.7°C	7.5°C
	Spring	10.4°C	11°C	12°C	12.6°C
Precipitation	**Total Annual Precipitation**	**1,223 mm**	**1,259 mm**	**1,275 mm**	**1,301 mm**
	Summer	98 mm	96 mm	88 mm	83 mm
	Autumn	481 mm	385 mm	395 mm	406 mm
	Winter	369 mm	517 mm	529 mm	538 mm
	Spring	275 mm	261 mm	263 mm	274 mm

Tree Species Suitability

Considering future climate conditions, natural trees currently adapted to the landscape are at risk for becoming less suitable in future conditions. By 2085, nearly 60% of the 31 climate futures forecasted using the TSST model (based on 15x GCMs, and RCP 4.5 and 8.5) suggest that the BEC subzone where UBC campus is situated will shift altogether, transitioning to the CWHdmz (Dry Maritime Coastal Western Hemlock Subzone) (Figure 11). This biogeoclimatic subzone is characterized by warm, dry summers and moist, mild winters (Green & Klinka, 1994). As a result of the projected climate and subsequent BEC zone shift by 2085, tree species suitability is also forecasted to change to reflect these conditions.

Thuja plicata (Western red cedar), *Acer macrophyllum* (Big-leaved maple), *Tsuga heterophylla* (Western hemlock), and *Alnus rubra* (Red alder) are currently the most well-suited species to the regions biophysical conditions and are prominent components in natural forests across the CWHxm1 BEC zone (Table 4). As climate conditions and the associated BEC subzone shift, species suitability will similarly change to reflect new conditions. Consensus of the predicted climate futures suggest that *Thuja plicata* (Western red cedar) and *Tsuga hereophylla* (Western hemlock) will become more suited and well-adapted to the climate conditions in 2085, whereas species such as *Alnus rubra* (Red alder) will become less suitable (Table 4). *Psuedotsuga menziesii* (Douglas-fir) is projected remain as well-suited in the future, and a novel species, *Chrysolepis chrysophylla* (Giant Chinkapin) is expected to become well-suitable to climate conditions (Table 4).

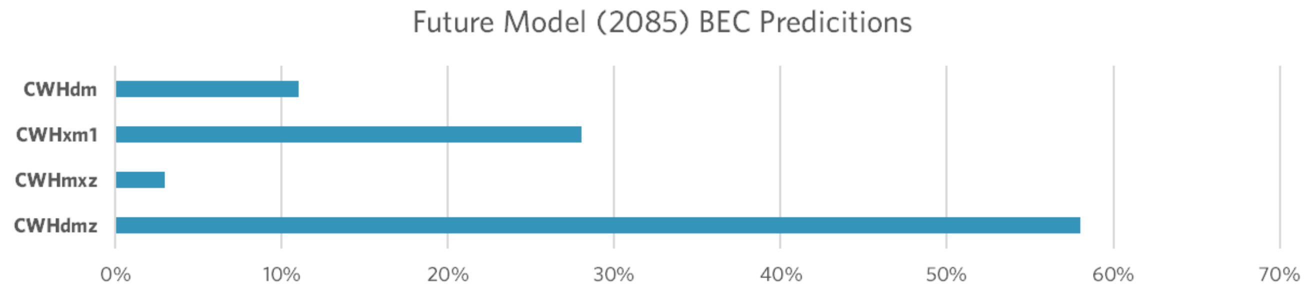


Figure 11. Future climate model BEC projections for UBC Vancouver campus in 2085 (TSST, 2018).

Table 5. Results of a future species prediction model that accounts for a range of potential climate futures in 2085 (TSST, 2018)

TREE SPECIES SUITABILITY

Site Series: CWHxm1/01

Species	Current Suit.	Future Suit.	Same	Improve	Decline	New	Not Suit.
Western Red Cedar	2 ↑	3	39%	58%			3%
Red Alder	2 -	0	39%				61%
Douglas-Fir	1	1	100%				
Western Hemlock	2 ↑	3	39%	58%			3%
Big-Leaved Maple	3 X	0	29%				71%
Western White Pine	3 X	0	39%				61%
Giant Chinkapin	0 ↑	3				58%	42%

***Interpretative Notes**: 15 Global Circulation Models and RCP 4.5 and 8.5 were used to estimate the suitability of tree species for the time period 2085, and treated as equally likely climate futures. The percentage of models that resulted in the same, improved, declined, or new suitability are shown in the table above. In some cases, models indicated a species as not suitability.

