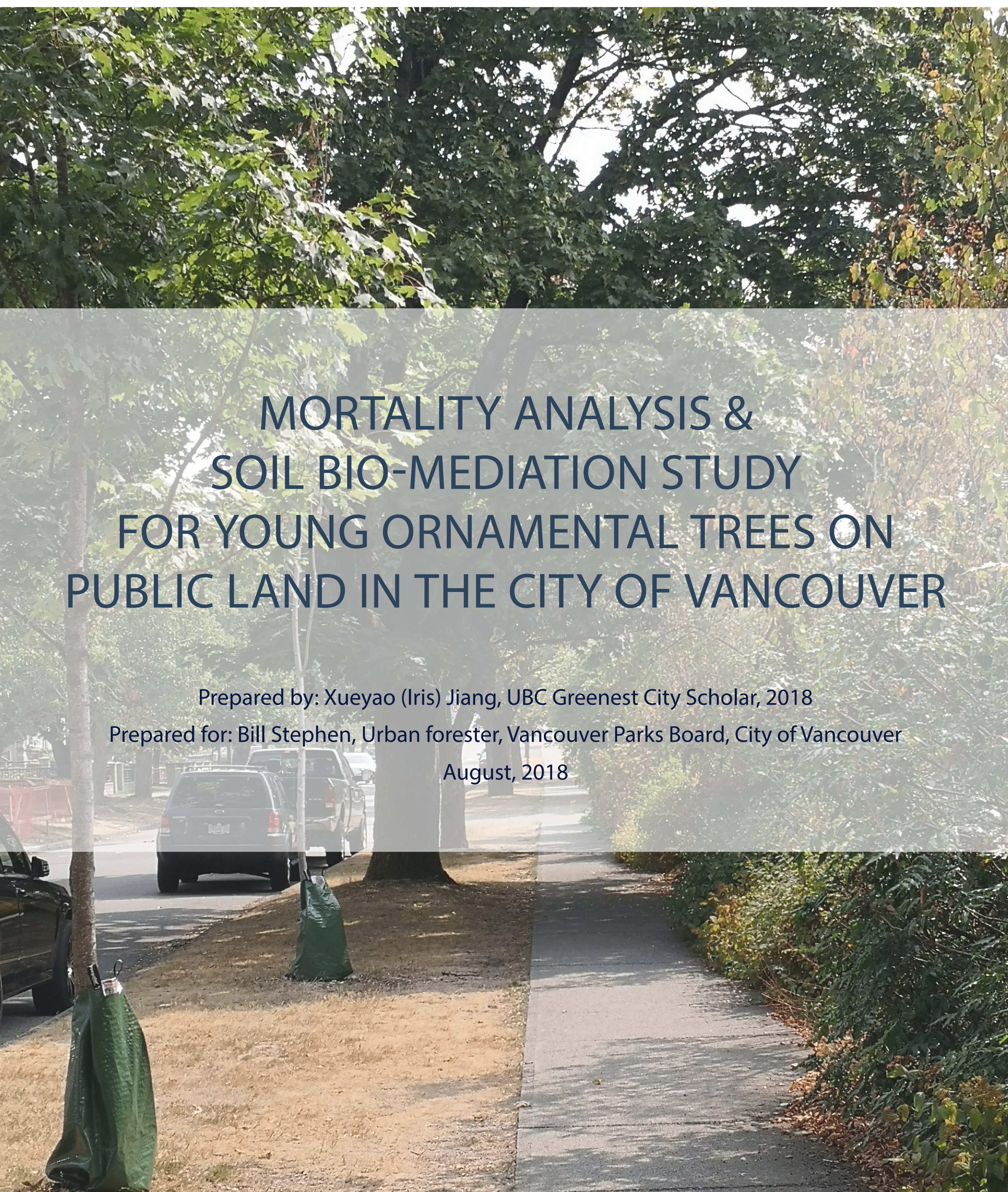

MORTALITY ANALYSIS & SOIL BIO-MEDIATION STUDY FOR YOUNG ORNAMENTAL TREES ON PUBLIC LAND IN THE CITY OF VANCOUVER

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CITY OF VANCOUVER | GREENEST CITY | THE UNIVERSITY OF BRITISH COLUMBIA sustainability

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This GCS project was conducted under the mentorship of City staff. The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the City of Vancouver or The University of British Columbia.

