UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC's Urban Tree Canopy: Growing Towards Sustainability or a Declining Resource?

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UBC Tree Canopy Study

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UBC'S URBAN TREE CANOPY: GROWING TOWARDS SUSTAINABILITY OR A DECLINING RESOURCE?

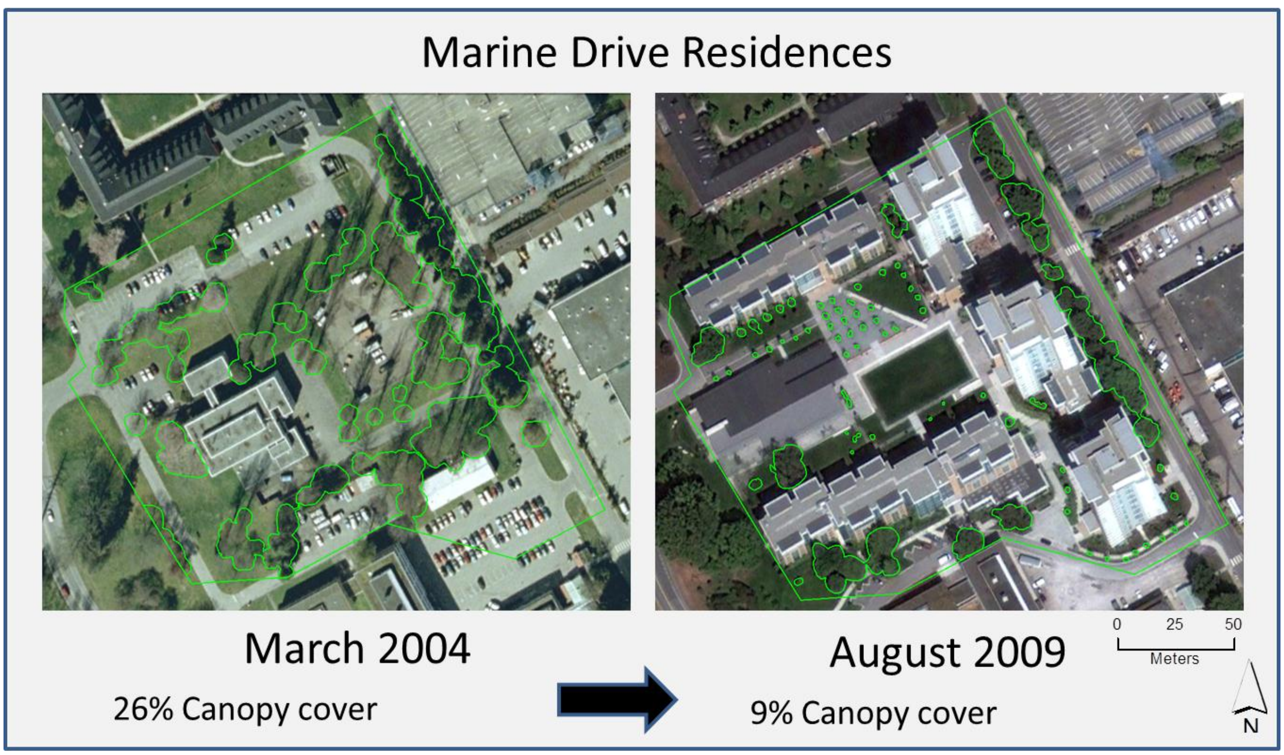
Abstract: UBC's urban tree canopy provides a broad suite of ecosystem services that support the community's well-being and many of the university's goals and values. Despite their importance, these ecosystem services are poorly understood and at risk of declining as the campus expands its built infrastructure. This study aims to provide a better understanding of the benefits provided by UBC's urban trees and elucidate possible implications of canopy reductions. Through a geospatial analysis this study estimates canopy cover and canopy structure changes at four study areas on the UBC Vancouver campus. At one of the study sites, placed in the south campus, canopy cover declined from 57% to 33% during the study period 2004-2009, which likely translates to a substantial decline in ecosystem services. This paper concludes with recommendations towards not only sustaining the benefits provided by UBC's urban tree canopy, but perhaps enhancing them through innovative ideas that support UBC's commitments to leadership in sustainability.

Executive Summary

The urban tree canopy at University of British Columbia is not only essential for campus sustainability but also for the community's well-being and UBC's reputation as an internationally renowned university yet this valuable resource is declining by as much as 5% per annum in portions of campus. It also appears that the campus tree canopy may be underutilized for promoting UBC's commitment to sustainability. This report is intended to help campus planning and landscape management by identifying what types of urban trees offer the most benefits to the university community. It also provides an improved ability to assess the costs and benefits of tree retention, replacement and management.

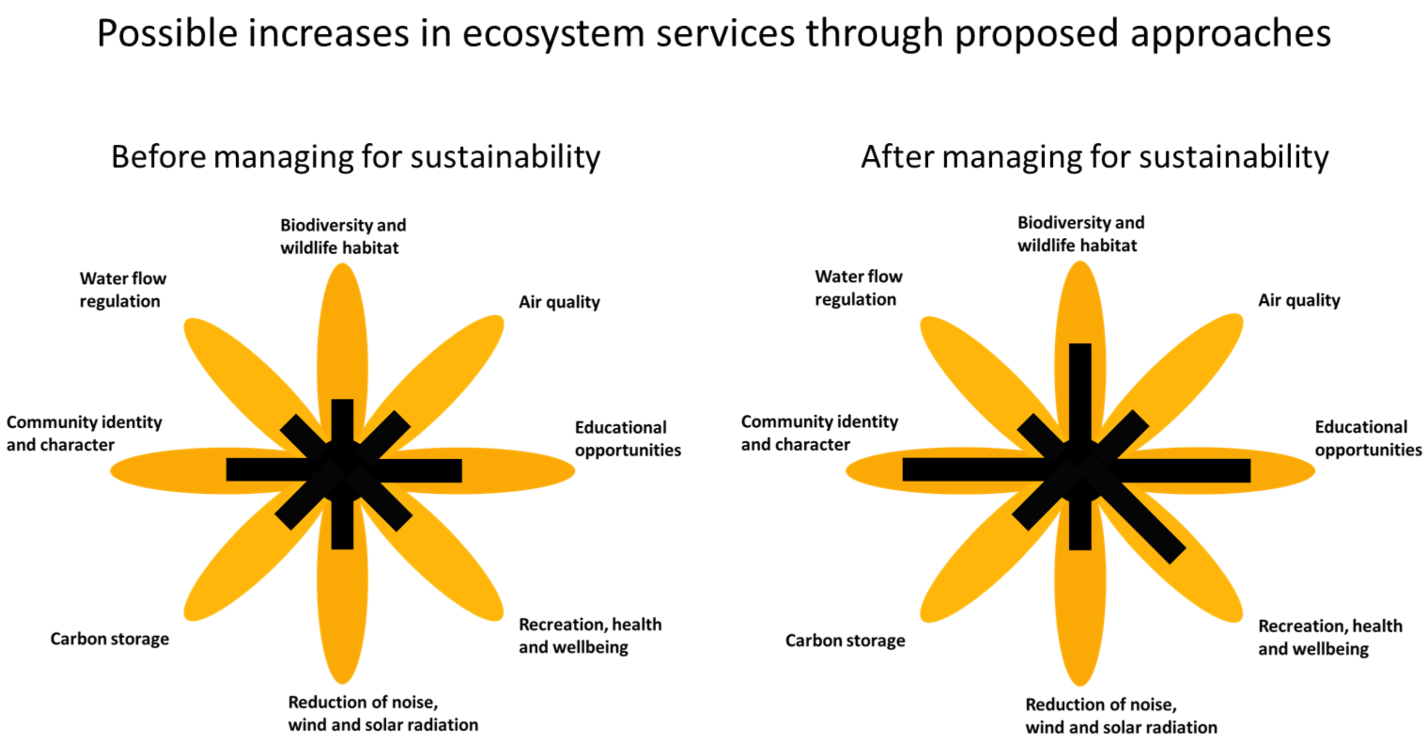
The benefits people obtain from nature are called ecosystem services (MA 2005). Urban tree canopies provide ecosystem services that often have measurable and significant monetary values. For example, carbon storage, air quality improvement, urban water regulation and other urban tree or urban forest ecosystem services, are valued at over $246 million in the Lower Mainland (Wilson 2010). Research has also shown that urban trees support vibrant communities, improve human health, reduce stress and enhance people's focus. The value of such services is difficult to quantify but clearly important to UBC's vision of promoting campus as a healthy, unique and internationally-renowned place capable of attracting high-quality staff, faculty and students. Lastly, the role of campus trees in supporting urban biodiversity is of fundamental importance to UBC's commitment towards sustainability.

UBC has the vision of becoming a world leader in sustainability Thus, it is critical that the university demonstrates stewardship and sustainable management of its own forests and tree canopy. Given current expansion and building infill plans at UBC this is an important time to evaluate impacts of development on the campus's urban trees. Canopy ecosystem services may be declining in areas where increasing campus development results in the replacement of large mature trees with small nursery trees, thus greatly reducing canopy coverage in some instances. This study conducted a geospatial analysis documenting canopy cover decline from 26% to 9% at the Marine Drive Residences study site between 2004-2009. Over this same period the south campus study site's canopy lost 11ha of canopy cover (from 57% to 33% cover) at the 46 ha site. Meanwhile, canopy cover in other parts of campus reviewed in this study are unaffected by development and experiencing very slow increases in canopy cover (e.g., 0.6% per annum) due to natural tree growth.



Canopy cover change at the Marine Drive Residences from the 2004 baseline canopy to the 2009 contemporary canopy. Canopies were digitized in Google Earth and their areas were determined using Arcmap GIS software.

This report concludes with recommendations for the university to sustain canopy benefits and better utilize trees for promoting campus sustainability. This may include maintaining or increasing campus canopy cover (currently at 30%) or enhancing the ecosystem services of existing trees by innovative management strategies such as using tree management to promote native biodiversity, recognize cultural values of Musqueam First Nations, support the "living lab" initiative, or encourage alumni engagement.



Where the black bars represents the magnitude of ecosystem services being produced at a given area of UBC tree canopy, this shows that some urban tree canopy ecosystem services can be increased through innovative management practices suggested in this report, thus potentially offsetting declines in canopy services experienced elsewhere on campus due to development. These approaches also carry the added benefit of supporting UBC's commitments towards sustainability.

Introduction

The University of British Columbia is striving to become a global leader in sustainability (Place and Promise 2009). The university has an opportunity to support this initiative by demonstrating stewardship and sustainable management of its own landscape including its forests and tree canopy. Many municipalities have studied their urban tree canopies and concluded that they enhance the livability and functionality of their cities as well as decrease adverse ecological impacts from urbanization (e.g., Nowak et al. 2009, Burkhardt 2009). To date UBC has not studied the benefits provided by the campus tree canopy, nor has UBC assessed the extent of changes in canopy cover as the university infrastructure expands and becomes increasingly dense. For example, the university's goal is to increase academic complex floor space by over 1 million square feet and increase student housing by 3.6 million square feet between 2010 and 2017 (Vancouver Campus Plan 2010a). Thus, this is a critical time to evaluate impacts of development on the campus's urban tree canopy.

Assessing the benefits provided by urban trees is often accomplished by studying the canopy they collectively form as well as the size and species of individual trees. The total canopy area as well as canopy structure, which includes the size and species of individual trees, have been identified as the most important features for studying the benefits provided by urban tree canopies (Nowak et al. 2009). Examining large areas of canopy yields a marvelous opportunity to easily compare the benefits offered by canopy cover across campus and how they have changed through time. The importance of tree species and size can be elucidated with an example contrasting a young flowering cherry (*Prunus* sp.) to an established 30m tall Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) (Figure 1). The former may offer an inspiring display of colour in spring but it has an inferior ability to store carbon, diffuse noise from construction, shelter pedestrians from rain, or provide habitat for biodiversity.

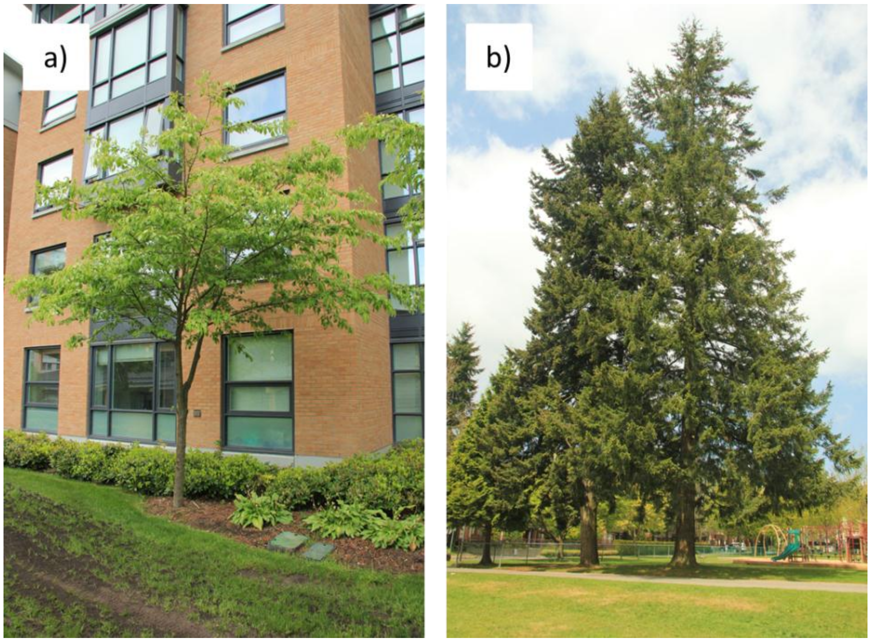


Figure 1 An example to elucidate the importance of considering tree species and size in determining the benefits provided by urban tree canopies. These two trees, (a) the small cherry tree and (b) the large Douglas-fir, have distinct forms and traits, which affect the benefits they offer to humans.

The benefits provided by urban tree canopies are best described by identifying the types and amounts of ecosystem services they provide (Nowak and Dwyer 2007). To facilitate understanding and management of the benefits humans derive from nature, the ecosystem services approach divides the overall benefit of nature into its constituent parts: provisioning services (e.g., timber and food provisioning), regulating services (e.g., water quality and climate regulation), cultural services (e.g., recreation and intellectual inspiration) and lastly, supporting services (e.g., biodiversity and pollination) which support all other services (MA 2005). Flower petal diagrams (Foley et al. 2005), are useful for conceptualizing how different ecosystem services are provided by different vegetation structures (Figure 2).