4. DISCUSSION

The amalgamation of analyses regarding UBC's urban forest tree canopy cover, surface cover, tree species composition, solar radiation, ecosystem services, and projected effects of climate change provide a valuable baseline to inform future decision-making and management of the campus' urban forest assets. As planting and development opportunities arise, it is critical that namely, planting locations and species selection are carefully considered to maximize the values and objectives of enhancing the viability, productivity, and functionality of the campus urban forest set out in the emerging UFMP.

4.1 Planting Location Priorities

Conducted analyses can be used to inform future planting location priorities to enhance associated benefits and help balance urban forestry values.

Species Composition

Species Diversity

When managing the peri-urban forest, species composition should be carefully considered to diversify assets, thereby managing for ecological, social, and economic risk. Many diversity metrics have been incorporated into core tenets and goals in urban forest management plans globally (Ordóñez & Duinker, 2013), as a robust urban forest should exhibit high species diversity that leaves the forest resilient to natural disturbances and stressors, such as pests, disease, and mechanical damage. A lack of species diversity exposes the population to a higher risk of ill health and morality through pests, pathogens, and extreme climate conditions. Species diversity enhances the resiliency, longevity, and stability of the urban forest as a whole and promotes biodiversity in the urban system to reverse biodiversity loss caused by urban development and restore ecosystem integrity (City of Melbourne, 2014; Alvery, 2006).

Ensuring species diversity in the urban forest minimizes risk factors, enhances local biodiversity, and indirectly affects a suite of other factors that promote urban forest vigour and productivity. Biodiversity enhancement in the urban forest has also been linked to species richness of non-tree species, such as birds, small mammals, and insects, which all contribute to ecosystem dynamics (Nitoslawski, 2016). Additionally, species composition diversity indirectly promotes forest structural diversity as branching and growth patterns vary by species. The maintenance of structural diversity is critical in avoiding even-aged conditions that leave stands susceptible to a variety of disturbance factors that require intermediate management activities, are effected by age- and/or species-specific pests or pathogens, or reach the end of their life cycle in a narrow period. In the future, we will likely see increasing importance being placed on promoting biodiversity in the urban forest. City planners and urban foresters will have the opportunity to incorporate more ecological perspective into management practices (Alvey, 2006).

Native Species

In recent years, native species restoration in the environment has been emphasized (Alvey, 2006). As urbanization often results in biotic homogenization, the importance of planting native species while reducing the presence of introduced or native species has been recognized (Alvey, 2006). Native trees are valuable assets to campus because of their natural acclimation, although urban forest environments generally offer less-natural conditions such as higher amounts of stress, different soil moisture regimes, and access to nutrients. Typically, native trees require less maintenance once established, are less susceptible to disease, and support native wildlife habitat. Less intensive management, for example, is being used to promote natural regeneration in urban parks in Christchurch, New Zealand (Stewart et al., 2004). This tactic was implemented as exotic species outnumber native species, particularly in urban cities in New Zealand (Stewart et al., 2004). By considering native species in urban forest composition and management, adaptability to local conditions, biodiversity, and resilience can be enhanced, likely reducing the need for intermediate management interventions of future health issues.

Spatial Diversity

Additionally, a lack of spatial diversity contributes to the vulnerability within the peri-urban forest. In order to realize the comprehensive suite of environmental, social, and economic benefits of the urban forest, up-to-date and in-depth information on the spatial distribution and heterogeneity of the urban forest ecosystem is necessary (Dogon-Yaro et al., 2016). The spatial heterogeneity of the forest influences ecosystem services and functioning, for example the distribution of ecosystem services across the landscape such air filtration (Escodedo & Nowak, 2009). Spatial diversity features of the urban forest including extent, species composition, distribution, and structure should be considered in management to further maximize effects of the forest.