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Summary

Vancouver's Greenest City Action Plan

In January 2011, Vancouver City Council set 14 targets under the Greenest City 2020 Action Plan (GCAP) to facilitate a number of urban sustainability goals. According to goal 6 of the Greenest City 2020 Action Plan (City of Vancouver, 2011), access to green spaces is vital for developing a sustainable and livable city where residents are proud of their community. Two targets outlined in the GCAP are 1) that residents live within a 5-minute walk of a green space, and 2) that 150,000 new trees be planted by 2020.

Objective

This project helps the Vancouver Board of Parks and Recreation to optimize treatment of young ornamental trees planted along streets and parks. Specifically, the recommendations in this report are intended to help decrease transplanting stress and enhance tree health and longevity. The desired outcomes of the project include a characterization of success rates of the planting program with attributes such as species and age at time of death, time of year planted, as well as to identify the primary causes of young tree mortality. The report also outlines an improved protocol to help better understand the effectiveness of bioremediation efforts over time.

The research explored three elements:

1. Analysis of the VanTree inventory database to calculate mortality rates of newly planted trees based on species, age, and the time of year of planting over the last five years.

2. Data collection to understand the causes of tree removal based on staff inventory database and field observation. Identification of opportunities are conducted to avoid, mitigate or minimize human and non-human impacts on young ornamental trees in Vancouver.

3. Develop and implement a two to three-year control plot study using 145 trees to measure the effectiveness of a commercially available treatments.

Key findings

- The July 2018 heat wave brought attention to the health risks of extreme heat for Vancouver's street tree health further reinforcing the seriousness of anticipated climate change on young tree survival in Vancouver.

- Other key challenges facing Vancouver's park and street trees include transplanting shock, pollution, human disturbance, soil disturbance, monoculture problem, and limited space.

- The overall survival rate of the studied trees over a five-year period fluctuated between 95.82% and 97.26%. *Prunus yedoensis, Acer rubrum, Carpinus betulus* have the highest survival rates of the studied trees. The average survival rate after five years is 98.81%, 97.49%, and 97.17% respectively. *Magnolia kobu* has the lowest survival rate (90.98%) among selected tree samples.

- Over a six year periods (2013-2018), the trees in the study sample had the highest mortality rate in 2014 (0.95%). The most significant signs of death occurred at the age of 2, 3, and 6.

- The cost of replacing (removing and establishing) the stressed trees (from 2013 to 2017) is about $97,500. Basal damage and water stress are the top two causes of tree removal. The cost of replacing trees for these two reasons is over $50,000.

- Creating a microbial appropriate root zone in landscape soils is the key to long-term plant health and ecological sustainability. One way to boost young tree establishment and soil structure is bio-mediation treatment. Acclim8™, a soil bio-mediation product that has been tested in labs and many other cities, claims to improve the water-nutrient capacity and increase the amount of available nutrients in the soil by adding soluble organic minerals, carbohydrates, and plant extracts with patented organic minerals specially designed to help catalyze natural bio-geo-chemical processes in compacted-low organic matter soils (Wicks, 2018).

Introduction

1.1 Background

Although the greatest tree canopy cover is found in remote locations, green canopies in urban areas also yield multiple benefits. These include air cleaning, the mitigation of storm water runoff, and energy cost reduction through providing shade to buildings. There is also the well-documented 'intangible' benefit of providing a sense of well-being and uplifting our communities. Young tree establishment depends on various factors ranging from natural phenomena, anthropogenic disturbances, to climate change impacts. A well-defined, proper tree management plan is critical to reduce the mortality rate and to create healthier conditions.

