UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

UBC Urban Forest Ecosystem Provisioning for Climate Change Mitigation

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University of British Columbia

GEOB 448A

Themes: Biodiversity, Climate, Wellbing

Date: Aug 26, 2020

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GEOB 448A: Directed Studies in Geographical Sciences
Supervisor: Dr. Nina Hewitt

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REPORT BY ANGELA LIU

UBC SEEDS SUSTAINABILITY

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Introduction

The urban forest interwoven within our cityscape has incredible potential to help mitigate and alleviate environmental pressures caused by climate change and rising temperatures. The need for these urban trees, or "green infrastructures", is also continuously increasing, with rising population densities every year in metropolitan areas that the United Nations is estimating 68% of the world population will live in urban areas by 2050 (United Nations, 2018). Urban trees are essential to the wellbeing and resiliency, both ecologically and socially, of an urban environment as they provide such a diverse suite of ecosystem services. Most notably, urban trees can sequester and store carbon dioxide, reduce air pollution levels, filter and retain stormwater runoff, provide recreational opportunities, and increase shade to help cool neighborhoods and buildings. The quantification of these services in monetary terms is also very important, as it can help decision-makers and city planners make informed choices about urban planning and increase public awareness of urban nature (Hong et al, 2018). For instance, the urban cooling effect of trees can be equivalent to US$18.5 million a year of reduced costs in Sacramento, USA, and the reduction of $PM_{2.5}$ can value up to US$60.1 million in New York, USA, considering their beneficial health implications that can reduce mortality (Nowak 2018).

The role that these ecosystem services play in today's climate change solutions is particularly important. Cities are exploring different climate mitigation and adaptation schemes, with Metro Vancouver targeting a 50% reduction of carbon pollution by 2030, and complete carbon neutrality for the region by 2050 (City of Vancouver, n.d.). Metro Vancouver was able to declare corporate carbon neutrality for its regional operations in 2019 (in sectors such as city waste and water management), and while this does not extend to its citizens and commercial sector, it places the region in a good position to advance its other climate targets. This was largely due to the revitalization of Burns Bog in Delta (Smart, 2020), which exemplifies the importance of natural carbon sequestration. However, to achieve complete neutrality by 2050, the city would need to enable other carbon reduction pathways, and great potential lies in the maintenance and growth of urban and sub-urban forests in the city (Mulligan et al, 2020). Operationalizing effective management plans to optimize urban forest ecosystem services can help Vancouver prepare for future climate scenarios and avoid exceeding climate targets, which are crucial goals for urban centres all over the world.

At the University of British Columbia (UBC), similar climate initiatives are underway, with the Climate Action Plan 2020 (CAP 2020) that delineates the university's action items and long-term vision in moving towards carbon neutrality by 2050 (University of British Columbia, 2019b). One of the primary and largest areas of concern is energy usage by existing buildings, as around 88% of UBC's greenhouse gas emissions are created for building energy. Other areas of concern and energy reduction potential are in new buildings, energy supply, behavior change, fleet, and various complementary opportunities (University of British Columbia, 2019b).

Objective

This study aims to understand the benefits provided by UBC Vancouver's (UBC-V) urban trees in terms of a select suite of ecosystem services specific to mitigating climate change effects. The importance of urban trees in climate mitigation strategies is not well understood or quantified across UBC-V, yet the valuation of these services could increase campus planning incentives to preserve stands of trees and increase forested green spaces. This study will also directly contribute to the action goal "Research UBC's tree inventory and calculate the amount of carbon sequestration that they account for per year" in UBC's CAP 2020 for Complementary Opportunities (University of British Columbia, 2019b).

To that end, this study will utilize the i-Tree Eco version 6 model produced by the United States Department of Agriculture Forest Service in cooperation with DaveyTree Expert Company, The Arbor Day Foundation, and several other developers. This model uses field-collected data of urban forest composition and characteristics to provide ecosystem services analyses and benefit assessment. This software can analyze data on several different ecosystem services, but carbon storage and sequestration, pollution removal, and energy savings for buildings will be primarily discussed in terms of their abilities to mitigate climate change effects. Previous work using this software was conducted by UFOR 101, which was implemented for the first time in 2019 where students in the cohort established subplots along Main Mall to investigate ecosystem services provided by UBC's campus trees (UFOR 101, 2019). However, the present investigation will be a much more holistic encapsulation of campus grounds and a much more targeted focus on the climate mitigating potential of our urban forest.