Solar Radiation

Solar radiation is the primary source of energy for many biophysical processes on Earth. The analysis of radiation impact at the landscape level is fundamental to understanding a variety of natural processes and informing human activities. Solar radiation affects the variability of the microclimate including surface and ambient temperature, evapotranspiration, snowmelt, and light available for photosynthesis (ESRI, 2018).

Urban heat island (UHI), for example, refers to a phenomenon of higher atmospheric and surface temperatures occurring in urban areas due to urbanization (Voogt & Oke, 2003). Impervious or artificial surfaces associated with urbanization and expansion are non-evaporation materials, which cover a large expanse of urban areas, and absorb a high percent of solar radiation (Taha, 1997). This resultantly creates a heat influx at the expense of latent heat (Owen et al., 1998). The UHI effect is exacerbated by anthropogenic factors that generate additional heat, such as traffic and buildings. Higher surface level temperatures in urban areas ultimately raises air condition demands, raises pollution levels, and may modify micro-precipitation patterns (Yuan & Bauer, 2007).

Due to increasing urbanization and the expected impacts of climate change, cities such as Vancouver are becoming more susceptible to heat stress. One of the most efficient ways to regulate the local climate conditions and reduce heat stress in cities during climate extremes is to increase vegetation cover (Akbari et al., 2011; Oke, 1989; Robitu et al., 2006). Trees and other vegetation types provide cooling effects through evapotranspiration as heat gain is reduced by converting solar energy or radiance into latent as opposed to sensible turbulent heat flux (Bowler et al., 2010). One study, for example, estimates the average cooling effect of urban parks to 1.14 Kelvin (Bowler et al., 2010), with effects that can extend up to 2 kilometers (Shashua-Bara & Hoffman, 2000). The temperature of exposed urban and impervious surfaces can be more than 40 K cooler in shadow than when exposed to direct solar radiation (Robitu et al., 2006).

Trees have a large impact on the urban microclimate, resultantly influencing surface temperatures and energy required to heat and cool buildings. There is a pressing need to adopt mitigation strategies against further increases in temperature in urban areas (Bowler et al., 2010). UBC Vancouver campus has several hotspots that currently receive large amounts of annual solar radiation, and should be planting priority locations.

Thermal Comfort

A study conducted by the IPCC conducted in 2011 suggests that the average temperature rise caused by urbanization will be greater than the temperature rise due to climate change over the next 100 years (Jamei & Rajagopalan, 2015). While thermal pedestrian comfort is not currently as issue in Vancouver's mild climate, the effects of climate change specifically in the summer season may make this an increasingly pressing issue. As the UBC Vancouver campus continues its development, effects of UHI and pedestrian thermal comfort should be considered in future planting operations and opportunities. Human thermal comfort is the condition achieved when heat flow from and to the body is balanced (Höppe, 2002). While a variety of factors such as air temperature, relative humidity, wind speed and metabolism contribute to thermal comfort, mean radiant temperature is found to be arguably the most critical component in establishing pedestrian thermal comfort (Jamei & Rajagopalan, 2015). Mean radiant temperature indicates the level of radiant temperature received by the human body, which is particularly critical in outdoor environments (Jamei & Rajagopalan, 2015). The relationship between urban trees and green infrastructure and pedestrian thermal comfort has been the subject of many studies (Golany, 1996; Sanaieian et al., 2014).

A study conducted by Shashua-Bar & Pearlmutter (2011) observed the effects of trees on pedestrian thermal comfort, and found that while any landscape treatment made a clear contribution to improved comfort, shade trees alone provide the highest cooling efficiency to the surrounding landscape.