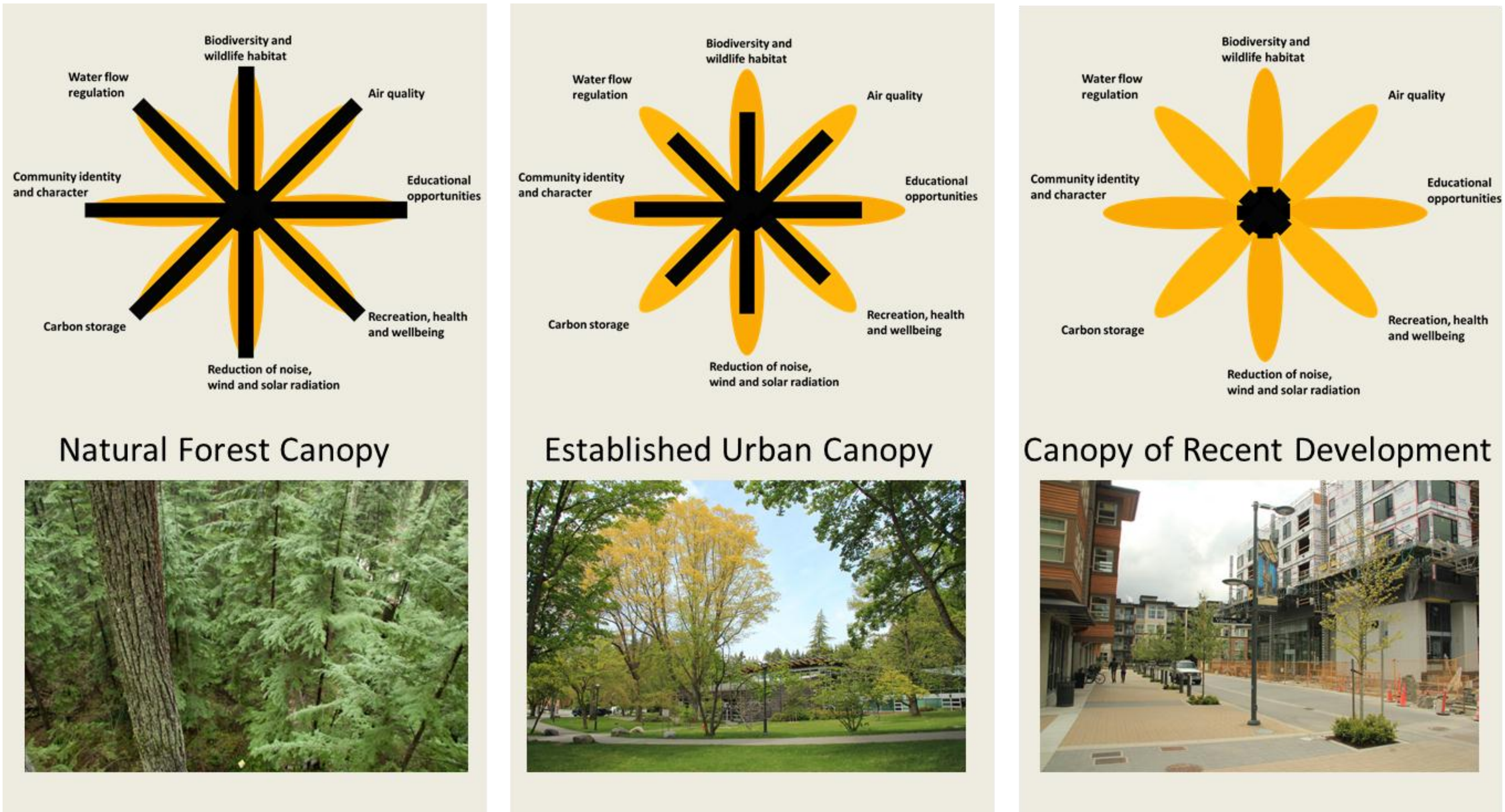


Figure 2 Flower diagrams can offer a conceptual understanding of how the relative magnitudes of different ecosystem services vary among vegetation structures. The black line represents the magnitude of ecosystem services likely to be provided by canopies with differing levels of cover as well as size and species of trees (Adapted from Foley et al. 2005). This diagram suggests that many ecosystem services are likely provided by a natural forest canopy. An established urban canopy likely provides many more services than a young canopy that has been recently established following development.

This study examines this important issue at UBC. First I review the scientific literature to provide a richer appreciation of the potential ecosystem services provided by UBC's urban tree canopy. These findings are then coupled with the results from a geospatial analysis of canopy change from "baseline" canopy conditions in 2004 to a "contemporary" canopy in 2009 to reveal trends in the provisioning of ecosystem services by tree canopy across campus. The geospatial analysis examines change to overall canopy cover as well as canopy structure (tree species and size classes). To focus this research, three research questions have been asked: (1) What ecosystem services are likely provided by UBC's urban tree canopy? (2) How has the tree canopy (including species, size and overall canopy cover) changed across campus? Thirdly I ask, (3) what are the implications of changes to the urban tree canopy for the university and community? Drawing from the results of question 1 and 2, this final question provides insight into whether current tree canopy management supports the principles, values and goals of UBC planning documents (e.g., Place and Promise 2009, Vancouver Campus Plan 2010). Lastly, the report concludes with some recommendations for the university to manage its urban tree canopy to sustain ecosystem services, and also support the university's vision of becoming a global leader in sustainability.

Methods

1. *What ecosystem services are likely provided by UBC's urban tree canopy?*

The primary ecosystem services provided by UBC's urban trees were determined by a review of the scientific literature and other urban tree canopy studies. For this, attention was also given to local conditions such as community and heritage values, climate and native biodiversity.

2. How has tree canopy (including species, size and overall canopy cover) changed across campus?

Geospatial analysis of the UBC tree canopy has never been conducted aside from a tree inventory completed in 1998 (Hole and Dunster) and then updated in 2007 (Beese adapted from Hol and Dunster 1998). These were intended to facilitate campus planning and grounds maintenance rather than assess canopy extent or change during this timeframe. Thus, this study conducted its own analysis of canopy change from a 2004 “baseline” canopy cover to a 2009 “contemporary” canopy cover using study sites in different parts of the campus. In addition, the 2009 contemporary canopy condition was studied using readily-available LIDAR satellite imagery and 2007 tree inventory data.

Study sites

Four distinct study sites were identified on the UBC campus representing differing levels and dates of development to capture a diverse snapshot of canopy change across the campus (Figure 3). Study sites included the Buchanan (Figure 3, panel A) and engineering academic complexes (Figure 3, Panel B) to represent the academic core. Neither of these areas had undergone construction during the study period. They differ in that the Buchanan complex was developed from 1956-1968 while the Engineering academic complex underwent various phases of construction from the 1970s through to 2003 (University Archives 2011). Another study site at the Marine Drive Residences (Figure 3, Panel C) represented a student housing hub constructed from 2004-2009. Previously this site was comprised of parking lots, green space, a utilities shed and the Fisheries and Food Sciences building. The final study site was located in south campus (Figure 3, Panel D), where tree cover had been noticeably reduced due to the ongoing development of a market housing community.

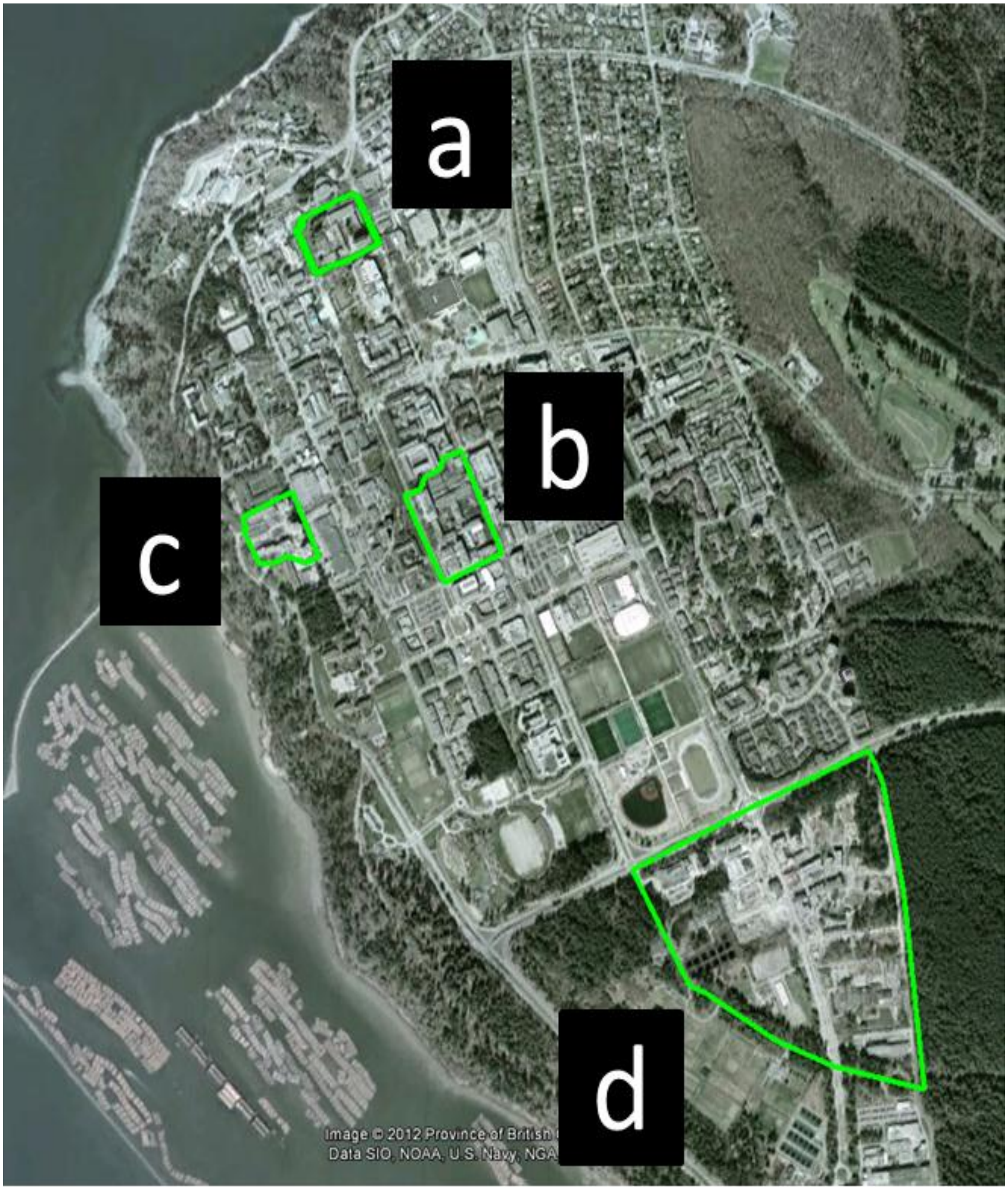


Figure 3 Boundaries of four UBC tree canopy study sites examined in this study. a) Buchanan academic complex, b) Engineering academic complex, c) Marine Drive Residences, d) south campus market housing development

Three criteria were used to delineate the boundaries of sites. First, the boundary was defined by bordering roads and pathways or the UBC land boundary if appropriate. All buildings within the complexes were included in the study areas. Finally, where possible, trees occurring near a boundary line were either entirely included in or excluded from the study areas.

Geospatial data

Assessment of each site's canopy structure and canopy change used readily-available geospatial data for UBC. This included Google Earth historical imagery and geo-referenced UBC tree inventory datasets from 1998 (Hol and Dunster 1998) and 2007 (Beese as adapted from Hol and Dunster 1998). The 1998 tree inventory dataset contained location, species, and diameter at breast height (DBH) (a standard measure of a tree's girth, measured at 1.3 m above the ground). The 2007 inventory dataset lacked any size measurements but described species and location as well as any special significance of individual trees such as those planted by graduating classes or commemorating UBC community members. Neither tree inventories include data for South Campus

Google Earth historical imagery from 2004 was used as the "baseline" imagery to capture both the Marine Drive Residences and south campus sites prior to major development. Google Earth imagery from 2009 was used as the "contemporary" image date for comparing canopy cover over the study period. Additionally, a pre-processed 2009 LIDAR canopy surface model (Tooke et al. 2009) was used to estimate total tree cover across the entire UBC campus delineated by a polygon of the UBC legal Boundary (UBC 2011).

Tree delineation and canopy mapping

The vegetation in UBC tree inventory data were used to assess the canopy structure (species and size of individual trees) at each site. DBH values in the 1998 inventory were used as rough proxies for the sizes of individual trees still in existence in 2004 and 2009 rather than attempt to estimate annual DBH increases across a variety of species and age classes. Thus, the size results provided for 2004 and 2009 DBH should be considered minimum estimates. Newly planted trees without known DBH measurements were assumed to be <20cm DBH. Similar to out-of-date DBH data, so was the presence or absence of many individual trees, as many were removed or planted since the inventories were conducted. Thus, individual trees were manually updated to accommodate tree removals or additions for each study site (Figure 4). The 2007 inventory was also summarized and then scanned for errors to produce an estimate of the total number of trees and tree species listed.

The second approach for assessing the canopies was to map canopy cover. For this, I first used the LIDAR-derived surface canopy model to evaluate 2009 campus-wide tree canopy cover as well as separate estimates for the greater south campus area (including the botanical gardens) and the south campus. Then, the Google Earth polygon tool was used to digitize study site tree canopies and determine canopy extent and area using GIS software. With these two approaches I was able to first provide an overview of the campus-wide contemporary canopy condition including canopy cover and structure (species and size of trees) and then explore how this had changed from 2004 to 2009 at the four study sites.