Methodology

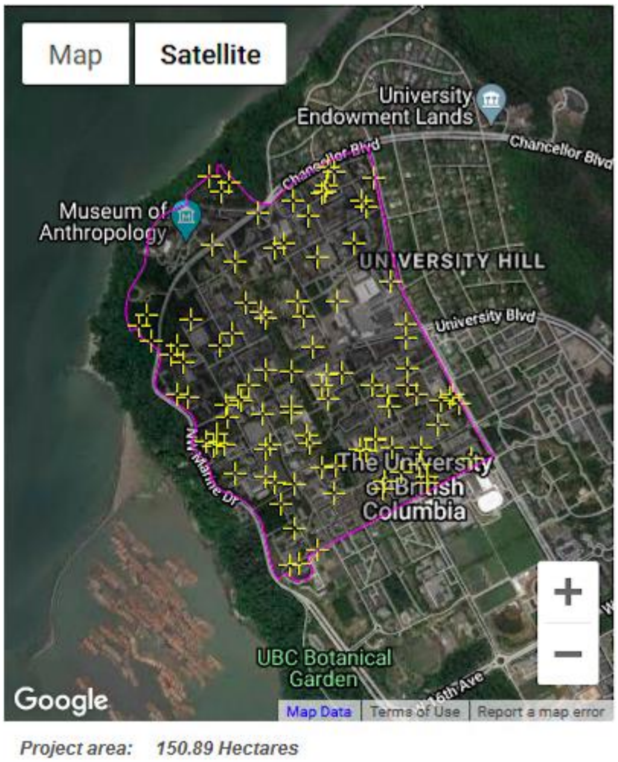


Figure 1: Study area with plot centre distributions and total project area

The project will be conducted on the University of British Columbia Vancouver north campus (49.2606°N, 123.2460°W), and the scope is constrained within the academic grounds of north campus due to residential private property concerns of south campus. Campus boundary maps were acquired from UBCGeodata Github repository and modified to remove campus grounds south of Thunderbird Boulevard. Sampling sites were determined using random sampling instead of pre-stratified sampling, which is often used when there are distinct land use differences - i.e. a city where there are parklands, residential, and/or agricultural areas differentiations. The campus grounds in question all fall under a predefined "Institutional" category by i-Tree Eco, therefore there is less need for a pre-stratified sample. This also allows true randomness, and thus an unbiased representation of the UBC campus to be achieved. A total of 110 plots were created and sampled. Considering the small study area, a complete tree inventory would have been more preferable, but due to limited time and personnel, a plot-based sample inventory was conducted instead. Thus, the large sample size was chosen to reduce standard error. Usually for an i-Tree Eco study city, 200 plots are suggested for a city-wide study. Due to the considerably smaller study area of campus grounds, 110 plots would be a reliable sample size. Furthermore, a study conducted in Minneapolis, US, used 110 plots, demonstrating that 110 plots for a significantly smaller study area will have appropriate representation. Sampling 110 plots is also when the relative standard error of the total number of trees begins to plateau (Fig. 2), where the tree abundance does not increase significantly anymore (Nowak et al. 2008). The plot sizes follow suggestions from the i-Tree Eco user guide, which is a 0.1-acre circular plot with a radius of 37.2 feet, or 11.33 meters.

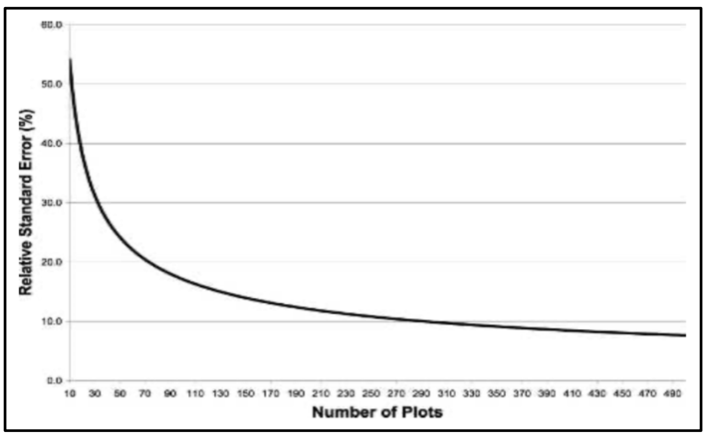


Figure 2: Estimated relative standard error (%) of tree abundance of number of 0.1-hectare plots in study (Figure from Nowak et al. 2008)

Several variables need to be input as integral base parameters for the model to run: tree species, diameter at breast height (DBH), tree height, crown dieback, and distance and direction to building. The distance to buildings was measured to the nearest point from the tree trunk and is used to estimate energy reduction potential. DBH was measured using a forestry diameter tape at a standard height of 1.4m unless specified. To measure tree height, a novel equipment was used—the Arboreal Forest mobile application, which uses augmented-reality (AR) technology to measure height from base to top using internal inclination sensors. The app was produced by a team of Swedish developers and foresters, and it has been tested against the Nikon Forestry Pro Laser Rangefinder, which had a percentage error of 2.6 for 50 samples, and Arboreal had a percentage error of 2 for 39 samples. This was corroborated by a study from the Swedish University of Agricultural Sciences (Lindberg, 2020), as well as by personal comparisons to a Silva clinometer where height difference between the application and the clinometer was consistently less than 2 meters. The model processes the field data externally from the user's software interface and returns an analysis report with graphical and statistical outputs. The model processes are summarized below.

Carbon storage and sequestration

Carbon storage is calculated using the DBH, which is converted into aboveground tree biomass, and then into whole tree biomass using a ratio of 0.26 (Cairns et al., 1997). Then using allometric equations, the biomass is converted into carbon stocks. Since trees in an urban setting have less biomass for the same DBH (Woodall et al, 2010), they are adjusted by multiplying biomass by a factor of 0.8 (Nowak et al. 1994). The i-Tree Eco software consolidates a variety of sources to compile a complete list of different species-specific equations. Multiple equations for different DBH ranges for one species are combined to create a final equation for the species.

Tree growth is taken into consideration when calculating carbon sequestration, where a base growth rate is determined using the growing season length, increases in diameter from year 1, and crown light exposure. Growth rate is also determined by the crown health input, where unhealthy trees are given adjustment factors to modify their growth rate (i-Tree Eco, 2004).