Energy Savings

Increased energy costs and the growing awareness that urban trees have the potential to modify our environment have created interest in potential energy savings with trees. Trees may increase, decrease, or have little effect on energy use depending on species, planting location, climate, and building design (Heisler, 1986). Urban forest features affect building heat gain and loss by air exchange, solar radiation transmission through windows, and heat conduction (Heisler, 1986). Air movement in and around buildings are caused in part by temperature differentials in and outside buildings, as well as wind pressure (cite). Trees are able to aid in deterring localized wind patterns around buildings, and can alter the immediate thermal environment around a building by ambient heat and by intercepting and altering the amount of solar radiation transmitted through windows (Heisler, 1986). On a percentage basis, tree shading provides large energy savings for buildings and is effective in reducing temperature of interior air and walls up to 7°C (Heisler, 1986).

Surface Cover

Impervious Surfaces

Land cover types, their proportions, and dynamics are important characteristics of a landscape that provide insight into terrestrial ecosystem processes, climate change impacts and adaptive capacity and human-environmental interactions (Shao & Lunetta, 2011). Impervious surface area is a key indicator of environmental quality (Yuan & Bauer, 2006). From a management perspective, impervious surfaces across landscapes alter local and regional hydrological cycles, changes in water quality, changes to local energy balances, habitat degradation, loss, and fragmentation, and changes to landscape aesthetics (McKinney, 2008; Yuan & Bauer, 2006; Barnes et al., 2001; Arnold & Gibbons, 1996). Spatially identifying grey or impervious and artificial surfaces across campus, can inform campus planning and help balance conservation and development values at UBC.

Tree Cover

Further, grey-green mapping and tree canopy proportions can be used for comparison and analysis in the future to monitor and evaluate UBC's urban forest assets and to set specific, measurable objectives and targets for campus urban forest management. Many municipalities and analogous institutions have incorporated tree canopy targets into their urban forest management plans and strategies (City of Melbourne, 2014; City of Toronto, 2014; University of California, 2012; University of Washington, 2014). Canopy cover is a useful proxy for the amount, character, and health of the urban forest, and is a repeatable benchmark that can be measured regularly and guide future planting programs (City of Melbourne, 2014).

Soft Landscape

Soft landscape features such as grass or shrubs represent opportunities for future planting programs. With the exception of vertical or rooftop forests or gardens, developed area such as buildings are effectively removed from the urban forest landbase. Soft landscape features, however, such as open green space and grass areas have a greater potential for future planting, as there is already soil volume required for tree establishment. The proportion and distribution of soft landscape features on campus should be carefully considered for potential feasible future planting locations.

4.2 Species Selection

In addition to planting location prioritization, tree species selection can directly influence the stability, diversity, and functionality of the urban forest (McPherson, 2003) and as such should be carefully considered in future urban forest management decisions. Results from the species composition, ecosystems service, and climate change analyses can help inform future species selection such that biodiversity, ecosystem service, and mitigation/adaptive values are maximized.

Maximizing Benefits

Although there can be a subjective tradeoff between traditional aesthetics and ecological value, special attention must be given to species selection such that benefits are maximized despite continuing development pressures on campus. Small ornamental trees such as flowering plum and cherry trees are prominent on campus and provide aesthetic qualities, however broad calculations suggest that large mature trees provide 75% more environmental benefits than smaller, ornamental trees (City of Melbourne, 2014). According to the ecosystem service analysis conducted in this study, the *Prunus cerasifera* provided the least extensive range of ecosystem service benefits in comparison to *Thuja plicata*- the most ecological beneficial species in the analysis. There are notable differences, however, in the type of ecosystem service benefits various species provide, which can be utilized as a management tool to improve local air quality or stormwater management in key areas.

Good species selection choices should result in relatively productive and sustainable urban forests, with long-term benefits exceeding the costs (Clark et al., 1997). Ideally, the largest tree suitable for a site (while considering species and spatial diversity) should be selected in planting operations, as the largest trees often provide the greatest magnitude of urban forest benefits (Diamond Head Consulting Ltd., 2016). Ecosystem services and broader urban forest benefits tend to be directly driven by canopy extent and forest structure, including features such as number of trees, size, and age (Diamond Head

Consulting Ltd., 2016). Carbon reduction benefits, for example, are generally highest for large, long-lived and fast-growing species (McPherson, 2014). Large species also provide greater cooling and heating affects to the urban environment, in addition to stormwater management and air filtration (Bowler et al., 2010).