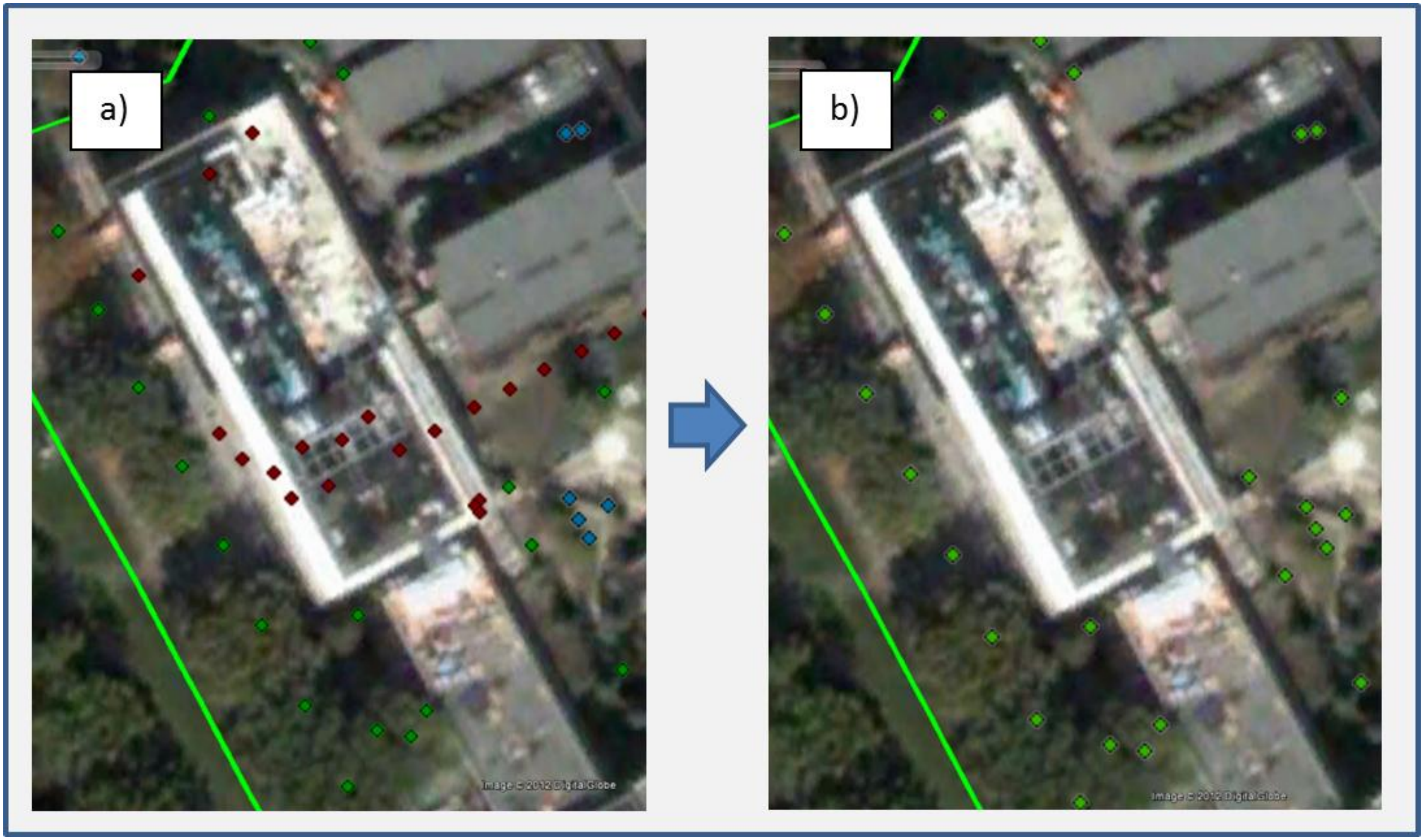


Figure 4 An example of updating the tree inventory data for a section of the engineering complex. a) Due to construction in 2002-2003, trees had to be manually deleted (red points) from the 1998 inventory while others were added from the 2007 inventory (blue points). Many trees were unaffected (green points). b) This updating resulted in an accurate inventory of the canopy structure in 2004 used to estimate ecosystem services provided by the canopy. The same procedure was done to depict canopy structure for 2009 and for all study sites.

South campus canopy structure

Because tree inventory data does not exist for the south campus study site, canopy structure was assessed from Google Earth images and ground observations in 2012. This was then digitized into conifer and deciduous class canopies. The conifer class was observed to be mostly mature second-growth forest of Douglas-fir, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red-cedar (*Thuja plicata* Donn ex D. Don). Field reconnaissance revealed that many of the conifers were noticeably larger than trees observed in the other study sites (Figure 5) and it is likely that they regenerated approximately 100 years ago following harvesting that occurred in this area in the 1910's (Thompson 1985). The deciduous class appeared to be a mix of mature and young trees establishing on recently disturbed sites, including red alder (*Alnus rubra* Bong.), big leaf maple (*Acer macrophyllum* Pursh) and possibly black cottonwood (*Populus balsamifera s*ubsp*. trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw).

Figure 5 An example of the conifer class delineated in the south campus study site including a large Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) featured center-left. Note the pedestrian to provide a sense of scale. Photo from May, 2012.

Results

1. What ecosystem services are likely provided by UBC's urban tree canopy?

Eight ecosystem services provided by urban trees were identified in the literature review as having high relevance to the UBC campus (Table 1) falling under the categories of regulating, cultural and supporting ecosystem services. Regulating canopy services offer substantial direct benefit to the UBC community by moderating urban water flow, storing carbon to aid climate regulation, improving air quality, reducing noise, wind and solar radiation. The cultural ecosystem services identified relate to educational opportunities, health benefits and the character and identity trees contribute to the community setting. The single supporting ecosystem service identified to be of high relevance is the maintenance of local biodiversity and wildlife.

These canopy-related services come with some costs. For example, the cost of tree maintenance and leaf litter clean-up exceeds $300 000 year^{-1} at UBC (Jeff Nulty Personal Communication). While costs associated with urban trees can be substantial, the costs are often negligible compared to the value of services provided (Nowak and Dwyer 2007). For example, forests in the Lower Mainland provide $246 million year^{-1} of ecosystem services (Wilson 2010) while Toronto's urban tree canopy services are valued at $60 million year^{-1} (Burkhardt 2009). Many regulating services provided by forests and urban tree canopies (such as improvements in air quality and carbon storage) can be evaluated using established methodologies and software (Nowak and Dwyer 2007). Contrastingly, the values of cultural and supporting ecosystem services are much more difficult to quantify (Anielski and Wilson 2009)

Ecosystem Service	Summarized benefits
Regulating Services:	
1. Carbon storage	Potential mitigation of urban carbon emissions and regulation of global climate, but strongly dependant on size of trees and their extent cover
2. Air quality	Absorb air pollution, but net benefit is highly dependent on species and size
3. Water flow regulation	Intercept falling rain and reduce runoff
4. Reduction of noise, wind, and solar radiation	Improve physical environment for human well-being while reducing building energy needs
Cultural Ecosystem Services:	
5. Community identity and character	Help define neighborhoods and build social ties
6. Educational opportunities	Restore attention, foster intellectual inspiration and offer research and learning opportunities
7. Health and well-being	Aesthetics offer stress and anxiety relief and potentially increase resilience to illness
Supporting Ecosystem Service:	
8. Wildlife habitat and biodiversity	Potential to lessen impacts to natural ecosystems displaced or harmed by urbanization

Table 1 Eight ecosystem services provided by urban tree canopy identified to be of high relevance to UBC with a brief summary of their benefits.

Carbon Storage

Carbon sequestration and storage by urban trees greatly depends on human activities and the structure of the urban forest, including the tree species, size, health and location (Norwak and Dwyer 2007). For example, carbon sequestration by the urban tree canopy in Los Angeles County was found to be negligible compared to the city’s sources (Pataki et al. 2011) with a similar situation reported in Chicago (Nowak and Dwyer 2007). At UBC there is likely much greater potential as the biomass-rich forests of this region have some of the highest carbon storage capacity in the world and store an average of 642 tonnes C ha^{-1} in primary forests (Keith et al. 2009). Estimates of carbon storage for a variety of second-growth stands in the Vancouver area range from 423 in forests 50-100 years old, 169 in forests 21-50 years old, to 55 tonnes C ha^{-1} in forests 1-20 years old (Wilson 2010).

Air quality

Trees improve air quality by trapping coarse particulate matter on leaf surfaces and by absorbing harmful gaseous compounds (namely, CO, NO_2, O_3 and SO_2) through their stomata (Nowak 2000). Wilson (2010) determined that on average trees of all forest types in the Lower Mainland remove about 100kg pollutants ha^{-1} $year^{-1}$. Trees over 77cm DBH with high leaf surface area can purify air 70 times faster than trees less than 8cm DBH (Nowak 2000). However, trees also emit harmful volatile organic compounds (VOCs) and allergens in amounts dependent on the species, so an evaluation of net benefits must consider tree species as well as size. Common trees found in UBC that are excellent in terms of overall positive impact on VOCs include: western hemlock, American elm (*Ulmus Americana* L.) and the tulip tree (*Liriodendron tulipifera* L.). Meanwhile, common genera of poplars (*Populus* sp.), oaks (*Quercus* sp.) and sweetgum (*Liquidambar sp.*) contribute the least benefit to air quality (see table 1 in Nowak et al. 2002 for a list of VOC emissions by 242 species). The overall benefit of urban trees on air quality is also affected by local meteorology, pollutant concentrations and pollutant sources (Nowak and Dwyer 2007).

Water flow regulation

Through canopy interception, soil water retention and root uptake, urban trees delay and moderate urban water runoff and reduce flashiness caused by impervious urban surfaces (Plat 2006). This translates to reduced risk of flooding damage, erosion and overall storm water treatment costs (Platt 2006). Also, through deflection and canopy interception, trees can shelter pedestrians from incoming rain. A study by Asadian (2010) of rain interception in the Vancouver area found that on average rainfall beneath conifer and deciduous tree canopies was reduced by 76.5% and 56.4%, respectively. Due to UBC's humid climate well placed trees may be a valuable asset to commuters.

Reduction of noise, wind and solar radiation

Urban forests make the physical urban environment more hospitable by reducing wind, noise and solar radiation. Residential areas with a substantial cover of large trees have been shown to experience 60% lower wind speed than similar nearby areas without trees. Denser more closed canopies may reduce wind by 90% (Heisler 1990).

Noise is also an important consideration in urban environments. On the UBC campus, late night gatherings, construction and outdoor concerts often coincide with studying and research tasks that require focus and restful sleep. Trees can mitigate noise either by blocking it directly or by reducing human's perception of it. Effective blockage requires barriers of tall trees at least 5m thick located near to the source of noise (Anderson et al. 1984). The sounds of singing birds within trees and rustling leaves can also drown out unwanted noise (Nowak and Dwyer 2007). Visually blocking the source of noise can also reduce human notice of it (Anderson et al. 1984).

Shade provided by urban trees is another highly valued ecosystem service. The combined effect of shading and evaporative cooling from transpiration of urban trees can reduce summer heat by up to 5^{o}C (Nowak and Dwyer 2007). Reductions in temperature and harmful ultraviolet radiation can have immediate positive benefits for human health as well as reduce building energy use. A study in Tennessee found that urban trees increased winter energy bills by $29 million but reduced them by $95 million in the summer (Nowak et al. 2009). The potential for energy savings are greatly dependent on the position of trees around a building. A study in Wisconsin found that well-positioned trees reduced annual energy costs by 4%, yet poorly-positioned trees increased costs by 13% (Nowak and Dwyer 2007). Optimal tree placement is on the east and west sides of buildings or in the direction of the prevailing wind (Nowak and Dwyer 2007).

Educational opportunities

Broadly, academic benefits of UBC's trees include the provision of shade for summer lectures and a source of intellectual inspiration for those who have become interested and mindful of their presence. More specifically, exposure to trees and green spaces has been shown to increase focus for children with attention deficit disorder (Taylor et al. 2001a) and restore people's attention as it naturally becomes fatigued from tasks such as problem solving or studying (Taylor et al. 2001b). The more greenery people are exposed to, the greater their ability to focus (Taylor et al 2005). UBC's trees are also directly utilized by at least seven courses taught by the Faculties of Forestry, Arts and Science (Personal Communications with Dr. Lori Daniels, Dr. Rob Guy and Shona Ellis). While these courses primarily use the campus trees to teach taxonomy, campus trees have been incorporated into statistics (Dr. Rob Guy Personal Communication), dendrochronology (Dr. Lori Daniels Personal Communication) soil science (Dr. Maja Krzic Personal Communication) lessons and likely many others. As well, UBC's trees provide a plethora of research opportunities, not reviewed here.

Health and well-being

Health benefits from interacting with trees are well studied. Brief experiences in forested urban parks (<30minutes) have significant positive impacts on people's moods, suggesting even short walks among trees can reduce stress and anxiety (Hull 1992). From within a building, having a view of nature has been shown to increase feelings of well-being and job satisfaction (Kaplan 1993). Views of trees may also increase resilience to illness. Hospital patients with a window view of trees recovered from surgery 10% faster and took less medicine than those with windows facing a brick wall (Ulrich 1984).

Community identity and heritage value

Trees are often cherished by individuals because of their aesthetic value and the personal relationships people build them or due to the social ties they have formed around them (Schroeder 2002). Due to their long lifespan and because they are a shared community resource, urban trees can be an enduring source of character and identity for a community. Social benefits can be greatly enhanced by active community participation in urban forestry activities such as tree planting and watering (Westphal 2003).

Biodiversity and habitat

The Lower mainland has lost between 50-70% of its natural habitat, of which 27% has been converted to urban land-use (Wilson 2010). In addition to supplying habitat for displaced wildlife, the campus tree canopy supports surrounding ecosystems by reducing adverse edge-effects at the park-urban interface (Vancouver Campus Plan 2010c) and by offering connectivity between portions of Pacific Spirit Park. A study of bird distribution in Vancouver and Burnaby found that proximity to landscape and habitat features, such as urban forests and large conifers, significantly increased the occurrence of all 48 bird species documented in the study (Melles et al. 2003). Another significant benefit for wildlife is the occurrence of trees with varying levels of heart rot decay, which when excavated by birds or through other processes, can create cavity-nests utilized by a wide variety of birds and mammals (Cockle et al. 2011).

Habitat for wildlife offers benefits to the human population as well. A survey of park visitors in the US determined that wildlife encounters were pleasing, intellectually inspiring and often resulted in such places having special significance in people's minds (Schroeder 2002). The UBC canopy directly supports or benefits many native birds that are interesting to observe such as flickers, white-crowned sparrows and the occasional pileated woodpeckers (Dr. John Richardson Personal Communication).

The vast majority of the campus's urban trees are not native; however they may still support native biodiversity and wildlife as well. Species diversity can confer resilience to the urban ecosystem as some detrimental insects and pathogens are incapable of transferring across species or genera (Nowak et al. 2009). Urban canopies may become increasingly valuable for biodiversity as local forests are expected to undergo significant stress and tree mortality from climate change (Hamann and Wang 2006). The suggestion that non-native trees may support native biodiversity, however, comes with a caveat. Some non-native tree species naturalize and compete strongly with native flora. For example, Irish holly (*Ilex aquifolium* L.) is a common tree growing in UBC but also one of the most ubiquitous and threatening invasive plants in Metro Vancouver parks (Page 2006).

Putting it to practice: some features useful for determining the provisioning of ecosystem services by urban tree canopies

Several important themes emerged from the literature review that can be used to guide estimation of the ecosystem services provided by the UBC tree canopy. Firstly, it appears that by far the most important general theme that influences the provisioning of ecosystem services is tree size. Larger trees are considerably better than smaller trees at offering all regulating ecosystem services reviewed in this study as well as the single supporting ecosystem service of wildlife habitat and biodiversity. Large trees also appear to increase the provisioning of cultural ecosystem services identified to be of high relevance to UBC. For example, trees utilized to teach plant taxonomy must be reproductively mature for students to examine their flowers fruits or cones, but are often most suitable when they are of sufficient size to demonstrate their overall form (Dr. Rob Guy Personal Communication). Large trees with distinct form also likely add the most character to neighborhoods while long-lived large trees may best support continuing social ties. Similarly, large trees provide a greater abundance of the foliage and greenery benefitting health and well-being (Taylor et al. 2005).

Other important themes that impact urban canopy services are the kinds of tree species present (e.g., varying contributions to improving air quality and wildlife habitat), the diversity of species (e.g., educational opportunities), the placement of trees (e.g., effects on building energy needs and noise reduction) and local conditions (e.g., climate conditions). It is also expected that deciduous trees offer fewer ecosystem services during winter months than conifers. One last important theme is that many of the cultural ecosystem services can be enhanced through management and various programs such as community involvement in tree planting or educational programs.