Air pollution removal

Air pollution removal by trees is calculated from the dry deposition of pollutant particles to tree canopies based on the provided tree cover data and weather data. The pollutant flux rate (F; in g m_2 s_{-1}) requires deposition velocity (V_d; in m s_{-1}) and pollution concentration data (C; in g m_{-3}) (i-Tree Eco, 2004).

$$F = V_d \times C$$

The calculation for monetary valuation for air pollutant removal in Canada is derived from the US Environmental Protection Agency's BenMAP model for conterminous United States. Regression equations for Canada are as follows (Hirabayashi, 2018):

- NO_2: y ($\$US\ ton$) = 0.7298 + 0.5242 x ($people\ km2$)
- O_3: y ($\$US\ ton$) = 9.4667 + 3.5089 x ($people\ km2$)
- $PM_{2.5}$: y ($\$US\ ton$) = 428.0011 + 121.7864 x ($people\ km2$)
- SO_2: y ($\$US\ ton$) = 0.1442 + 0.19 x ($people\ km2$)

Particulate resuspension by leaves are also taken into account and deducted from total pollution reductions.

Building energy effects

Data collected on tree species, tree height, distance to building, and direction to building are used to calculate the effects of any tree more than 6 meters and within 18.29 meters from a building on the building's energy use.

An adjustment factor is used depending on the tree's dieback condition, following methods from McPherson and Simpson, 1999.

$$Energy\ adjustment = 0.5 + (0.5\ x \times\ tree\ condition)$$

Tree condition = 1 – percent dieback

The increase of tree cover in an area decreases individual tree influence, so the percentage tree cover is used to interpolate tree effects on building energy use.

The benefit pricing in Canada are calculated with the following defaults in the software:

- Electricity in Canada/kWh: CAD$0.09
- Heating in Canada/therm: CAD$1.78
- Carbon in Canada/metric ton: CAD$114.87

Results

The i-Tree Eco model estimates that the UBC north campus will remove 2,148 pounds of pollution per year, saving up to CAD$39.5 thousand a year. Trees will store 4.78 thousand tons of CO_2 a year, equivalent to CAD$498 thousand annually, and sequester 89.27 tons a year, equivalent to CAD$9.3 thousand. The building energy savings produced by trees is up to CAD$84 thousand a year.

Air pollution removal

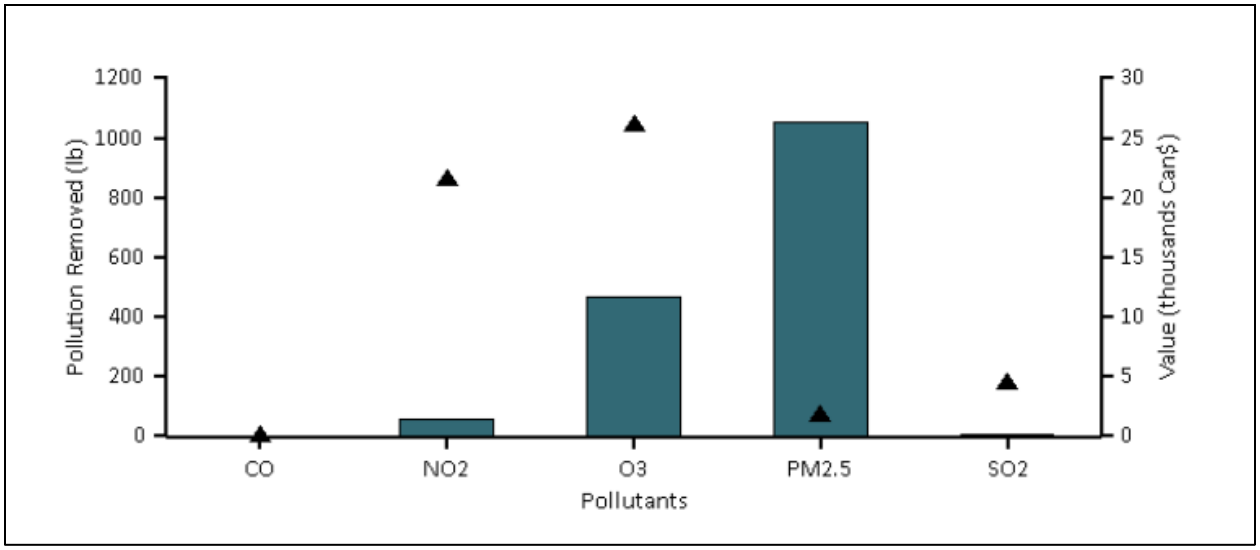


Figure 3: Annual air pollution removal in pounds (triangles) and corresponding monetary value in thousands CAD$ (bars)

The removal of O3 and NO2 was the most significant contribution for the urban forest, as trees mostly only intercept and suspend particulate matter on leaf surfaces, whereas gaseous pollutants like NO2 and O3 are able to be absorbed into the intracellular leaf structure (Environmental Protection Agency, 2015). The value of PM 2.5 removal, however, is significantly higher than other pollutants due to its close links to health effects (Hamanaka and Mutlu, 2018).