Although it is generally known that larger tree species provide greater environmental benefits, often smaller, ornamental trees are selected for urban planting for their aesthetics, such as cherry trees occupy a significant portion of the street trees in Vancouver for the purpose of tourism. Ornamental species may be perceived as more attractive species, however large natural tree species can similarly enhance aesthetics across the landscape. Most urban dwellers appreciate the idea of a natural urban forest (Tyrväinen et al., 2005), and the importance of ecological management has increased in the past decade (Tyrväinen et al., 2003). Environmental education and publically accessible information can increase the awareness of residents and help them appreciate native and ecologically valuable flora and fauna (Tyrväinen et al. 2005).

Selection of Resilient Species

Climate change will alter environmental conditions and subsequently alter the composition of well-suited species which are likely to thrive here at UBC. The adaptive capacity of the urban forest refers to the ability of the forest to absorb and recover from some disturbance or change (Diamond Head Consulting Ltd., 2016). Increasing temperatures and more frequent forecasted drought events will intensify the stress levels of urban trees, which are already exposed to more complex and frequent environmental stressors as compares to forest trees (Gillner et al., 2014). More drought-tolerant species should become integrated into the campus urban forest in order to keep trees viable under future climatic conditions and pressures. The Vancouver Board of Parks and Recreation recommends six drought-resistant species (24hrs Vancouver, 2015) for planting to thrive in future conditions, including:

1. Beech
2. Hornbeam
3. Oak
4. Dogwood
5. Redbud
6. Ironwood

5. ASSUMPTIONS & LIMITATIONS

Several assumptions and limitations were made for the purpose of this study.

5.1 UBC Campus Tree Inventory

The current campus tree inventory is 8 years out-of-date and fails to consistently record tree-specific attributes such as height and health. Updating the current tree inventory has been recently prioritized in campus planning, as this information is critical to monitor and quantify the benefits of the current campus urban forest. This information is not necessarily representative of UBC Vancouver campus' urban forest assets, given the lack of a comprehensive, up-to-date tree inventory and the longevity of tree species, this inventory was used to inform this study. The inventory does represent, however, historic planting efforts with regards to species composition and location that were previously selected on campus. Although this information is not particularly reflective of the current campus urban forest, this inventory still facilitates future insights into the urban forest and broader campus ecosystem as the new campus tree inventory is underway.

5.2 i-Tree: Ecosystem Service Quantification

Using the i-Tree MyTree v1.2 requires only a couple of parameters (species, diameter at breast height, sun exposure, health, and proximity/direction to buildings) to quantify ecosystem services associated with the tree. The reduction in data fields is meant to accommodate users with restricted data (i-Tree, 2016). The i-Tree Design model uses various approached to extrapolate missing variables such as crown width, health, light exposure, and height to live top (i-Tree, 2016). Where default values are not used, regression equations populate missing values based on tree genus. One of the caveats of this program is that the model will tend to predict average values for missing tree information when calculating ecosystem services, resultantly overestimating the benefits short or dying trees and underestimating the benefits provided by tall, healthy trees (i-Tree, 2016). Further, this application was developed for the United States, and as such may not provide as accurate information in the Canadian context.

As the current UBC tree inventory fails to consistently record tree-specific attributes such as height and health, this i-Tree MyTree application is well-suited to forecast annual ecosystem services from common trees on campus. One draw back in design, however, is that i-Tree quantifies only regulatory ecosystem services, and fails to account for cultural or provisioning services. These estimations should not be taken literally, however are useful parameters to help inform future species selection and management strategies.

5.3 Tree Species Suitability Tool

Additionally, another limitation of this study includes the use of the Tree Species Suitability Tool (TSST). The TSST is only released as a beta model, therefore its projection trends should be cautiously interpreted, as the tool is still being tested and the general effects of climate change and species adaption is relatively unknown. Great uncertainty exists in climate modelling and around the potential impacts of climate change. As climate change futures between RCP 4.5 and 8.5 are treated as equally likely climate future in the TSST, users should interpret the trend projections to forecast more moderate to severe climate change scenarios.