2. ***How has tree canopy (including species, size and overall canopy coverage) changed across campus?***

2009 Contemporary canopy conditions

Analysis of the 2007 tree inventory showed that the “main campus area” (Figure 6) had between 7300 and 7500 trees of 207-217 different species at the time of the inventory (not counting cultivars). It is expected that this had changed little by 2009. Analysis of the 2009 LIDAR-derived surface canopy model show the total 2009 tree canopy covered 30% of UBC campus (Figure 7, Panel A). Tree canopy cover was proportionately higher in the south campus and UBC Botanical Garden area where the canopy covered 44% of the 139.44 ha area (Figure 7, Panel C) while the tree canopy in the “main campus area” covered 22% of the 262.38 ha area (Figure 7, Panel B).

Figure 6 UBC main campus as delineated using a UBC legal boundary layer (UBC 2011) and then removing the UBC Botanical Garden and South campus. This area is covered by the 2007 tree inventory (Beese adapted from Hol and Dunster 1998) allowing me to estimate that there are between 7300 and 7500 trees in this area among 207-217 species (not counting cultivars).

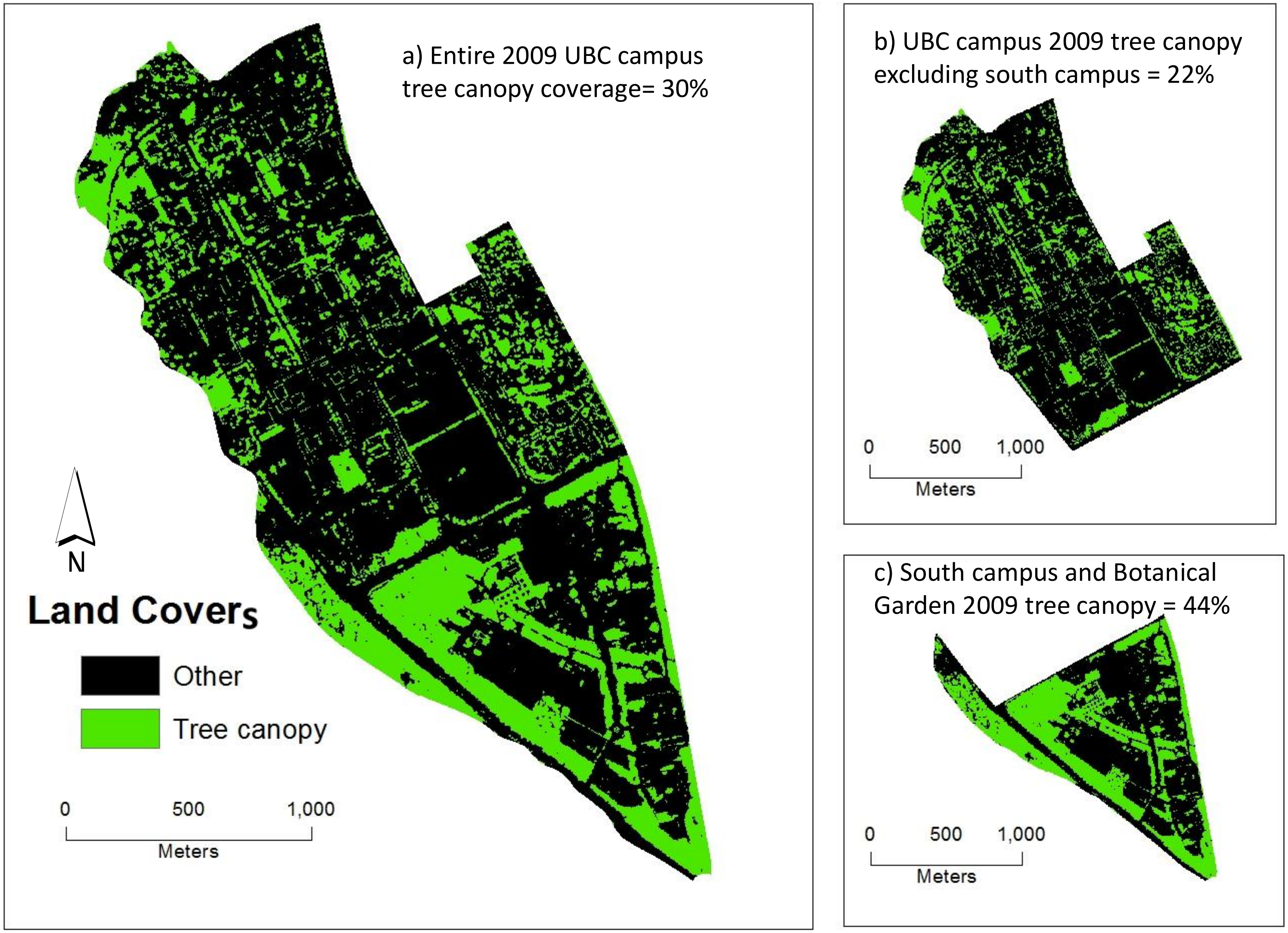


Figure 7 UBC tree canopy cover as estimated from a 2009 LIDAR-derived surface canopy model (Tooke et al. 2009). Panel a shows tree canopy cover for the entire UBC campus (30%) as defined by the UBC legal land boundary (UBC 2011). Panel b shows canopy cover for the "main canopy area" (22%) (excludes south campus and the Botanical Gardens) and Panel c shows canopy cover for the south campus and UBC Botanical Garden area (44%).

South campus

In 2004, the South campus study area had a canopy cover of 26.5 ha representing 57% of the total area of the study site (46.1 ha) (Figure 9). Of this 26.5 ha, 59% (15.6 ha) was coniferous and 41% (10.9 ha) was deciduous (Figure 8). By 2009 tree cover was considerably reduced to 33% (15.1 ha) of the total area. Of the remaining 2009 canopy 56% (8.1 ha) was coniferous and 44% (6.4 ha) was deciduous. Based on site visits in 2012 and corresponding digitization, it appears that the 2009 canopy had further been reduced by 1.5-2 ha, while numerous small street trees had been planted along finished portions of the development. From reviewing the Wesbrook Place Neighborhood Plan (2011) it is evident that a further 1-2 ha of mostly mature conifer class forest will be removed for future development.

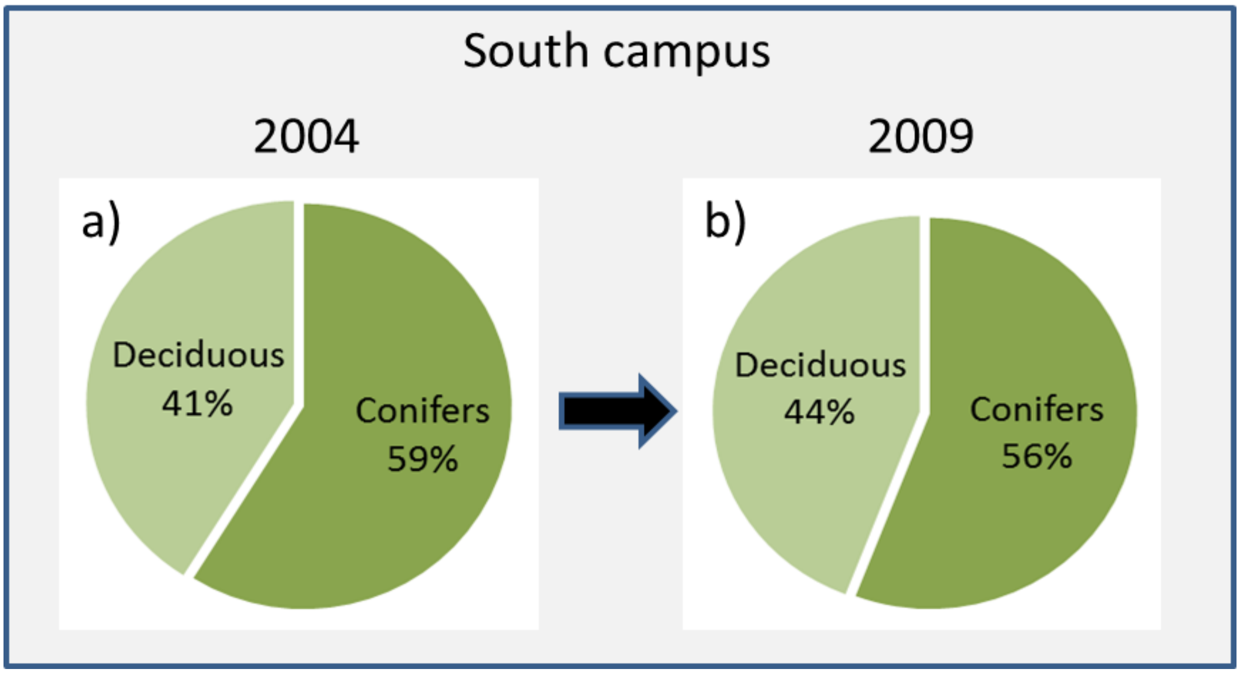


Figure 8 Canopy structure change at the south campus study site from 2004 to 2009. Canopy structure was assessed from Google Earth images and ground observations in 2012. This was then digitized into coniferous and deciduous class canopies. The coniferous class was observed to be mostly mature second-growth forest of Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red-cedar (*Thuja plicata* Donn ex D. Don). The deciduous class appeared to be younger trees of mostly red alder (*Alnus rubra* Bong.), big leaf maple (*Acer macrophyllum* Pursh) and black cottonwood (*Populus balsamifera* subsp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw).

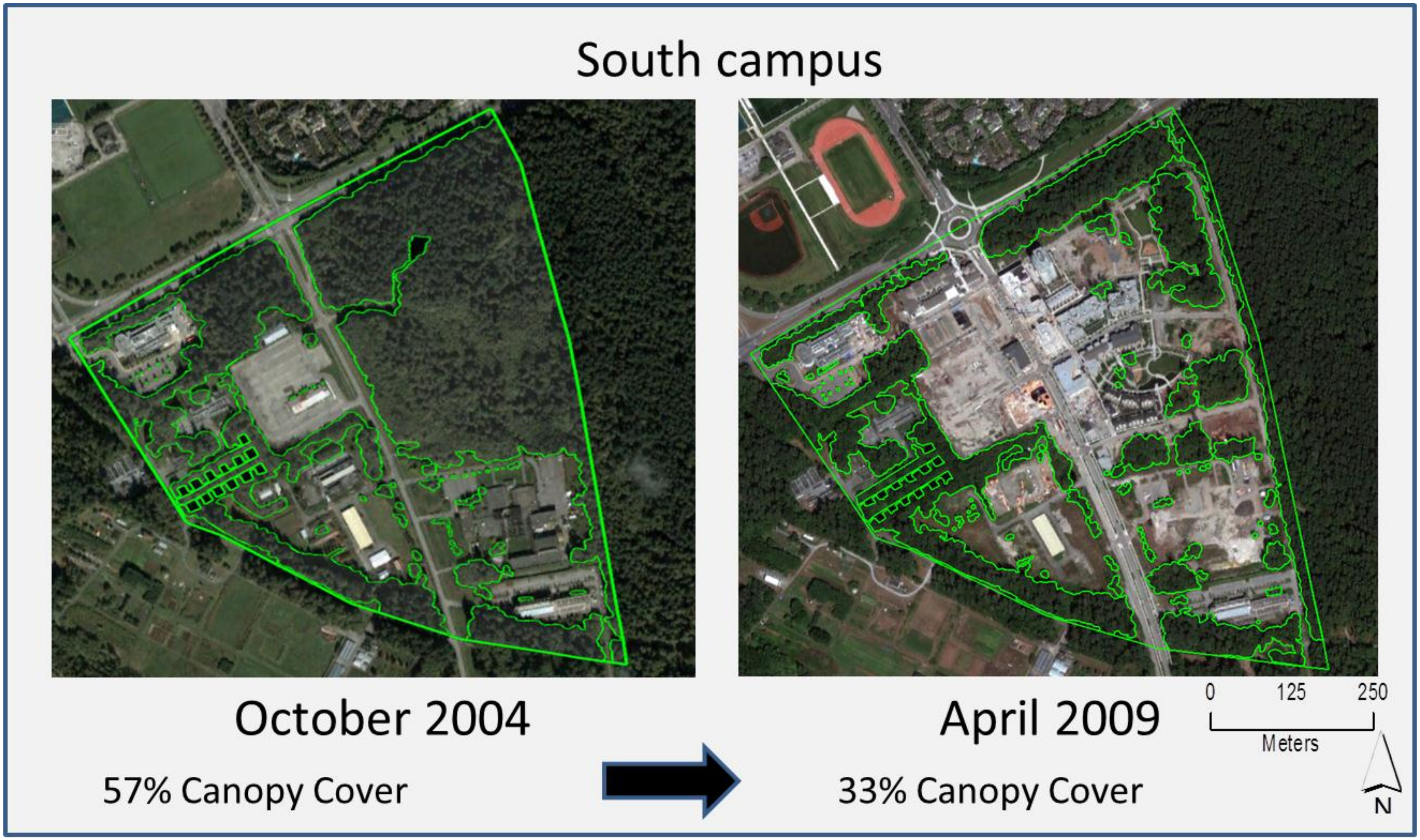


Figure 9 Canopy cover change at the south campus study site from the 2004 baseline to 2009. The canopies were digitized in Google Earth and their area calculates conducted using Arcmap GIS software.

Marine Drive Residences

In 2004, the Marine Drive Residences study site had 127 trees of 25 species (Figure 10). Almost all exceeded 20cm DBH while the 20 largest trees exceeded 60cm DBH (Figure 11). In total, the tree canopy cover was 26% (.70 ha) of the total study area (2.75 ha) (figure 12). As a result of the development that took place during the study period, 36 trees of 40-59 cm DBH, and 17 trees of 60-80 cm DBH were removed. Forty one of the trees >40 cm DBH removed were Lombardy poplars (*Populus nigra* L.). It was observed using Google Earth Imagery and ground observations that by 2009 roughly 90 trees of unknown species had been planted since the 2007 inventory. Supplanting of many large trees with smaller nursery trees resulted in notable in tree size classes. In the 2004 baseline canopy there were only six trees < 20cm DBH, whereas in the 2009 contemporary canopy well over half of the study site`s 150 trees were <20cm DBH (Figure 11). The 2009 contemporary canopy covered 9 % (.25 ha) of the site. This represents a loss of 0.45 ha of tree cover from the 2004 baseline to the 2009 contemporary canopy coverage.