Unfortunately, very often the importance of trees is most evident when the impacts of climate change are noticeable. Data-driven information specific to Vancouver's growing conditions and local tree stock is considered more valuable than currently available literature articles and available testimonial descriptions. This work will support the City of Vancouver's Green City Initiative and its accompanying Urban Forest Strategy.

1.1 About this research

In January 2011, Vancouver City Council set 14 targets under the Greenest City 2020 Action Plan (GCAP) to facilitate a number of urban sustainability goals. According to goal 6, it is vital to offer residents "incomparable access to green spaces, including the world's most spectacular urban forest." To achieve this, the Vancouver Park Board is tasked with the planting of 150,000 new trees, of which 54,000 (36%) are to be placed on public property.

The Vancouver Park Board plants several thousand street trees per year. However, these 6 cm caliper trees undergo some degree of transplanting shock when they are moved from nurseries and then planted at their destination sites. The management of all sick and dead trees costs the city millions of dollars each year. However, if trees are protected, there is a greater chance that they will do well. Each tree costs about $500 to purchase, establish, and water for the first year.

This research focuses on the data-driven analysis and field observations of Vancouver's newly planted trees based on local tree growing conditions, complemented by recommendations on tree management and soil remediation treatments based on a literature review of best management practices. This is meant specifically to decrease transplanting stress and to enhance tree health and longevity.

Literature Review

2.1 Climate change impacts on street tree heath

Climate projections for the City of Vancouver indicate that by mid-century, extreme heat events that now occur about once every 25 years will triple in frequency, with summer temperatures beyond 24°C expected to occur twice as often as today (Lesnikowski, 2014). The July 2018 heat wave brought attention to the health risks of extreme heat for Vancouver's street trees, furthering awareness of anticipated climate changes and their impacts on young tree survival rate in the future.

Prolonged dry spells and water summer temperature reduce soil moisture in the summer, and may cause widespread decline in urban tree growth and increased tree mortality. Longer drought periods, coupled with more intense precipitation at other times, have an impact on soil chemistry and the capacity of soil to retain water, and contribute to the frequency and severity of flooding. The decrease in snowpack, frost days and summer precipitation, combined with increasing temperatures, will also increase the risks of vulnerable species. Pests that are currently managed by cold temperatures may experience population outbreaks. Invasive species may be better able to thrive in changing conditions and out-compete native species (Pinna Sustainability, 2018)

2.2 Soil characteristics in urban landscapes

Urban soils are is observably different from natural soils. The environment in urban settings is mostly modified to some extent by grading and construction activities. Created by mixing, compacting, or grading, urban soils have artificial surfaces and horizons (Harris et al., 2004). The chemistry presented in urban soils arguably contributes to tree stress and mortality. To understand these problems, it is necessary to analyze the anthropogenic modifications in physical, chemical, and biological properties of urban soils (Craul, 1992).

Craul (1992) concluded that there are eight general characteristics of urban soils that contrast with their natural counterparts.

1. Great vertical and spatial variability;
2. Modified soil structure leading to compaction;
3. Presence of a surface crust on bare soil;
4. Modified soil reaction;
5. Restricted aeration and water drainage;
6. Interrupted nutrient cycling and altered soil organism population and activity;
7. Presence of waste materials and other contaminants;
8. Highly modified soil temperature regimes.

2.3 Challenges of urban trees

The City of Vancouver faces the pressures of planning for economic and population growth, urban boundary expansion and densification in creating a livable city. Urban trees play a vital role in climate change, but at the same time, they experience a wide range of barriers to healthy growth. The key challenges in a growing city like Vancouver, in terms of the vulnerability of its urban street trees, are: transplanting shock, pollution, human disturbances, soil disturbances, monoculture, and limited space.