6. CONCLUSIONS

Trees are a keystone structure of urban ecosystems. Maintaining and enhancing the health and resilience of the campus urban forest is essential for the continual supply of its broad range of environmental, social, and economic benefits it provides, in addition to climate change mitigation and adaptation. UBC and its broader context within in Vancouver have a strong local identity associated with its urban forest and natural assets. UBC Vancouver campus has developed a strong green brand associated with its juxtaposition and integration to its natural environment, which draws student interest from students, faculty, and staff around the world. Maintaining and enhancing both the current viability and future resiliency of our campus' natural assets is crucial in maintaining the local identity and brand that is so closely associated with UBC, and ensuring a livable and thriving campus environment in the future.

7. RECOMMENDATIONS

Research regarding the campus urban forest should be ongoing to help provide a more established baseline and monitoring/evaluation tools to compare future conditions. Working towards establishing a complete inventory is critical to the development of urban forest strategies, goals, and objectives to inform the framework for the emerging UFMP. Ensuring key attributes such as diameter at breast height (DBH), health, species identification, and live crown ratio will help inform the status of the current urban forest and allow a more representative and thorough analysis of tree species composition, spatial diversity, and tree canopy cover on campus. This information could help facilitate a more in-depth technical analysis of ecosystem service valuation by species. Research into other ecosystem services and benefits of our urban forest would be valuable, for example the relationship between the urban forest and wellbeing or health, as well as the perception of 'naturalness' on campus.

Enhancing and maintaining the University of British Columbia Vancouver Campus' urban forest will require a coordinated effort from Campus & Community Planning as well as the broader campus community. We expect to see growth in UBC's development and campus community over the coming years. An associated growth in the campus urban forest and associated suite of ecosystem services will respond to these pressures, reduce environmental costs of grey infrastructure, and improve the quality of the urban environment. The composition of the UBC forest should include a sustainable mix of tree species representing a variety of age classes, environmentally critical native areas, and wildlife corridors, flourishing soft landscape features, and open spaces that create a healthy and contiguous ecosystem, while prioritizing planting locations to benefit the campus community.

7.1 Species Composition

Although urban forest diversity can be defined in a number of ways, the most common metrics used in urban forestry relate to species richness and evenness (Nitoslawski, 2016). As previously discussed, an international 10-20-30 guidelines ensures species diversity in the forest (Santamour, 2004). Several cities, however, have adapted this rule to further promote species diversity and resiliency across their urban forest assets. The City of Toronto, for example, uses a 5-10-20 rule to help guide species diversity in the city's urban forest (Vander Vecht & Lunett, 2015). Under this rule, no more than 5% of the population should be a single species, no more than 10% a single genus, and no more than 20% a single family (Vander Vecht & Lunett, 2015). The City of Melbourne has adopted the same policy in their Urban Forest Strategy (2014), which is one of the key components of their management plan and targets by 2040. As per the current tree inventory, *Acer* and *Thuja* exceed the 10% threshold and inverse SDI for a single genus, and should be emphasized in future planting efforts. Additionally, in a study observing the climatic response and impact of drought on frequently planted tree species (Gillner et al., 2014), *Acer* species displayed the highest sensitivity.

Approximately 22% of identified trees from the 2010 campus tree inventory are of maple (*Acer*) genus, including namely red maple (*Acer rubrum*), Norway maple (*Acer platanoides*), and Japanese maple (*Acer japonicum*). To better maximize ecosystem services and resiliency to the effects of climate change, UBC Planting Operations should de-emphasize the continued planting of maple, and seek to enhance the diversity and resiliency of the urban forest by planting other genera. Genera and species that provide optimal ecosystem services such as stormwater interception and air filtration should be prioritized in planting operations in planting operations while seeking to increase campus biodiversity and resilience. The campus should further assess its urban forest assets against the 10-20-30 threshold to identify vulnerabilities in species, genera, and families that can be promoted in future planting.