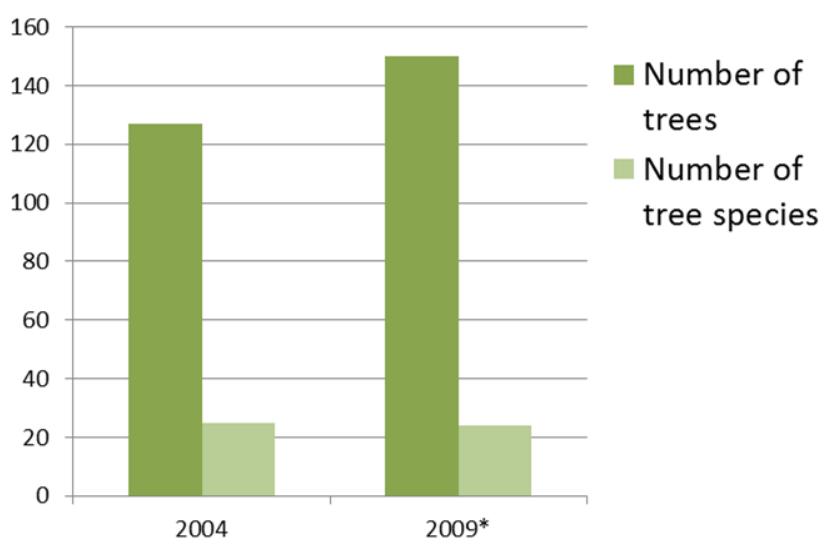


Figure 10 Number of trees and tree species at the Marine Drive Residences study site. The number of trees and species were assessed by updating the 1998 (Hol and Dunster 2007) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) using Google Earth. *The number of trees for 2009 includes an estimate based on Google Earth imagery and ground observations in 2012 that 90 trees were planted since the 2007 inventory. The number of tree species in 2009 is a minimum estimate because it is unknown how many species were introduced.

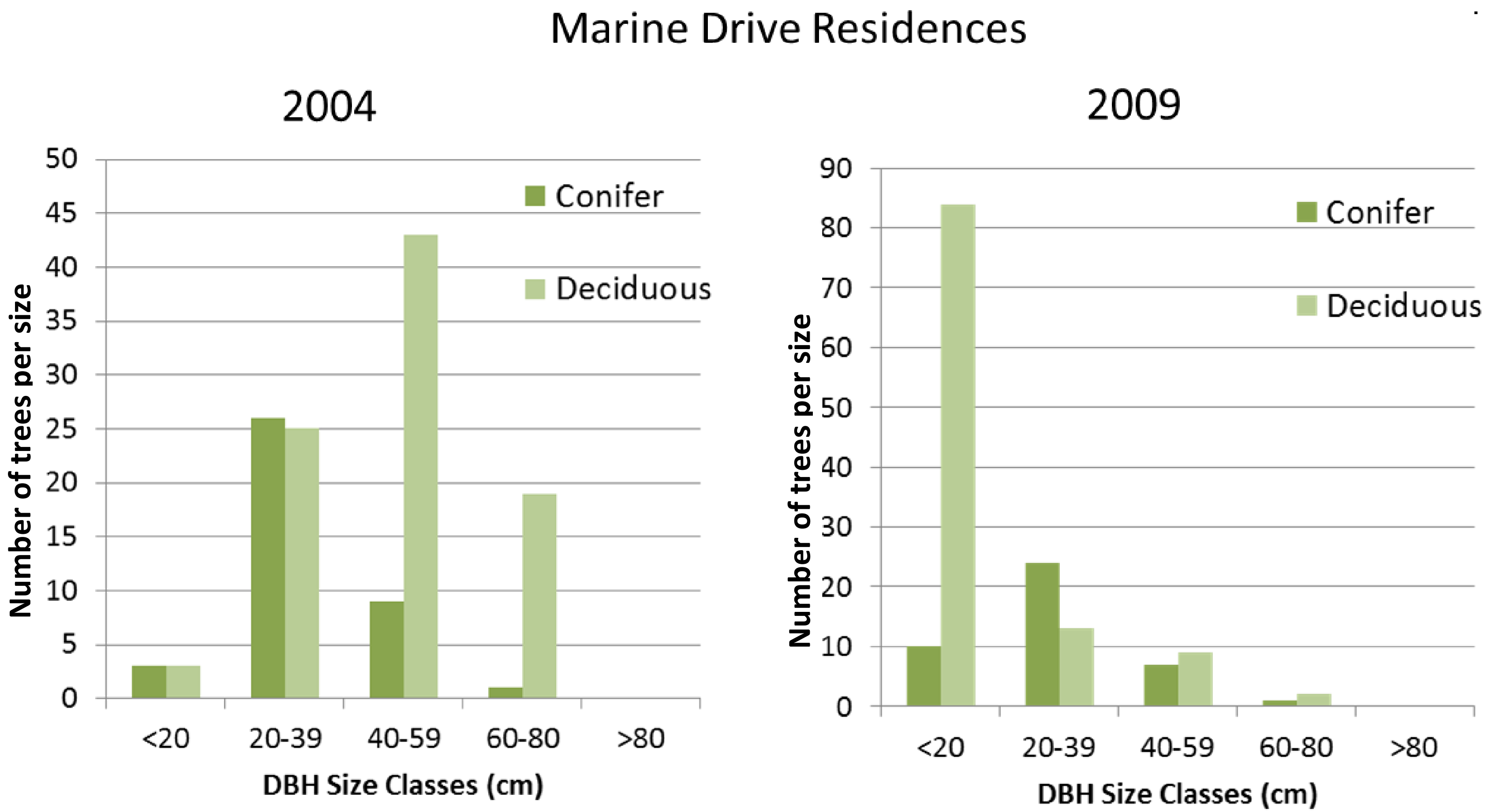


Figure 11 Changes to the size class distribution and conifer to deciduous ratio that occurred due to development of the Marine Drive Residences student housing complex from 2004 to 2009. The number of conifer and deciduous trees in each age class were assessed by updating the 1998 (Hol and Dunster) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) by using Google Earth imagery for reference.

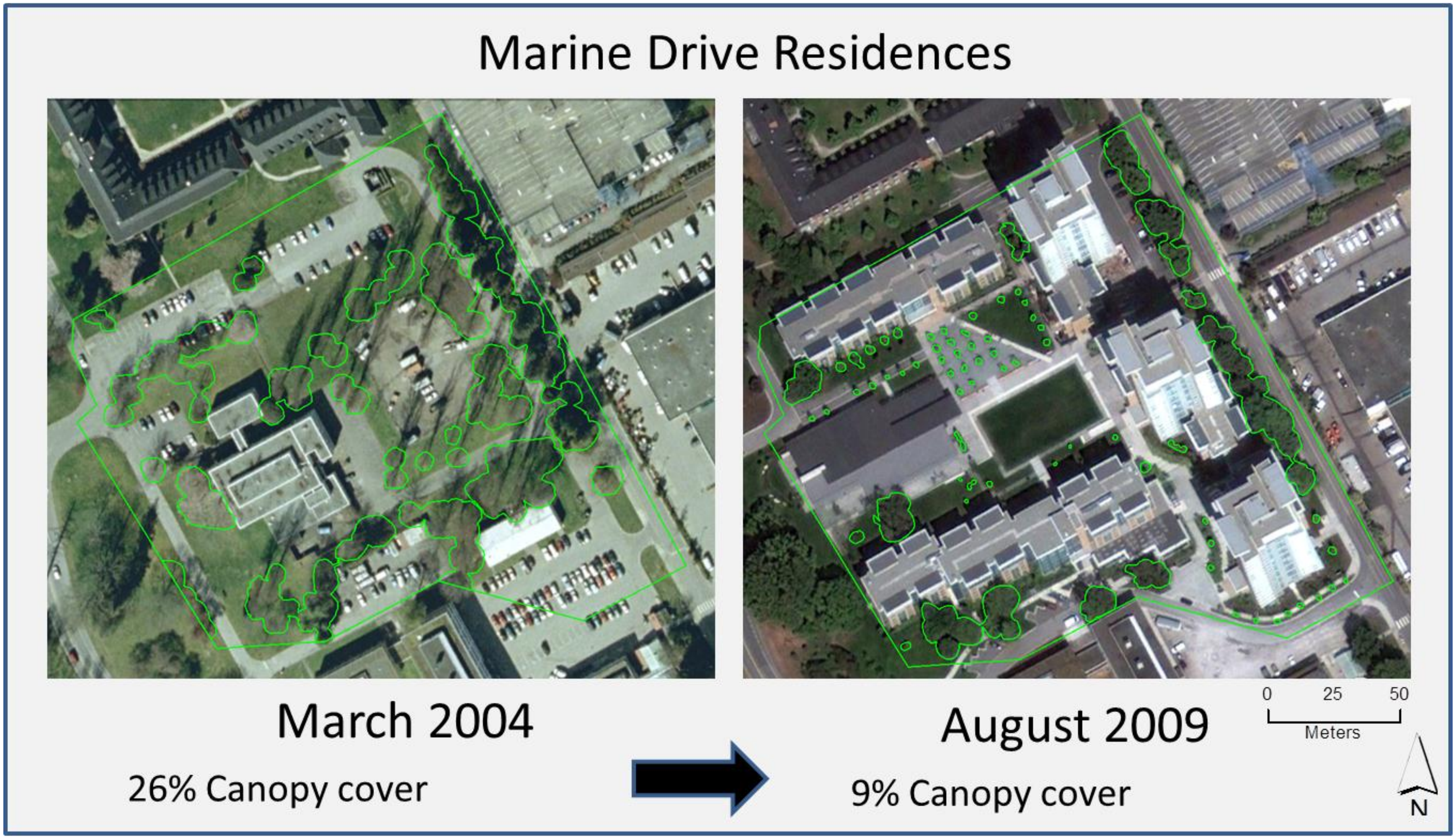


Figure 12 Canopy cover change at the Marine Drive Residences from the 2004 baseline canopy to the 2009 contemporary canopy. Canopies were digitized in Google Earth and their areas were determined using Arcmap GIS software.

Buchanan complex

The 2004 baseline canopy was comprised of 110 trees of 34 species (Figure 13). These trees had a mean DBH of 44.69cm and a fairly even size class distribution (Figure 14). Notable large trees included 12 trees >80cm DBH with seven red oaks (*Alnus rubra* Bong.) along the site's western edge, an 87cm DBH American elm (*Ulmus americanus* L.), a 115cm DBH beech (*Fagus* sp.) and several western red cedars with DBHs up to 118cm. Also of interest, were several memorial and graduating class trees along the site's eastern boundary including three English oaks (*Quercus robar* L.) from classes of the 1930's. In 2004 trees covered 32% (0 .98 ha) of the Buchanan study area (3.08 ha) (Figure 15). By 2009 although a single paper birch (*Betula papyrifera* Marsh.) had been removed the canopy had increased to 35% (1.1 ha) of the site. This small increase appears to be due to growth of established trees.

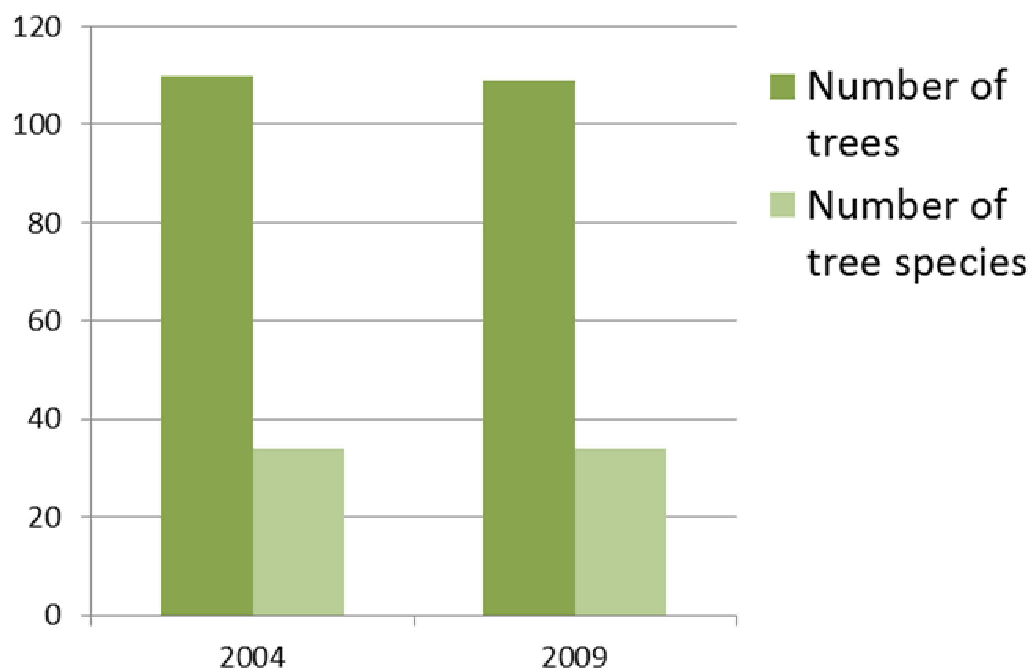


Figure 13 Number of trees and tree species at the Buchanan academic complex study site. The number of trees and tree species were listed in the 1998 (Hol and Dunster 1998) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) and verified to be accurate by comparing with Google Earth imagery.

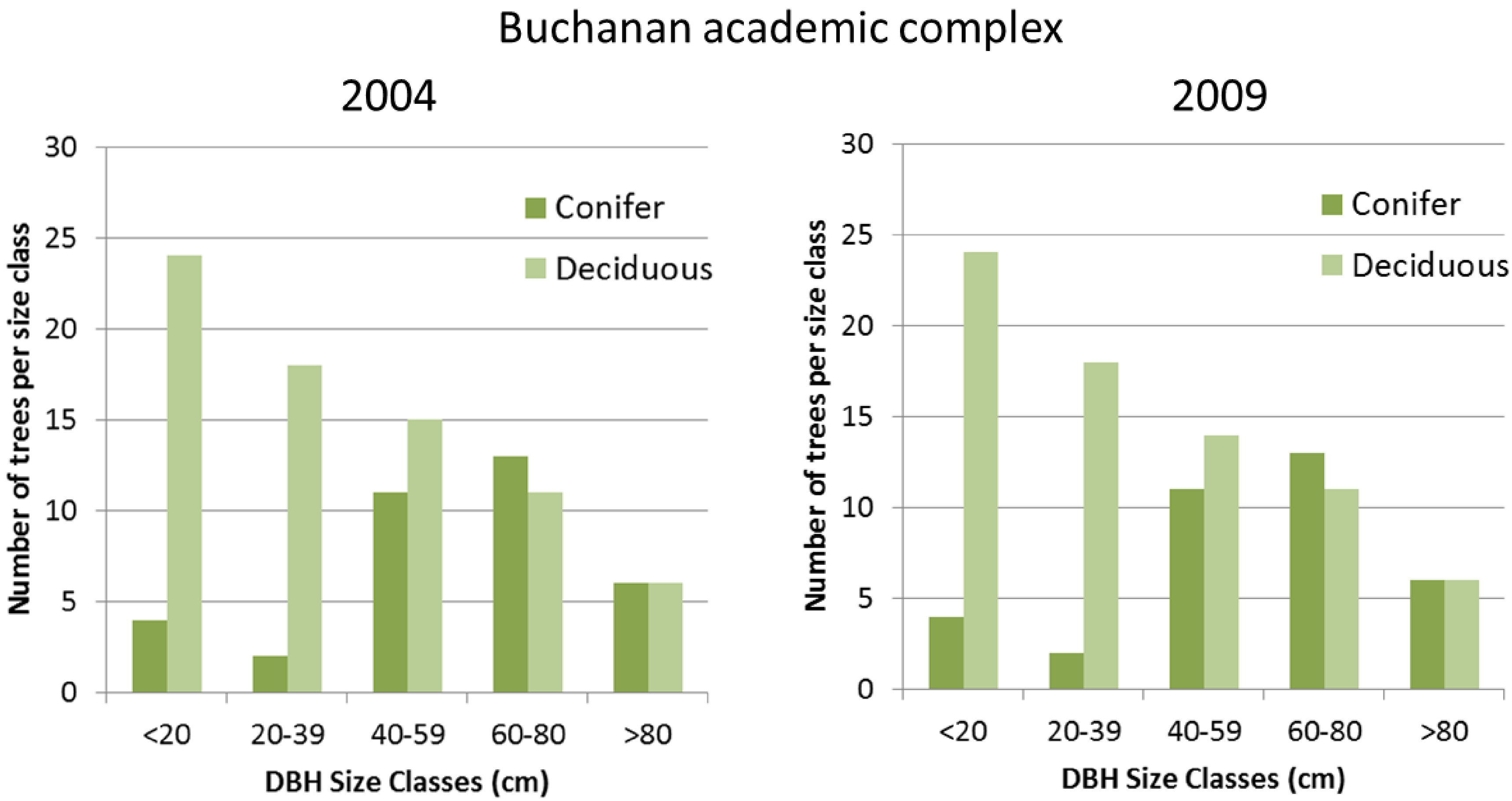


Figure 14 The Buchanan complex study site's tree canopy structure changed little from 2004 to 2009. The number of conifer and deciduous trees in each age class were assessed by updating the 1998 (Hol and Dunster) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) using Google Earth imagery for reference.