Carbon storage and sequestration

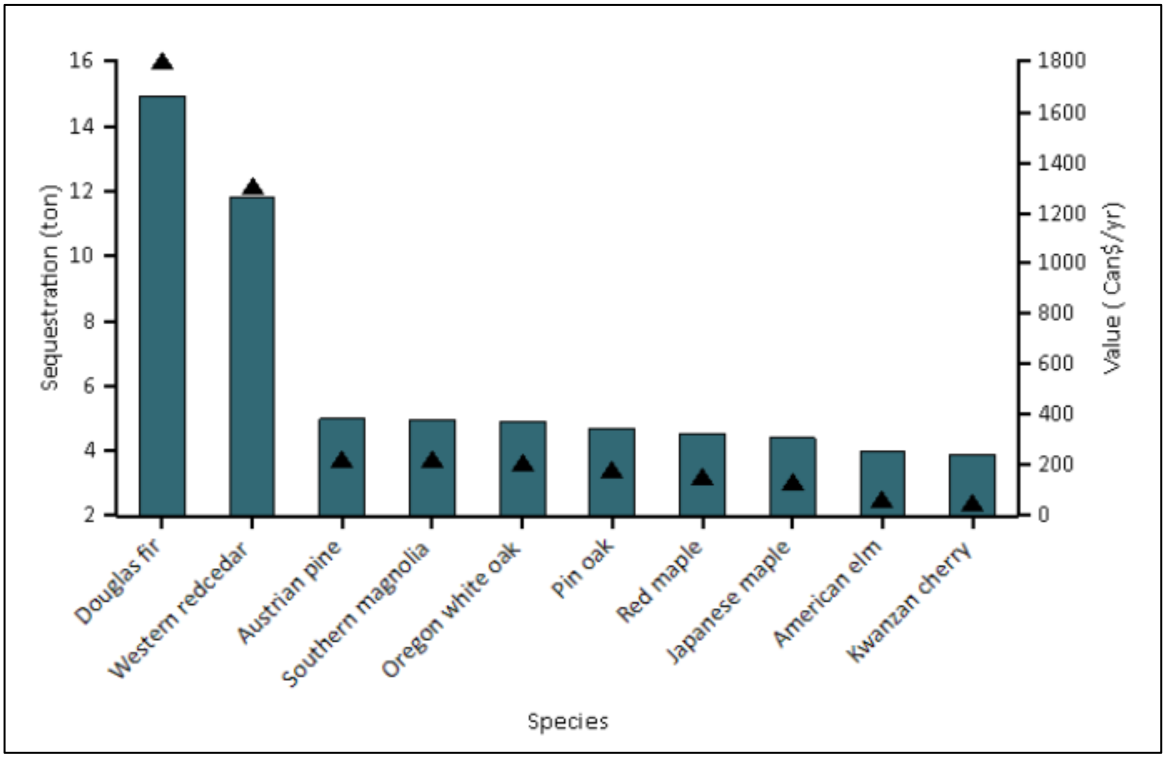


Figure 4: Estimated annual gross carbon sequestration by ton (triangles) and monetary value in thousand CAD$ (bars) for 10 tree species with greatest sequestration.

The carbon sequestration by species shows that the Douglas fir and western red cedar sequester the most amount of CO_2. These two species are the only two species native to Canada's west coast and are also the most abundant species on campus, and often the only two species to be found in the smaller undisturbed pockets of forest near the edges of the study boundaries. Douglas fir trees tend to have faster early-growth rates, which is conducive to higher rates of carbon sequestration, and most of the Douglas fir trees found on campus were fairly young in comparison to the older, second-growth stands in the surrounding Pacific Spirit Park (de Montigny and Nigh, 2007).