The spatial distribution of species, accounting for age classes, height classes, and composition and structure should more carefully considered in planting operations. UBC should consider planting principles that improve spatial diversity at the local scale, such: (i) as planting multiple species of similar form and appearance on a single street; (ii) planting a high diversity of species in open spaces and parks where growing conditions are easier; (iii) planting trees with diverse life expectancies over a long period of time to promote age diversity; (iv) and planting species in layers (considering shade tolerant understories) to promote vertical structure and biodiversity (Diamond Head Consulting Ltd., 2016). Additionally, greater emphasis should be placed on planting native species and the connectivity of urban forest assets and corridors.

7.2 Planting Locations

Thermal comfort

Given total annual solar radiation on campus and considering pedestrian thermal comfort in high trafficked areas such as walkways and buildings, the following areas have been identified as a priority for future planting:

1. Thunderbird Blvd. from Wesbrook Mall to East Mall;
2. Agronomy Rd. from West Mall to Main Mall;
3. University Blvd. West Mall to Main Mall;
4. The east side of Memorial Rd. from Somerset Ln. to Main Mall;
5. Stadium Rd from Main Mall to East Mall;
6. Southwest side of West 16th Av from SW Marine Drive to Ross Dr.;
7. The north side of the University Bld. bus loop.

Energy Savings

Considering the cooling benefits of tree shade to buildings for energy savings and the total annual radiation received by buildings across campus, the following southeastsouthwest building façades can be prioritized in future planting efforts to reduce energy costs:

1. Forest Sciences Centre;
2. Landscape Annex;
3. Henry Angus Building;
4. Chemistry D Block;
5. Alumni Centre;
6. Frederic Lasserre Building;
7. Chan Centre for the Preforming Arts.

Alternatively, considering the warming effects trees provide during winter months, the following buildings can be planting location priorities to reduce energy costs by planting:

1. Orchard Commons;
2. Ponderosa Commons (West, Oak, and Cedar Houses);
3. Bioenergy Research and Demonstration Facility;
4. Chemistry C Block.

7.3 Emerging UFMP

The development of a comprehensive Urban Forest Management Plan (UFMP) will help balance future campus development with conservation values. Ultimately, the UFMP should ensure that urban forest management practices continue to improve the quality and quantity of tree canopy such that potential benefits are maximized to the entire campus community. It is critical the UFMP establishes clear governance and responsibility, with enough buy-in or status from campus entities. The UBC UFMP should be designed and enforced to compliment other pre-existing and emerging campus policies and guidelines such as the Green Building Plan, Public Realm Plan, UBC's Land Use Plan, Sustainable Planting Guidelines, and the campus Biodiversity Strategy. This amalgamation of policies and guidelines should collectively support UBC's Strategic Priorities and guide UBC in enhancing campus sustainability and well-being, while maintaining and enhancing its environmental assets.

This emerging plan should envision a healthy, resilient, and diverse urban forest that contributed to the health and well-being of the campus ecosystem, and be dynamic and evolve accordingly to the challenges and priorities of the campus. The management plan should outline specific, achievable targets and guide decision-making to achieve this vision. Objectives such as increasing forest canopy cover, enhancing species biodiversity, improving vegetation health, and improving campus resilience to climate change should be integral components of the emerging plan. Such guiding targets will help UBC mitigate and adapt to climate change, reduce the UHI effect, create thriving ecosystems that embody cultural integrity, and position UBC as a global leader in urban forestry. UBC Planting Operations should work closely with designers and maintenance staff to increase the biodiversity and resiliency of campus when new planting opportunities arise.

An Urban Forest Management Plan (UFMP) for the UBC Vancouver campus would also provide residents and the broader campus community with knowledge and tools to assess the health and status of the campus urban forest, and would provide information about how residents can act to mitigate and adapt to climate change within their communities. Such tools could provide UBC a mechanism to engage and empower its residents, and use citizen science to help monitor the campus urban forest and update the old inventory and promote urban forest management in residential and special neighbourhood zoning areas across campus. Nonetheless, further research is critical to conducting a baseline of the current forest assets at UBC Vancouver campus, which will be critical to the developmental of an urban forest management plan, and meeting our future goals and objectives.

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