In an urban setting, young trees are cultivated in the nursery stock and then are transplanted to different locations. If trees are not planted properly, for instance, if they are set too deep or too shallow, their ability to grow will most likely be hindered. Water loss and root cutting during transportation contribute to establishment stress. The differences in soil profile between root balls and planting sites also restrain water filtration and root penetrations.

When trees are planted along streets, the site environment is usually not ideal for them. Excessive air pollution caused by passing vehicles impedes the leaves' ability to photosynthesize, as well as the capability to guard against diseases and pests. The poor quality soil makes urban trees less resilient to drought conditions, as the soil disturbances (compaction, layer inversion, etc.) and surface crusts prevent roots from absorbing water.

Acer and Prunus dominate total Vancouver street tree population, and large numbers of trees are cloned from the same cultivar. A lack of genetic diversity exposes the population to a higher risk of ill health and mortality through pests, pathogens, extreme heat events and summer rainfall deficit.

Additionally, there is limited space underground for root systems to develop healthily. It is hard for trees to absorb enough nutrients and water to thrive. Trees with weakened root systems can be considered a liability. For instance, during extreme weather events, trees with weak roots are vulnerable to falling over, creating damage to people and infrastructures.

Apart from underground constraints, the aerial space is not sufficient either. In most cases, tree growth is compromised for human-made structures. If trees are not planted in suitable sites, or have to compete with new development, they may have to be removed to create space for power lines, adjacent buildings and road view clearance. Furthermore, if pruned improperly, trees are weakened by losing thriving branches. The remaining leaves might not be able to maintain a healthy state with reduced photosynthesis.

Urban trees also suffer from human disturbances like basal damage (e.g. grass mowing), motor vehicle accidents, vandalism and construction damage.

Study 1: tree mortality analysis

3.1 Methodology

This study is based on two major tables from Vantree data: one presents newly planted tree data (2013-2018)[1], and the other presents removed tree data (2013-2018)[2]. Eight common street tree genera in Vancouver are selected. They are *prunus yedoensis, Parrotia persica, Carpinus betulus, Acer rubrum, Styrax japonica, Magnolia kobus, Quercus palustris,* and *Fagus sylvatica* (table 1). Each tree has a serial number, as a unique reference.

When comparing the serial numbers in the two tables, it is observed that sometimes, when the same individual tree is mentioned in both, it is recorded in the new established tree table as having died. For each type of tree, the annual tree mortality rate is derived from an equation whereby the number of lost trees is divided by the total number of trees from the previous year.

$$MR_{n}^{*} = (O_n - S_n)/O_n \times 100\%; \quad MR_{n} = (S_{n-1} - S_n)/S_n \times 100\%$$

MR_{n}^{*} = Tree mortality rate for the first year in YEAR n

MR_{n} = Tree mortality rate for each year after the first year in YEAR n

$$\text{Overall tree mortality rate by year (OTM n)} = MR_{n-5} + MR_{n-4} + MR_{n-3} + MR_{n-2} + MR_{n-1} + MR_{n}$$

MR is valid only when n-5, n-4, n-3, n-2, n-1 >2012

n=2013, 2014, 2015, 2016, 2017, 2018

$$\text{Overall tree mortality rate by age (OTM x)} = MRn_{1x} + MRn_{2x} + MRn_{3x} + MRn_{4x} + MRn_{5x} + MRn_{6x}$$

MRn_1, MRn_2, MRn_3, MRn_4, MRn_5, MRn_6 represent tree mortality rate in tree certain age X, which depends on the year tree planted

X= tree age (1,2,3,4,5,6)

The overall tree survival rate in the last five years is calculated by dividing the number of living trees from the previous year by the number of living trees from five years ago. In this research, I calculated the survival rate of trees that were planted in 2013 and 2014, to get a tree survival rate variation and average. The same method can be applied to each tree species.