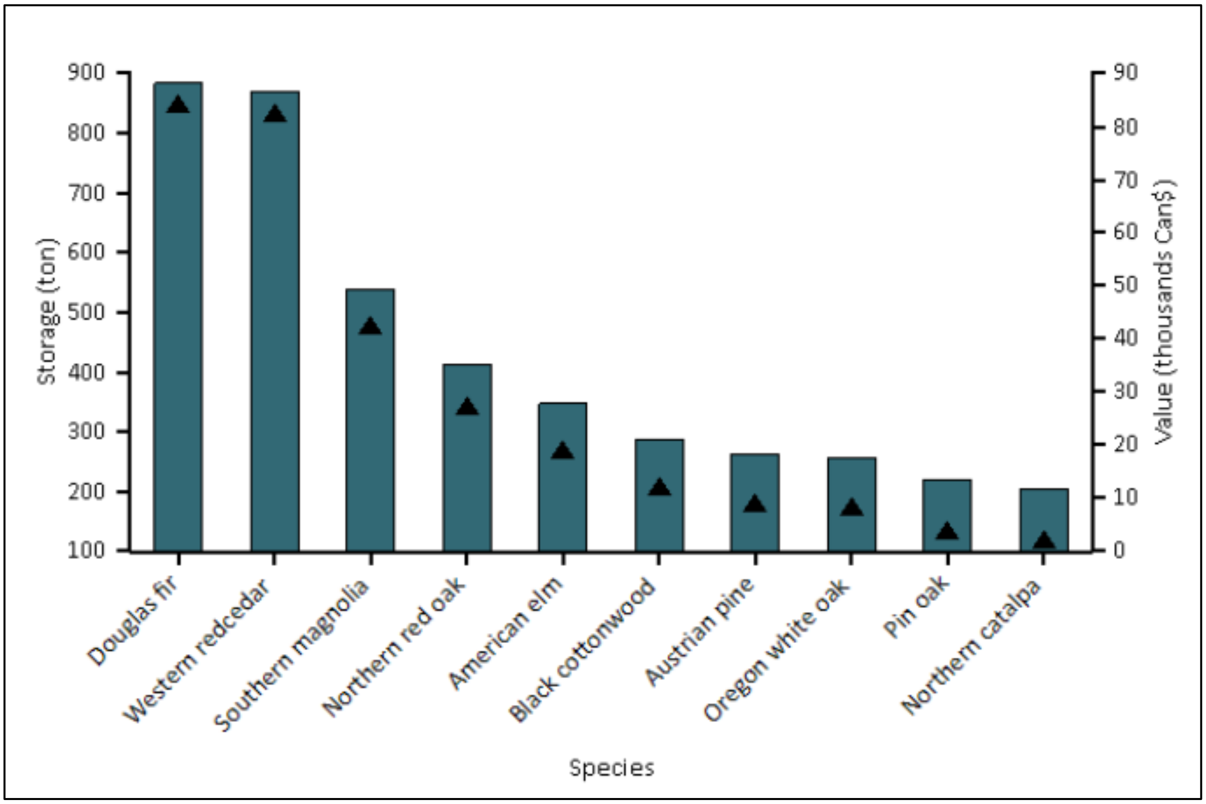


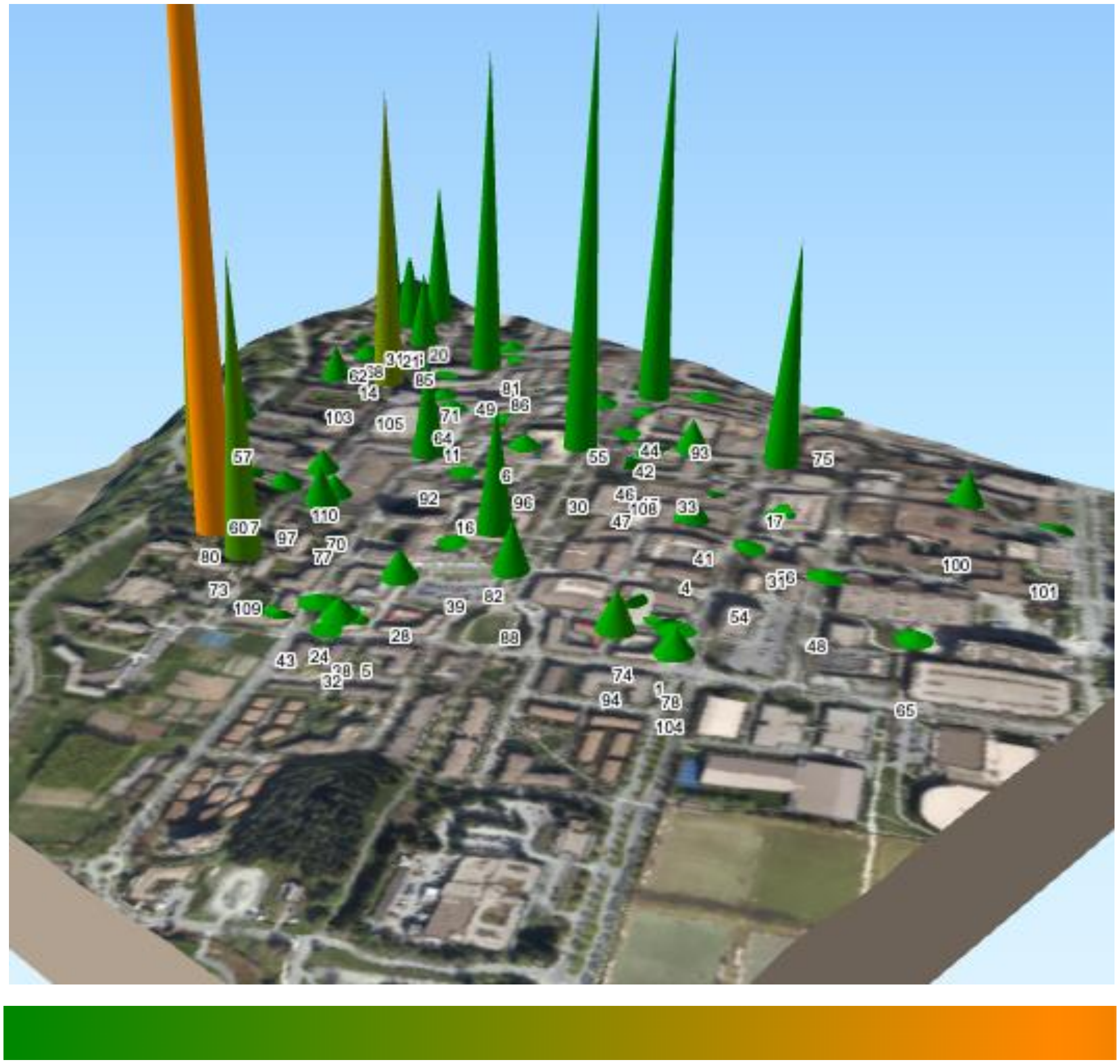
Figure 5: Estimated carbon storage values by ton (triangles) and monetary value in thousand CAD$ (bars)