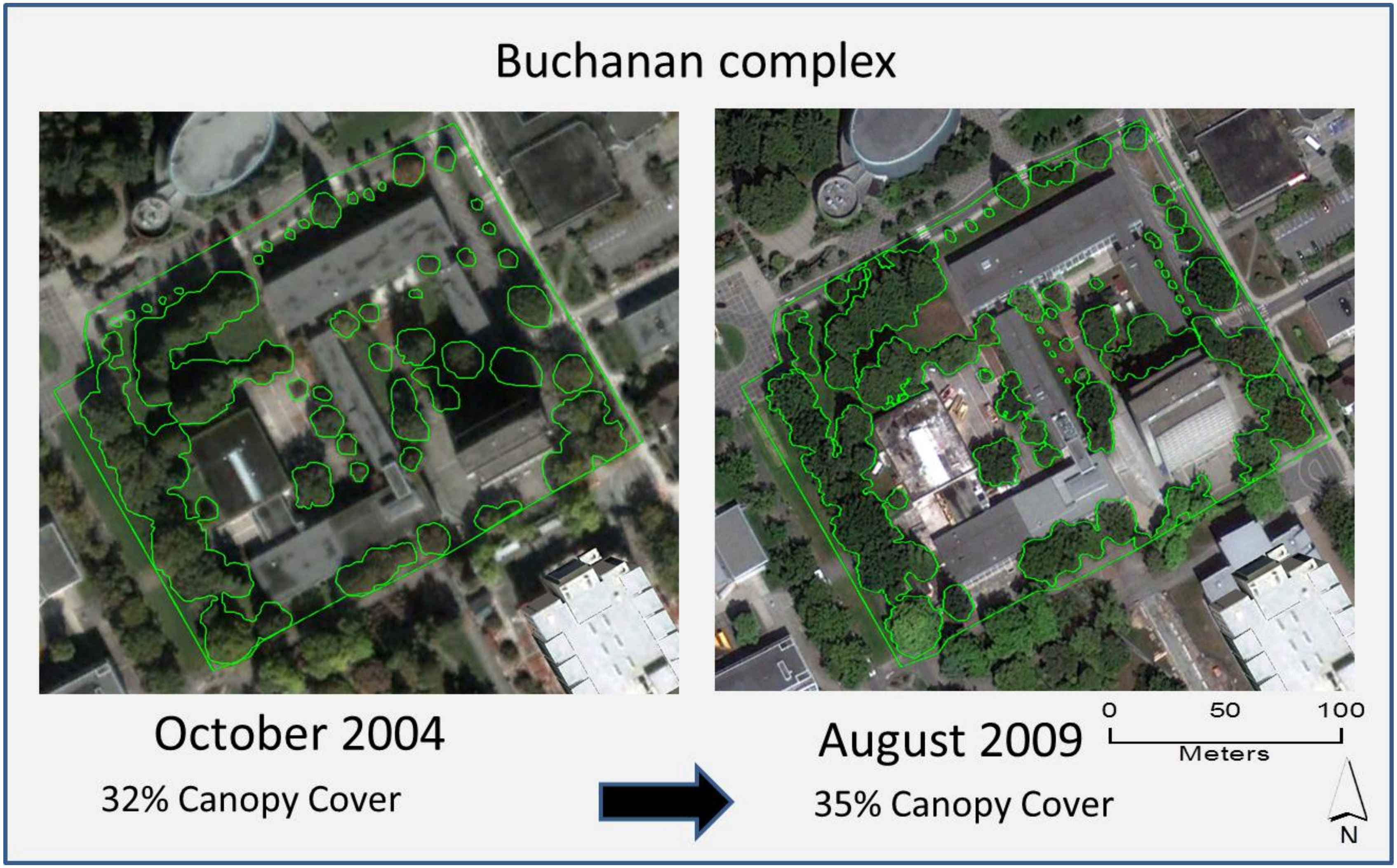


Figure 15 Canopy cover change at Buchanan academic complex study site from the 2004 baseline canopy to the 2009 contemporary canopy. The canopies were digitized in Google Earth and their area calculates conducted using Arcmap GIS software.

Engineering complex

In 2004, this site had 129 trees representing 29 species (Figure 16) averaging 22.5 cm DBH, with a high proportion in the <20 cm, 20-39 cm and 40-59 cm DBH size classes (Figure 17). A few notable exceptions were the nine red oaks exceeding 60 cm DBH along the western boundary. Other notable specimens included a 46cm DBH Japanese cedar (*Cryptomeria japonica* (L.f.) D.Don), two Chinese-firs (*Cunninghamia lanceolata* R. Br.) of 31 cm and 33 cm DBH and an oak tree (*Quercus* sp.) planted by the class of 1984. The 2004 baseline canopy covered 10% (0.55 ha) of the 5.50 ha site (figure 18). No trees had been removed by 2009, while planting of 58 additional trees introduced eight new species to the site and increased canopy cover to 13% (.69 ha) of the site. These new plantings also increased the proportion of the site's trees under 20cm DBH.

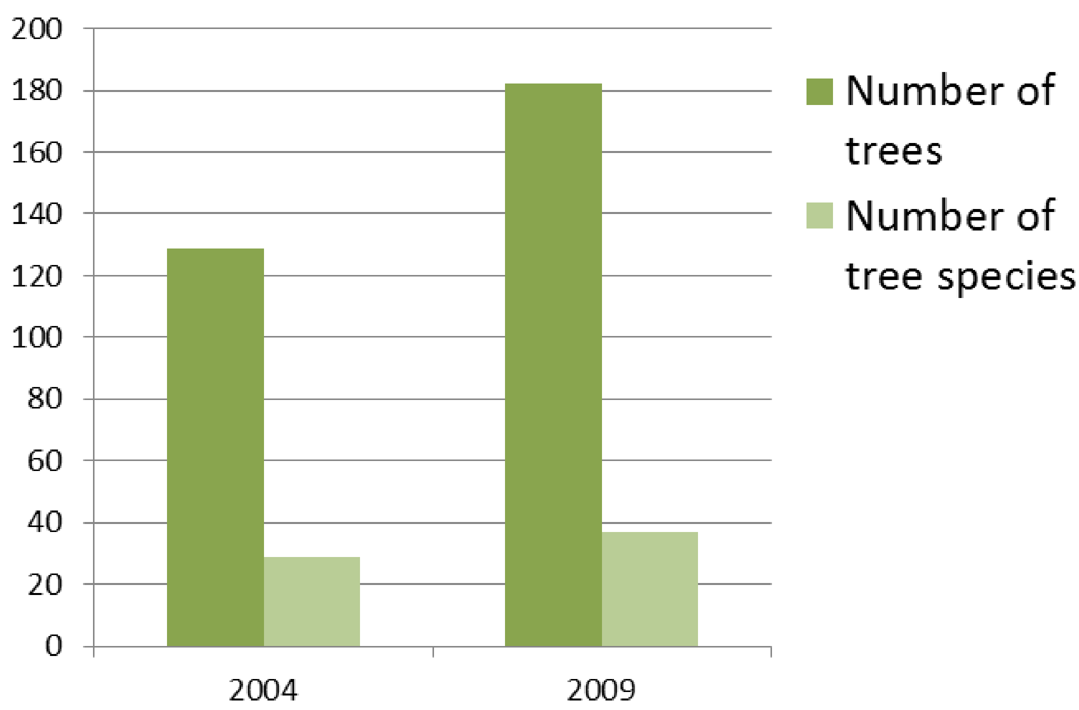


Figure 16 Number of trees and tree species at the Engineering academic complex study site. The number of trees and species were listed in the 1998 (Hol and Dunster) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) and updated to be accurate for each of the 2004 baseline canopy and the 2009 contemporary canopy using Google Earth imagery.

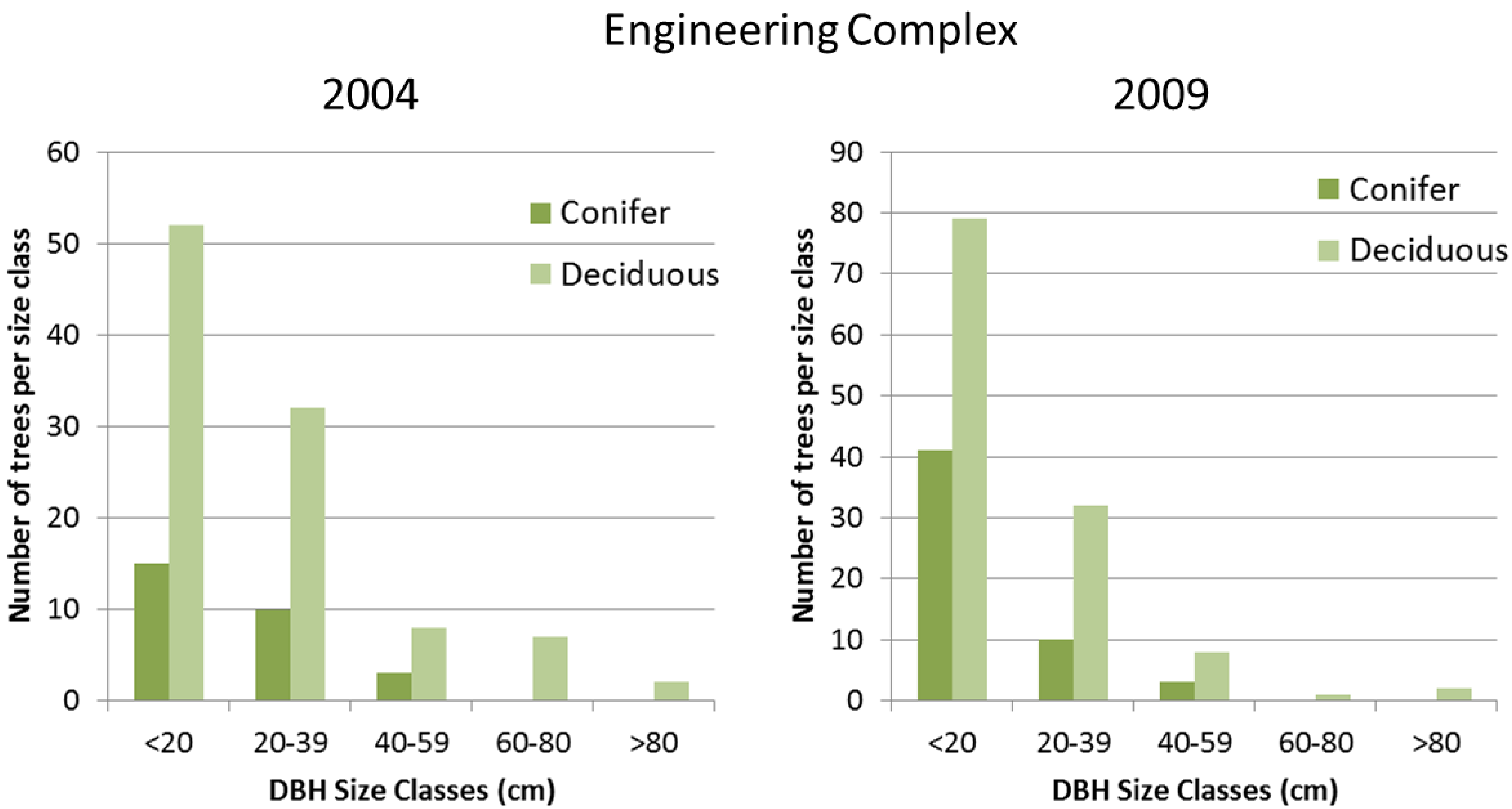


Figure 17 Changes to the size class distribution and conifer to deciduous ratio that occurred from tree planting at the Engineering academic complex study site from 2004 to 2009. The number of conifer and deciduous trees in each age class were assessed by updating the 1998 (Hol and Dunster) and 2007 UBC tree inventories (Beese as adapted from Hol and Dunster 1998) by using Google Earth imagery for reference.