Forests with high biomass have high carbon storage potential, and coastal temperate rainforests are known to be very biomass-dense. These old growth forests in British Columbia are largely dominated by Douglas firs and western red cedars, as categorized within the coastal Douglas fir Biogeoclimatic Ecosystem Classification (BEC) zone stocks (Simon Fraser University, 2007), and thus have high carbon storage potential. This can be seen in the above Fig.5, where have the highest carbon stocks come from those species. Southern magnolia was a popular ornamental tree in many of the student residences, therefore making up for its smaller size and thus lower carbon capture with its population numbers. Black cottonwood is interesting in its storage capacity as only one black cottonwood was identified in all the plots. This particular tree had an exceptionally high DBH, and literature has concrete results indicating the disproportionately higher benefit values of larger, more mature trees (Nowak and Crane, 2002; Jim, 2004).

Northern red oaks along the campus Main Mall also have high stores of biomass, thus contributing fairly significantly to carbon storage. Although this is likely an underestimation of northern red oak stocks as the random site distribution only placed accessible two plots along Main Mall.

Spatial distribution of carbon storage and pollution removal hotspots

https://angela-xz-liu.github.io/qgis2three/index.html



1 oz/year 239 oz/year

Figure 6: Carbon storage hotspots by height and air pollution removal potential rendered using QGIS2threejs plugin

Although it's important to help understand more species-specific rankings in terms of carbon sequestration and storage and the types of pollutants being removed, the spatial distribution of such ecosystem services can be equally as important as it can reveal spatial patterns. The data was visualized using a QGIS plugin called Qgis2threejs which renders digital elevation models (DEMs) and vector data into HTML. The above interactive 3D cartographic visualization is coded to represent the raw carbon storage data and air pollution data of all pollutants, with corresponding plot numbers. From this map, it is noticeable that the edges of the study boundaries tend to have higher carbon storage abilities, correlating to plots with undisturbed natural forests nearing the edges of the campus. For instance, Plot 73 has particularly high carbon storage and air pollutant removal, as it is located in the small plot of natural forest behind Totem Park Residence.

Building Energy Use

Table 1: Annual energy savings due to trees near buildings

	Heating	*Cooling*	*Total*
MBTU[a]	3,349	N/A	3,349
MWH[b]	158	98	256
Carbon Avoided (tons)	94	7	101

MBTU – one Million British Thermal Units; MWH – megawatt hour

Table 2: Annual savings (CAD$) in residential energy expenditure during heating and cooling seasons

	Heating	*Cooling*	*Total*
MBTU[b]	59,907	N/A	59,907
MWH[c]	15,178	9,372	24,550
Carbon Avoided	9,769	761	10,530

MBTU – one Million British Thermal Units; MWH – megawatt hour

Table 1 and 2 presents the savings in terms of energy units and monetary units. There is a considerable amount of avoided carbon (101 tons) that the urban trees mitigate, which would play an important role in assisting emissions reductions in one of UBC's main concerns in the university's CAP 2020. Since the proximity to a building is one of the main considerations in these calculations, the effect of the undisturbed forest plots on campus may be underestimated as they are not within a model-specified distance to a building, but studies have shown that areas with denser, taller trees has significantly more productive assets than smaller trees, and building just outside the 18.29m radius will likely benefit from shading effects as well (Nowak and Crane, 2002).

Normalized difference vegetation index time series

Lastly, a time series analysis was performed using the normalized difference vegetation index (NDVI) in ArcGIS 10.8 to situate the study temporally and get a better understanding of urban forest change over time. NDVI is a good metric for general vegetative land cover because it uses high resolution Landsat 8 data to observe the spectral signature produced by plants, where healthier and denser canopies would reflect more near infrared light than unhealthy, diminished canopies (Liang et al, 2018). It provides a broad conception of the trend of UBC's urban forest and campus development trajectory.