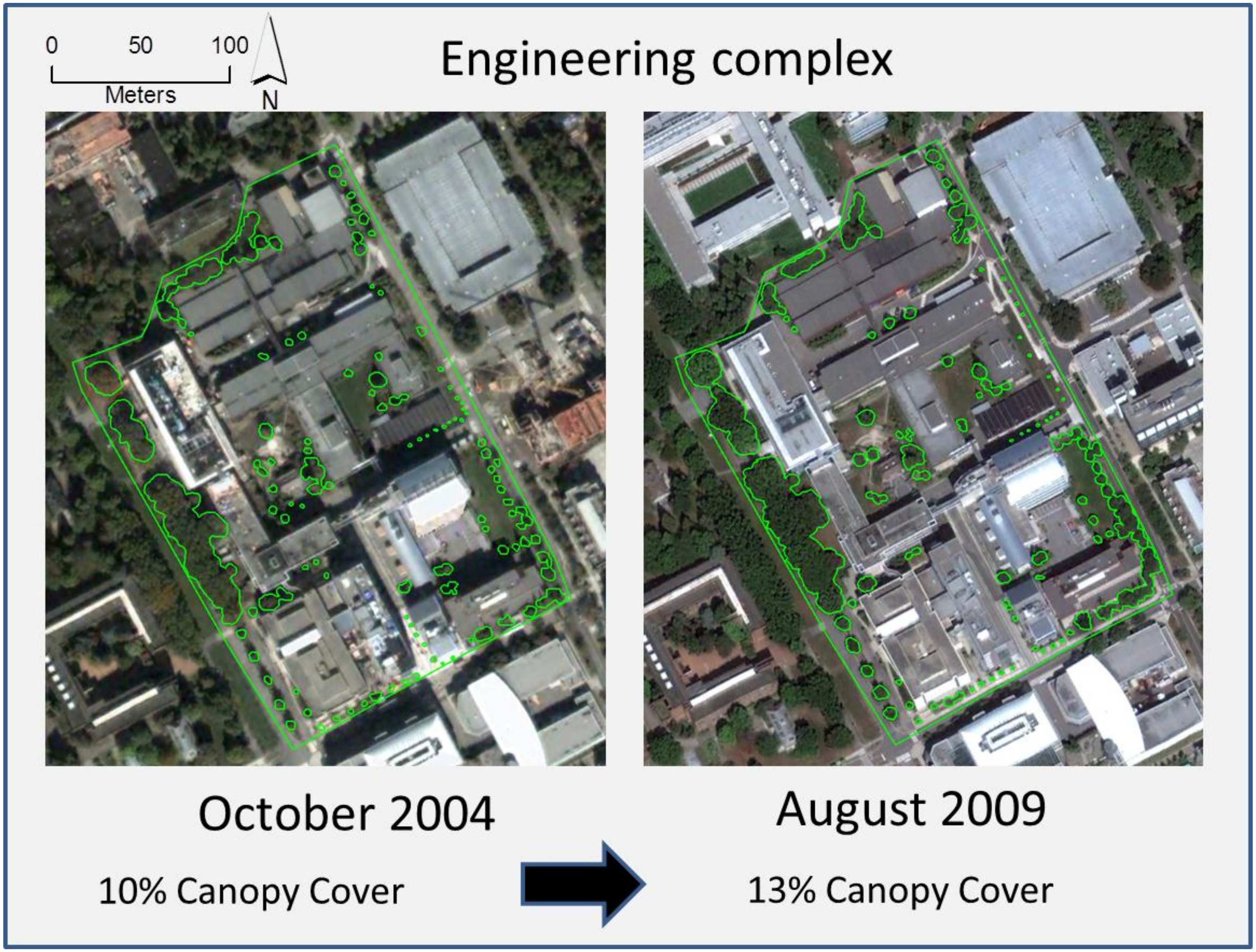


Figure 18 Canopy cover change at the Engineering Complex study site from the 2004 baseline canopy to the 2009 contemporary canopy. The canopies were digitized in Google Earth and their area calculates conducted using Arcmap GIS software.

Summary of findings from geospatial analysis

Comprised of 7300-7500 trees, the "main campus area" tree canopy covered 22% of the total area in 2009, suggesting that tree canopy is a dominant feature of the campus environment. The 2009 campus canopy cover is quite variable between the south (44%) and main campus (22%) and even more so among the study sites examined (33%, 09%, 35%, and 13%).

Results from the geospatial analysis suggest that areas unaffected by development (Engineering and Buchanan) are experiencing very slow increases in canopy cover (ie. 0.6% year $^{-1}$) from natural tree growth as well as tree planting at the engineering complex. Meanwhile, both sites where development occurred during the study period (south campus and Marine Drive) had substantial decreases in their urban tree canopies exceeding 17% over the 5 year period. Both areas affected by development are also experiencing a simplification of the tree canopy as large trees are supplanted with smaller ones.

Discussion

Campus-wide canopy coverage (30%) is greater than the average urban canopy cover of US cities (27%) (Nowak et al. 1996), however, canopy cover in the main campus area (22%) is less than the average US city while in the south campus (44%) it is much greater. It should be noted that canopy cover can decrease relatively quickly but is slow to recover. For example, Seattle's urban tree canopy coverage declined from 40% to 18% over 35 years, prompting the city to establish a 30-year goal to restore the canopy to 30% cover (City of Seattle 2007).

This study has attempted to capture a snapshot of UBC tree canopy change (2004-2009), however, the results cannot necessarily be extrapolated to the rest of campus. The broader goal of this study was to better understand the benefits provided by UBC's urban tree canopy and determine whether these benefits are likely being managed to support the university's sustainability vision. While noting that landscape planning in UBC is a complex process with many regulations, goals and values to consider, next I discuss the implications of the results for campus tree canopy management.

What implications may changes to the urban tree canopy have for the university and community?

It is expected that changes to UBC's urban tree canopy will affect the quality and quantity of ecosystem services provided. Before discussing the potential implications of change to the UBC campus it is useful to compare how the tree canopy at each study site likely contributes to provisioning of ecosystem services. With guidance from the literature review, flower petal diagrams have been created to help communicate relative differences in baseline (2004) ecosystem services at each site (Figure 19). Flower petal diagrams have also been created to show that both the south campus and Marine Drive Residences developments have likely resulted in substantial declines in the ecosystem services that their canopies provide (Figures 20 and 21).

Contrasting these declines the provisioning of ecosystem services at both the Buchanan and Engineering study sites have likely increased slightly due to natural growth of existing trees (size and canopy coverage) as well as tree planting at the Engineering complex study site. However, these incremental increases are likely insufficient to compensate for the substantial losses at the other two study sites examined.

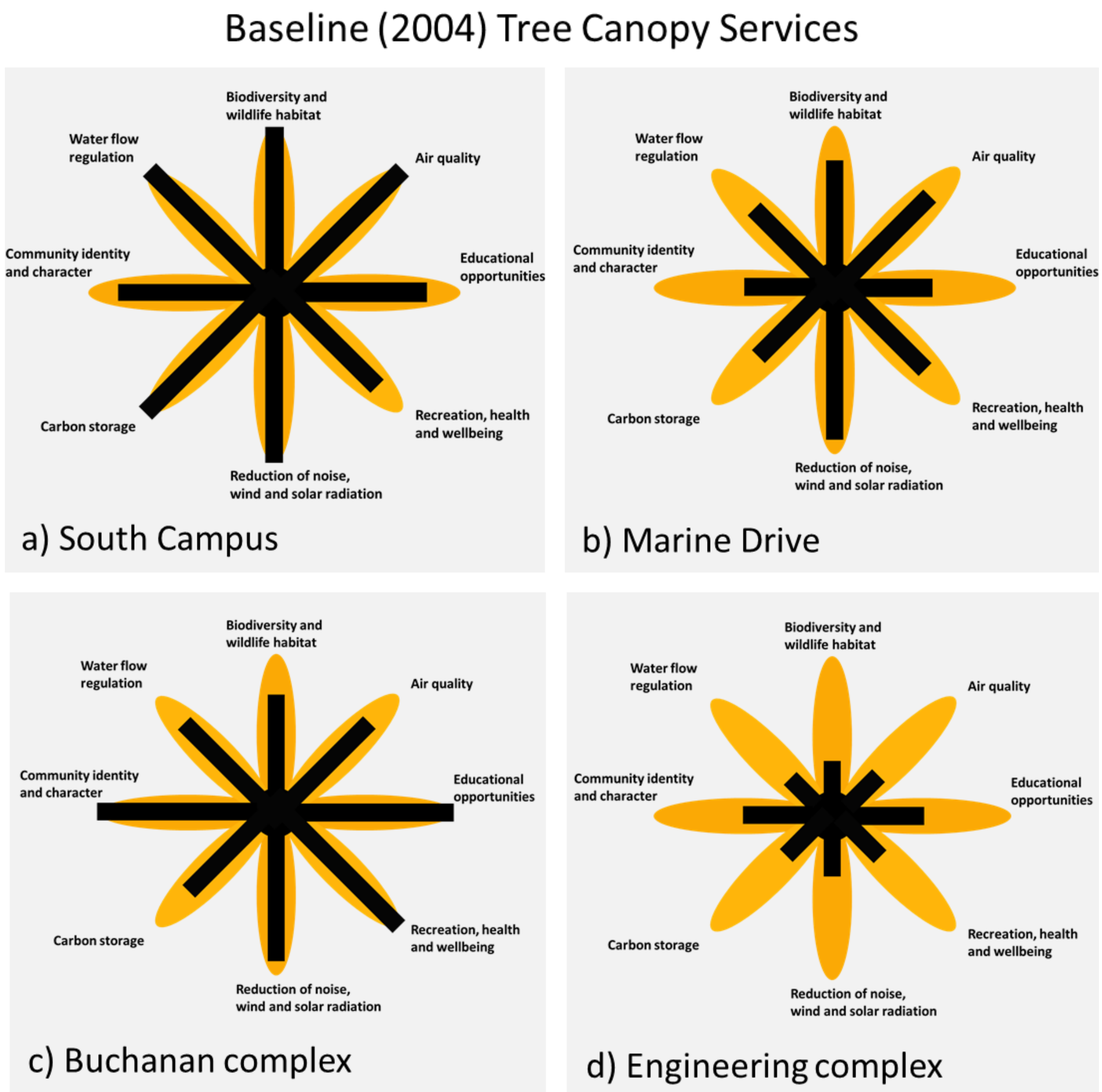


Figure 19 Approximations of relative magnitude of ecosystem services provided by trees and canopy cover at campus study sites examined in this work. These are based on literature reviews and geospatial analysis of canopy coverage, tree size distribution, tree placement and whether the trees have other cultural significance. (Panel A) South campus ranks the highest for many services due to canopy coverage (58%) and the site's large trees. (Panel B) Marine Drive Residences study site had 52 trees 40-59cm and 20 trees >60 cm DBH and a canopy cover of 26%, which exceeded the main campus area's average of 22%. However, almost all of the largest trees were a single species: Lombardy poplars, which are short lived (Farrar 1995) and among the worst emitters of VOCs (Nowak et al. 2002). (Panel C) Buchanan academic complex study site likely provides an abundance of all services reviewed due a to canopy coverage of 32%, many large trees (>80 cm DBH) of a variety of species and enhancement of cultural services due to the presence of many memorial and class trees. Additionally, many trees appeared to be well placed to intercept rain for commuters, reduce noise and wind passing through the main courtyard and add character to many parts of the complex including the main courtyard, which is designated as a heritage landscape area (Vancouver Campus plan 2010b). (Panel D) The engineering complex study site's canopy cover was only 10% and the great majority of trees were small, thus, poorly providing many ecosystem services relative to other sites.

Likely Declines in Tree Canopy Services from Development (2004-2009)

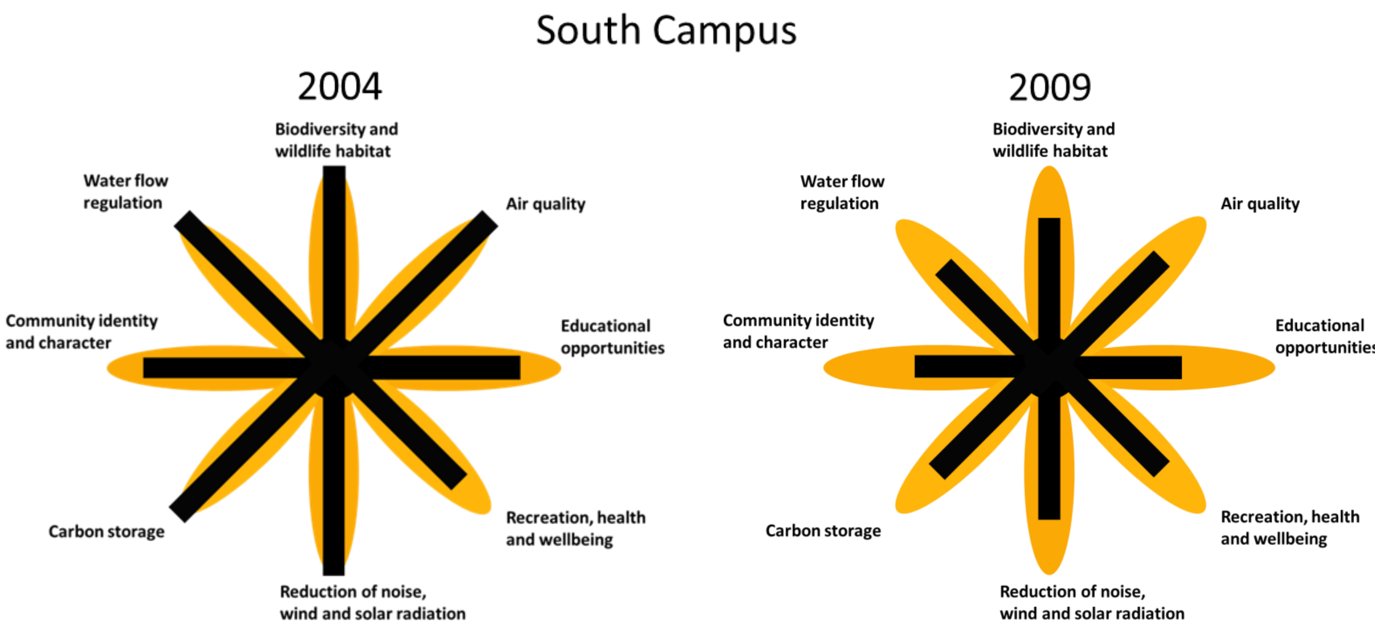


Figure 20 Likely declines in in tree and canopy-based ecosystem services at the south campus study site from 2004 to 2009. Declines are due to the substantial reduction in canopy cover from 58% in 2004 to 33% in 2009.

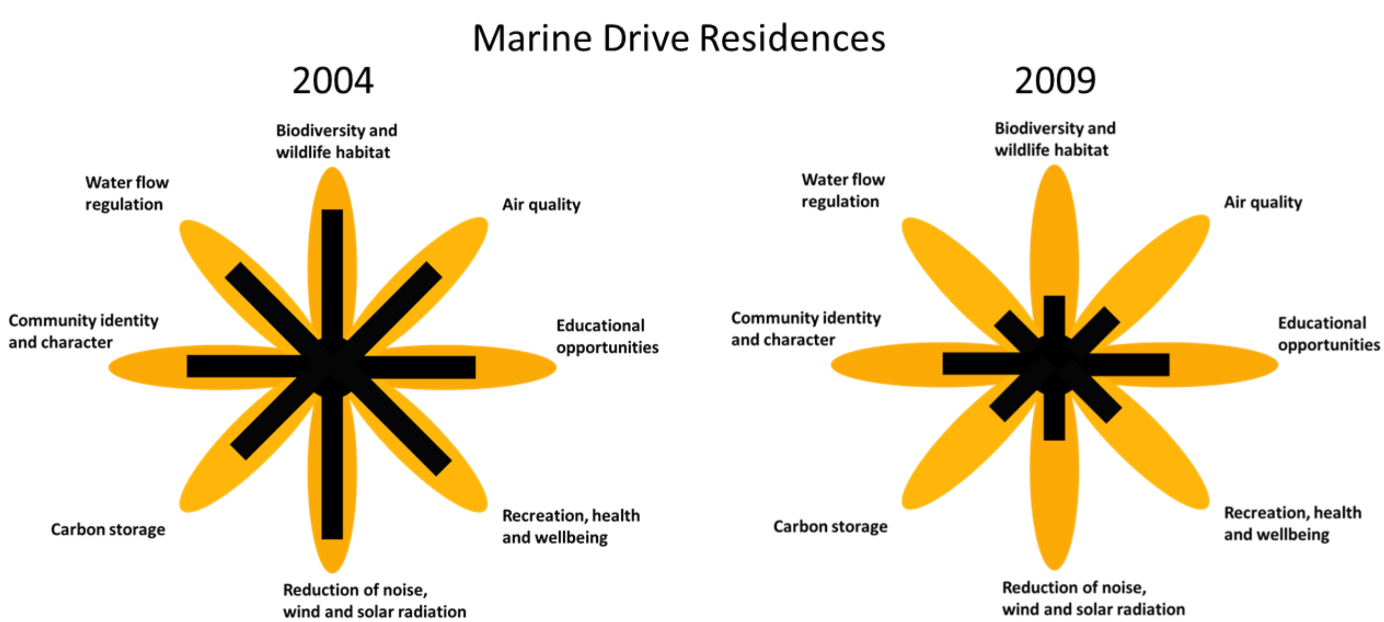


Figure 21 Likely declines in tree and canopy-based ecosystem services provided at the Marine Drive Residences study site from 2004 to 2009. Declines are due to the reduction in canopy cover from 26% in 2004 to 9% in 2009. Coinciding with the decline in canopy cover was a significant change to the tree size distribution: 17 trees (60-80 cm DBH) and 36 trees (40-59 cm DBH) were removed and ≈90 small nursery trees (< 20 cm DBH) were planted.