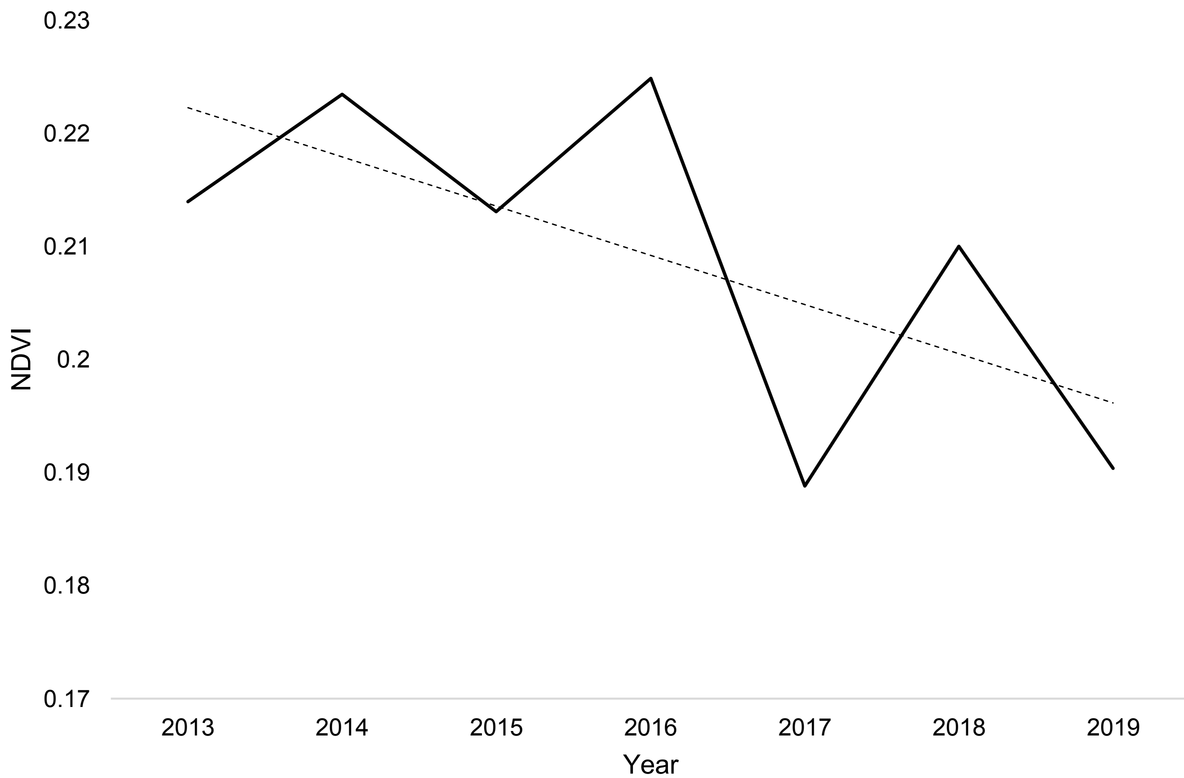


Figure 7: Mean normalized difference vegetation index (NDVI) for UBC study boundaries between 2013 – 2019.

From Fig. 7, the decrease in NDVI values over time is indicative of canopy loss in UBC's urban forest. Projecting this trend for ten years into the future (until 2030), the forecasted vegetation loss would be around 31.1%. This percentage loss is troubling as UBC's urban forest has high potential to assist in UBC's climate action plans and carbon reduction goals, and the ecosystem services they provide can also extend beyond ecological resilience and regulation into sociocultural wellbeing.

Discussion and Recommendations

The UBC campus urban forest has a lot of potential to provide essential ecosystem services that can help the university achieve its climate action goals. In 2018, the total emissions that UBC Vancouver campus buildings needed to offset to achieve climate neutrality was 37,941 tCO_2e, and while the current 4,780 tons that the UBC urban forest is estimated to currently store within its stands may not seem significant, it is able to entirely offset the natural gas emissions burned to power UBC's ancillary buildings, such as student housing and athletics facilities, which produces 4,049 tCO_2e in 2018 (University of British Columbia, 2019a). For building energy reductions, the 101 tons of carbon dioxide emissions avoided by UBC trees can be put into perspective when noting that the TRIUMF centre produced 101 tCO_2e in 2018. The removal of air pollutants by the urban forest, however, has more debate within its literature for its long-term effectiveness (Litschke and Kuttler, 2008). This is because urban trees are mostly only able to intercept and suspend particulate matter pollutants, and resuspension can occur frequently due to precipitation.

Through this investigation, it is noted that a significant portion of carbon capture was performed by certain species in certain environments, which can provide a suggestion for future urban forestry management at UBC. In Fig. 4 and Fig. 5 it is evident that Douglas firs and western red cedars have significantly higher carbon storage and sequestration properties. These trees are a few of the only native trees in the top ten species for carbon sequestration and storage, and their growth complements each other within more natural forested areas – conducive of fostering old growth stands (de Montigny and Nigh, 2007). Research has also indicated that coniferous trees and the acicular shape of the leaves allow for more efficient particulate retention (Chen et al, 2017). On the other hand, to improve upon the building energy effects of urban trees, deciduous trees are more beneficial, as their broad leaves tend to allow wider canopies in the summer, and the winter defoliation allows solar heat to be absorbed by the building easier (Akbari, 2002). From Fig. 6, it is also noteworthy that areas with the highest carbon sequestration and storage potential are not within close proximity to campus centre, where there are more buildings. A consideration to campus planning could be to incorporate more of these pockets of high carbon capture, natural forest areas, such as the plot of oak trees across from the Irving K. Barber Library. Another consideration can be to increase deciduous tree species along walkways and near buildings and foster the growth of older and more mature conifers along campus edges, to increase both building energy use and carbon capture.

However, while increasing species with desirable ecosystem services and select traits, studies have shown that carbon sinks are maximized in mixed species stands (Lecina-Diaz et al. 2018, Ruiz-Benito et al., 2014). The rivet-redundancy hypothesis proposed by Ehrlich and Walker (1998) also dictates that systems are buffered against catastrophe by the diversity of species, despite whether only several species are providing the ecosystem services needed for human welfare. Thus, it is important that functional diversity of species increases as well (Diaz and Cabido, 2001). The role of native tree species is also highly critical – native species tend to be more adapted to the regional climate and can be considered as more permanent carbon sinks rather than temporary. Recent research reveals that non-native trees can potentially accelerate carbon release back into the atmosphere due to their fast-growing nature and that their less dense, easily decomposable tissues (Waller et al, 2020).

Finally, an additional consideration for a benefit assessment like this study is the implications of valuing nature. While placing monetary importance to ecological functions helps advance environmental protection resolutions in a neoliberal economic framework, there could be negative implications where the intrinsic value of species is diminished, and sociocultural connections of nature are undervalued.

Limitations

While this study was spatially extensive, this sample inventory has a few limitations that could be modified for future projects. Firstly, the randomly dispersed plot design allows for true randomness, but a pre-stratified sample design would have allowed for a more even distribution of plots. In addition, an academic campus provides a slightly different land use composition than a standard urban region, as campus grounds like UBC have areas of relatively undisturbed forest (e.g., behind the Liu Institute and adjacent to the Totem Park Residences). The tree density is high while species diversity is low, as they are predominantly Douglas firs and western red cedars, which also increases biomass as these trees tend to be older. This could skew the overall data as the habitat type that these trees are growing in is different from the more urban environment from the rest of the study; however, these plots were still included in this study to have a more representative sample of the study area. The scope of this project was also primarily focused on aboveground arboreal ecosystem services and biomass. This is not to undervalue the importance of ecosystem services provided by grass and shrub biomass and soil carbon storage, which could be considered as a part of the definition of "urban forest". Regardless, this study focuses on urban trees, often considered a desirable biotic asset of the green infrastructure of a community, and their individual biomass content tends to be greater, which is correlated with carbon storage. The composition and placement can also be specifically arranged to achieve certain benefits.

Additionally, models like i-Tree Eco tend to underestimate urban tree carbon stock because they include a factor for urbanization that diminishes the tree's carbon capture abilities. However, trees that are in good health or trees found in more undisturbed forested areas within an urban environment are comparable to naturally forested trees (Russo et al. 2014). Limitations inherent to the model also play a role in overestimating or underestimating tree properties. The model suggests variables for field collection, and if any of these variables are not obtained, the regression equations will move estimates towards an average (i-Tree Eco, 2020). The i-Tree Eco model calculation for air quality improvement uses meteorological data from a specific weather station and is then interpolated homogeneously over the entire region. It is therefore not an entirely accurate estimation for more local effects of trees on air pollution removal (Heisler et al. 2007). Studies have paired the i-Tree Eco model with other models such as the Weather Research and Forecasting (WRF) model and the Community Multiscale Air Quality (CMAQ) to achieve a better understanding of pollutant removal by dry deposition (Cabaraban et al. 2013).

Recommendations for Future Research

The i-Tree software suite has a lot of applicability at the UBC campus and its urban forestry curriculum, as it provides a user-friendly interface for students to learn about fieldwork procedures and ecosystem service assessment process for urban forests. The UFOR 101 project has the potential to create a complete inventory of the UBC campus over the years, although it could be limited as the results are less accurate when the course is conducted in the leaf-off winter seasons. Currently UFOR 101 is not collecting data for building energy reductions, which is a primary concern listed in the UBC 2020 Climate Action Plan (University of British Columbia, 2019b), therefore it is suggested that if a complete inventory is being conducted, it should aim to maximize the outputs from the model by including building energy benefits as well. This would be able to produce a rich dataset that can assist the formulation of the upcoming Urban Forest Management Plan (UFMP) from UBC Campus + Community Planning. i-Tree Eco also analyzes other ecosystem services such as avoided runoff, oxygen production, and avian habitat suitability, and a complete inventory would have the capacity to include analysis and discussion on these other services.

An additional research area to investigate is to broaden the spatial scope beyond the academic campus and study Metro Vancouver. Using remote sensing data such as Landsat, Sentinel, or LiDAR, vegetation indices such as enhanced vegetation index (EVI) can obtain a biomass estimate over a larger area of land, which can be used to infer aboveground biomass (Situmorang et al. 2016). Historic data can also be used to map ecosystem service provisioning through time. Using allometric equations, carbon capture of Metro Vancouver could be estimated and help advance the city’s climate change mitigation and adaptation strategies.

Lastly, this synergy between arboreal diversity and carbon sequestration and storage is poorly understood and researched. The studies that do exist in the field produce conflicting results on the impact of species richness on carbon storage capabilities, and little research has been directed to urban systems (Adair et al. 2018, Liu et al. 2018,). The importance of reconciling urban arboreal diversity and urban forest carbon stocks is crucial for invigorating conservation efforts for urban biodiversity, which is often undermined in its importance and is facing rapid declines with loss of habitat and invasive species (Kirby & Potvin, 2007). This is especially important today as the rapid growth of urban centers and population often results in a trade-off of land and resources for ecological spaces (Dearborn et al. 2010). Biodiversity thus should not be considered only a secondary benefit of carbon sequestration and storage.

Conclusion

The urban forest at the University of British Columbia provides a myriad of irreplaceable socio-ecological ecosystem services for the academic community. It also can play a critical role in UBC's climate action plans as the university is pioneering the path in combating climate change. Urban forestry benefit assessment models such as the i-Tree Eco are important tools in quantifying these ecosystem services to inform planners and stakeholders the importance of conserving biotic green infrastructure as well as the best methods to manage them. Atmospheric pollution removal, carbon sequestration and storage, and building energy reductions is a select suite of benefits that this study investigated; however, the sociocultural necessity of green spaces for community adaptation and resilience-building in response to climate change is equally as critical. Ultimately, with the right management, UBC's urban forest presents a pathway towards a greener, cleaner, and more sustainable future.

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