Implications of canopy change for the university and community

Reductions in the provisioning of ecosystem services will have implications for the functionality of the campus, the wellbeing of community members, and for UBC's goals and commitment to sustainability. Loss of some services could have immediate fiscal implications as well as implications for externalized costs. UBC is currently paying $25 tonne^{-1} in carbon offsets to the Pacific Carbon Trust (Pacific Carbon trust 2012). Wilson's (2010) estimates are that 423 tonnes of carbon ha^{-1} are stored by 51-100 year-old local forest. As an approximation, the 7.6 ha of mature coniferous forest removed from the south campus study site from 2004-2009 potentially stored 3195 tonnes of carbon, which would be valued at nearly $80,000 worth of carbon storage. It is conceivable that the entire campus canopy provides several hundred thousand dollars' worth of carbon storage. Additionally, the fiscal implications of water regulation ecosystem services provided by the urban tree canopy are evident when examining UBC planning requirements to install infrastructure for moderating urban water flow (e.g., Wesbrook Village Neighborhood Plan 2011).

Declines in canopy cultural services such as educational opportunities, health and well-being and character and community identity, also carry great implications for UBC as evidenced in several recent surveys. A 2009 UBC survey showed that health issues impacted the academic performance of students more than any other factor. Of those surveyed, the grades of almost 40% were affected by stress, 26% by cold and flu and 24% by anxiety (Mirwaldt and Washburn 2009). Similarly, stress was cited by staff and faculty members as one of the three top reasons they may leave UBC within the next three years (Ipsos Reid 2011). UBC's goals of promoting campus as a healthy, unique and internationally-renowned place capable of attracting high-quality staff, faculty and students may be affected by declines in cultural canopy services. Similarly, the losses of old campus trees may erode linkages alumni have to the university and can stimulate strong emotions such as grief and anger (Schroeder 2002) for those with strong appreciations for them. UBC's location surrounded by Pacific Spirit Provincial Park on all sides means that the loss of the supporting ecosystem service of biodiversity and wildlife habitat may have implications for UBC's goal of fostering local and global citizenship (Place and Promise 2009).

UBC tree management policy and ecosystem services

Several planning documents demonstrate that UBC recognizes its trees as an integral part of the campus environment. However, the campus does not have any tree management planning document, nor has it conducted the research required to fully understand the benefit of its urban trees. Currently, UBC's limited tree management guidelines may be insufficient to ensure the campus canopy's ecosystem services are sustained. Some UBC landscape design guidelines may unintentionally reduce some services. For example, UBC appears to be encouraging the simplification of canopy structure to support its goals of creating a coherent campus-wide aesthetic and maintaining the university's historic setting of being in a "clearing in a forest" (Vancouver Campus Plan 2010c). While these policies have been put forward with many of UBC's values and goals in mind, they have been made with an incomplete understanding of their implications.

An incomplete understanding of the benefits provided by campus trees may also be behind UBC's tree replacement policy, which applies to some neighborhoods on campus. This requires that any "viable mature tree" over 15 cm DBH that is removed must be replaced with another tree planted elsewhere on campus. The intention of this policy appears to be to compensate for the loss of mature trees; however, the benefits provided by young nursery trees are not identical to mature trees. Supplanting large established trees with new ones entails a long period of decreased ecosystem services. For example, in the Engineering site very few trees have grown to be > 60 cm DBH even though parts of the complex have been undisturbed for decades. In fact, the only 9 that exceed 60 cm DBH are the historic red oaks found in the continuous line of red oaks along the Mainmall Greenway. The slow growth of trees, together with their unique individual forms and community significance, suggest older established trees should be retained whenever possible, even at considerable inconvenience or cost (Figure 22). This would likely require a long term management plan that lists heritage trees and guides meaningful compensation if they must be removed. Otherwise, the significant expansions that UBC has planned in the coming 15 years may degrade this essential resource.

Figure 22 Ponderosa pines, native to the interior of BC, rarely grow to such a size as this one on the coast. Nonetheless, this regionally significant specimen is at risk of inadvertent harm from construction of the Ponderosa Hub Student Development in 2013. It is a legacy of the former UBC arboretum, which has been reduced over the years from building infill (Straley 1992).

Recommendations

Proper protection and enhancement of campus trees and canopy could help UBC fulfill its commitment to demonstrating leadership in sustainability and help foster both local and global citizenship. Planting of indigenous plant gardens and using infrastructure and interpretation to facilitate outdoor learning opportunities is occurring (Vancouver Campus Plan 2010a, 2010c) and could result in increased ecosystem services. Further possibilities for demonstrating leadership by enhancing UBC's urban tree ecosystem services are explained next.

UBC's location in the middle of Pacific Spirit Park, a valued conservation area, is an added incentive in demonstrating stewardship of its landscape. Reflecting the harm being caused by invasive plants to Metro Vancouver Parks (Page 2006), UBC has banned the planting of plants listed by the Greater Vancouver Invasive Plant Council (Vancouver Campus Plan 2010c). In addition, proactive removal of fruit-bearing invasive plants from the campus's grounds, thus limiting their constant dispersal of seed, may be a logical, and cost-effective strategy to permit the success of efforts to contain the spread of invasive plants. For example, of 7300-7500 trees in the main campus area, only 60 are planted Irish holly trees (Figure 23), and these are all quite small (<20cm DBH).

Figure 23 An abundance of Irish holly (*Ilex aquifolium* L.) can be found in Pacific Spirit Park as well as in UBC's urban forests (seen here). Numerous other invasive species were observed on a site visits to several UBC urban forests in May 2012.

Removing the planted female fruit bearing trees would likely be an acceptable loss if community members were notified of the purpose and this would set an example for other Lower Mainland municipalities to follow.

Figure 24 Urban forests of UBC. a)Nitobe, b)Totem Park, c) Fairview, d)Rhododendron Wood

Enhancement of the urban canopy for local wildlife could be supported by implementing suggestions of Milles et al. (2003) for appropriate landscape and habitat features across campus. Habitat could also likely be improved in the small urban forests on campus (figure 24). The removal of invasive species in these stands is one logical start but within these stands exists considerable potential. A novel approach to managing some of these stands, would be to encourage old-growth forest attributes such as multi-layered canopies, coarse woody debris and leaving safe portions of dead standing trees with some interior rot (Figure 25) (Kimmins 2003). Currently, UBC's urban forests, with the exception of the Nitobe Gardens urban forest have simple second-growth forest structure and may benefit from habitat improvement programs.

Figure 25 A wildlife tree retained in the Nitobe Gardens urban forest. Features like this mimic old-growth forest structure and offer habitat for several native species. They can also be visually appealing and offer educational opportunities.

Increased public engagement in UBC's trees will likely spur the cultural ecosystem services they offer and support many of UBC goals towards sustainability. Educational canopy services could be enhanced by planting and maintaining interesting horticultural specimens nearby the faculties that study them. Interpretive tree walks might spread canopy educational benefits to others and help manifest UBC goal of creating a living laboratory (Place and Promise 2009). Such tours could go beyond the labeling of tree species and strive to enhance understandings of nature, sustainability and human relationship with the forest. Appropriate themes might describe traditional aboriginal forest use, explain ecosystem services or account UBC's natural history (Figure 25). Such themes may be explained more efficiently using technology, which can be conveniently loaded onto smart phones or laptops.

Figure 25 The Nitobe Gardens urban forest contains large western-red cedar stumps, such as this one, that are legacies of the old-growth forests that once covered the UBC campus area.

Figure 26 The Nitobe Gardens urban forest is in a culturally-rich setting surrounded by the Asian Center, the C.K. Choi building (seen here), the Nitobe Gardens and the Museum of Anthropology.

Another innovative possibility that aligns closely with UBC's commitments to Aboriginal Engagement (Place and Promise 2009) would entail access to the harvesting of non-timber forest product within these small urban forests for Musqueam First Nations. Activities such as the stripping of cedar bark do not only provide a sacred traditional forest product for the Musqueam but also result in a rich educational opportunity for First Nations and non-First Nations students. Furthermore, the culturally modified trees that result could stand for centuries as legacies of recognition, respect and reconciliation. While this could be considered in any of UBC's urban forests, an excellent location may be the Nitobe Gardens urban forest (Figure 26). This forest is marked by remnant stumps of massive western red-cedars and is already a culturally, perhaps spiritually, significant site. Enhancing these values will make the site increasingly ideal for an interpretive walk and to showcase UBC's unique history and west coast setting.

Urban tree management could also help achieve the campus's commitments to fostering community and alumni engagement (Place and promise 2010). Class trees already support this but other options include community tree care programs, which involve shared responsibilities and participation in planting. Another fundamental way to support participation is by expanding the research currently going into the campus's trees. Considerable opportunities exist for faculty members as well as students to engage.

These recommendations for enhancing benefits provided by the UBC's urban tree canopy (Figure 27) are critical to consider as the campus's expansion plans will undoubtedly lead to

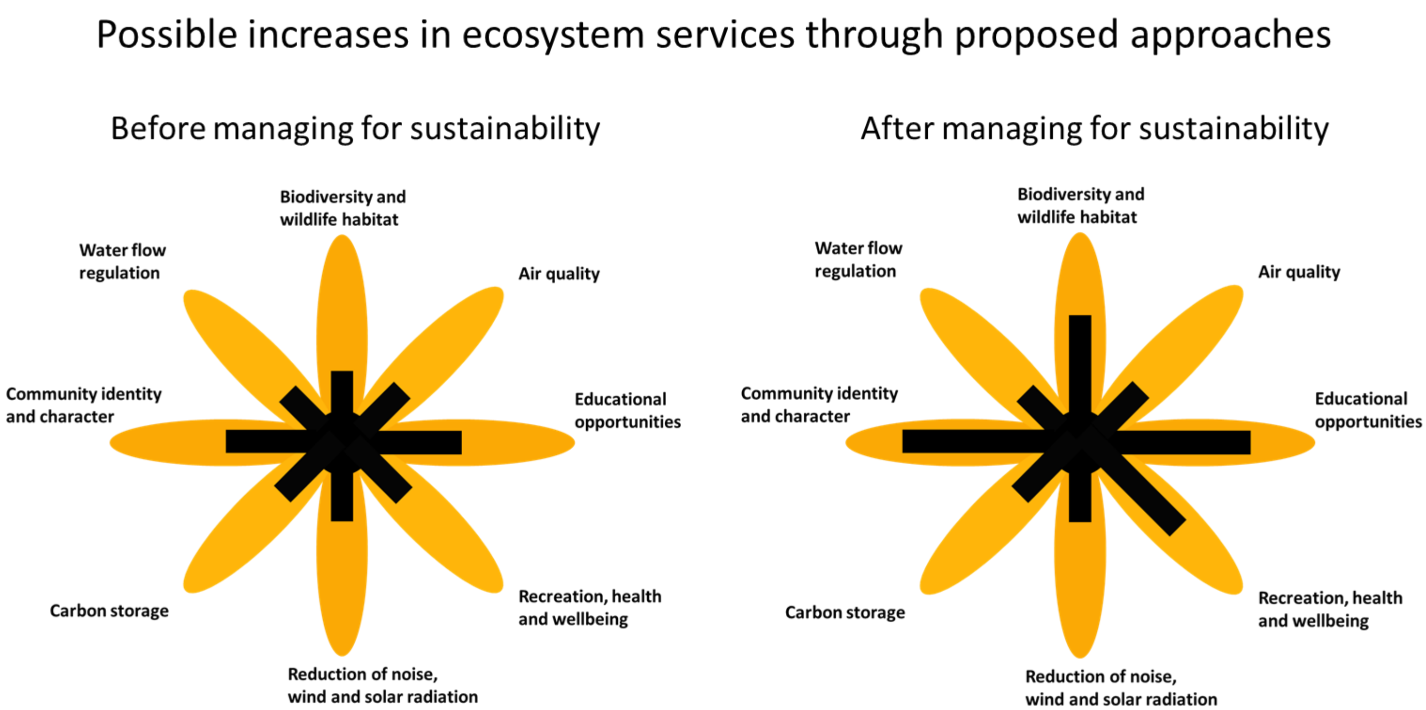


Figure 27 Where the black bars represents the magnitude of ecosystem services being produced at a given area of UBC tree canopy, this shows that some urban tree canopy ecosystem services can be increased through innovative management practices suggested in this report, thus potentially offsetting declines in canopy services experienced elsewhere on campus due to development. These approaches also carry the added benefit of supporting UBC's commitments towards sustainability.

further declines in the UBC tree canopy. In some cases this loss of trees will be met with new infrastructure that supports UBC's commitment to sustainability, such as energy efficient student housing. An important complement to these efforts towards building a sustainable campus includes a deeper understanding of the social, ecological, economic, global and local implications of campus tree canopy ecosystem services. An option for doing this, pursued my many North American cities, is a detailed canopy study that quantifies the value of canopy services (e.g., Nowak et al 2009, Burkhardt 2009). This study concludes with a final recommendation that the university establishes a long-term campus tree management plan (e.g., City of Seattle 2007) that sets feasible canopy cover objectives and a unifying vision for campus trees that supports the university's commitment to sustainability. Many cities have derived their own canopy cover goals from research done by American Forests, a leading urban forest management group, which suggests that 40% cover is an ideal and often feasible goal for city-wide canopy cover in this part of North America (City of Seattle 2007).

Conclusion

UBC's urban tree canopy provides a broad suite of ecosystem services that are intrinsic to campus functionality, the community's well-being and serve many of the university's goals and values. This study has coupled the results from a geospatial analysis of historical imagery to information from the literature to demonstrate that development may be leading to substantial declines in canopy services at UBC. As UBC infrastructure grows and the campus becomes increasingly dense, declines in the urban canopy resource will persist for many decades. Demonstrating world-class leadership in sustainability requires understanding the losses and benefits associated with future development plans. As the university pursues its goals of constructing a more environmentally friendly and sustainable campus it should not be perceived that the urban trees are an impediment. Rather, they should be seen as an already established form of infrastructure, a solid foundation on which authentic sustainability can be built.

Acknowledgements

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