Overall tree survival after five years (2013-2017) = $S_{17} / O_{13} \times 100\%$

O_{13} = # original trees planted in 2013

S_{17} = # remaining trees in 2017 (from trees that are planted in 2013)

Overall tree mortality after five years (2014-2018) = $S_{18} / O_{14} \times 100\%$

O_{14} = # original trees planted in 2014

S_{18} = # remaining trees in 2018 (from trees that are planted in 2014)

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[1] For more information of newly planted tree data excel sheet (2013-2018), refer to https://drive.google.com/file/d/11latnpCRMmyTAJXgAEz2Sf0XLiM9CgI0/view?usp=sharing

[2] For more information of removed tree data excel sheet (2013-2018), refer to https://drive.google.com/file/d/1ptP12yZrIfg_ZJHycJHBmObrkPaNuBdr/view?usp=sharing

Species Code	Scientific name	Common name
PRYEAK	Prunus yedoensis	Japanese flowering cherry
PAPE	Parrotia persica	Persian ironwood
CABEFA	Carpinus betulus	Common hornbeam
ACRU	Acer rubrum	Red maple
SXJA	Styrax japonica	Japanese snowbell
MGKO	Magnolia kobus	Magnolia
QUPA	Quercus palustris	Pin oak
FASY	Fagus sylvatica	European beech

Table 1: name list of selected trees

3.2 Results

Appendix 1 shows the annual mortality rate of each tree species by year and total survival rate within five years. Tables of annual mortality rates for different tree species are merged to get the overall tree mortality rate by age (table 2) and by year (table 3) that encompass all selected tree species.

tree mortality rate by age													
	planted	year 1	MR (1 year old)	year 2	MR (2 year old)	year 3	MR (3 year old)	year 4	MR (4 year old)	year 5	MR (5 year old)	year 6	MR (6 year old)
2013	369	368	0.27%	365	0.82%	363	0.55%	362	0.28%	360	0.55%	355	1.39%
2014	646	639	1.08%	634	0.78%	627	1.10%	623	0.64%	619	0.64%	x	x
2015	517	514	0.58%	504	1.95%	497	1.39%	497	0	x	x	x	x
2016	678	677	0.15%	671	0.89%	667	0.60%	x	x	x	x	x	x
2017	313	313	0	313	0	x	x	x	x	x	x	x	x
2018	282	282	0	x	x	x	x	x	x	x	x	x	x
average			0.35%		0.89%		0.91%		0.30%		0.60%		1.39%

Table 2: overall tree mortality rate by age (2013-2018)

tree motality rate by year													
	planted	2013	MR	2014	MR	2015	MR	2016	MR	2017	MR	2018	MR
2013	369	368	0.27%	365	0.82%	363	0.55%	362	0.28%	360	0.55%	355	1.39%
2014	646	x	x	639	1.08%	634	0.78%	627	1.10%	623	0.64%	619	0.64%
2015	517	x	x	x	x	514	0.58%	504	1.95%	497	1.39%	497	0.00%
2016	678	x	x	x	x	x	x	677	0.15%	671	0.89%	667	0.60%
2017	313	x	x	x	x	x	x	x	x	313	0	313	0
2018	282	x	x	x	x	x	x	x	x	x	x	282	0
average			0.27%		0.95%		0.64%		0.87%		0.69%		0.44%

Table 3: overall tree mortality rate by year (2013-2018)

Analyzing the Vantree raw data, four graphs are produced to show the tree mortality and survival rate in several aspects, which can be used to answer different research questions.

In Figure 1, tree mortality rate by age is displayed. There was a significant increase from year 1 (0.35%) to year 2 (0.89%), and a substantial decrease from year 3 (0.91%) to year 4 (0.30%). Then tree mortality rate jumped back rapidly to 1.4% in the last year.

Figure 2 illustrates tree mortality rate by year. Tree mortality rate peaked to 0.95% in 2014. After dropping to 0.64% in 2015, it significantly increased again to 0.87% in 2016. From 2016 to 2018, tree mortality rate decreased again.

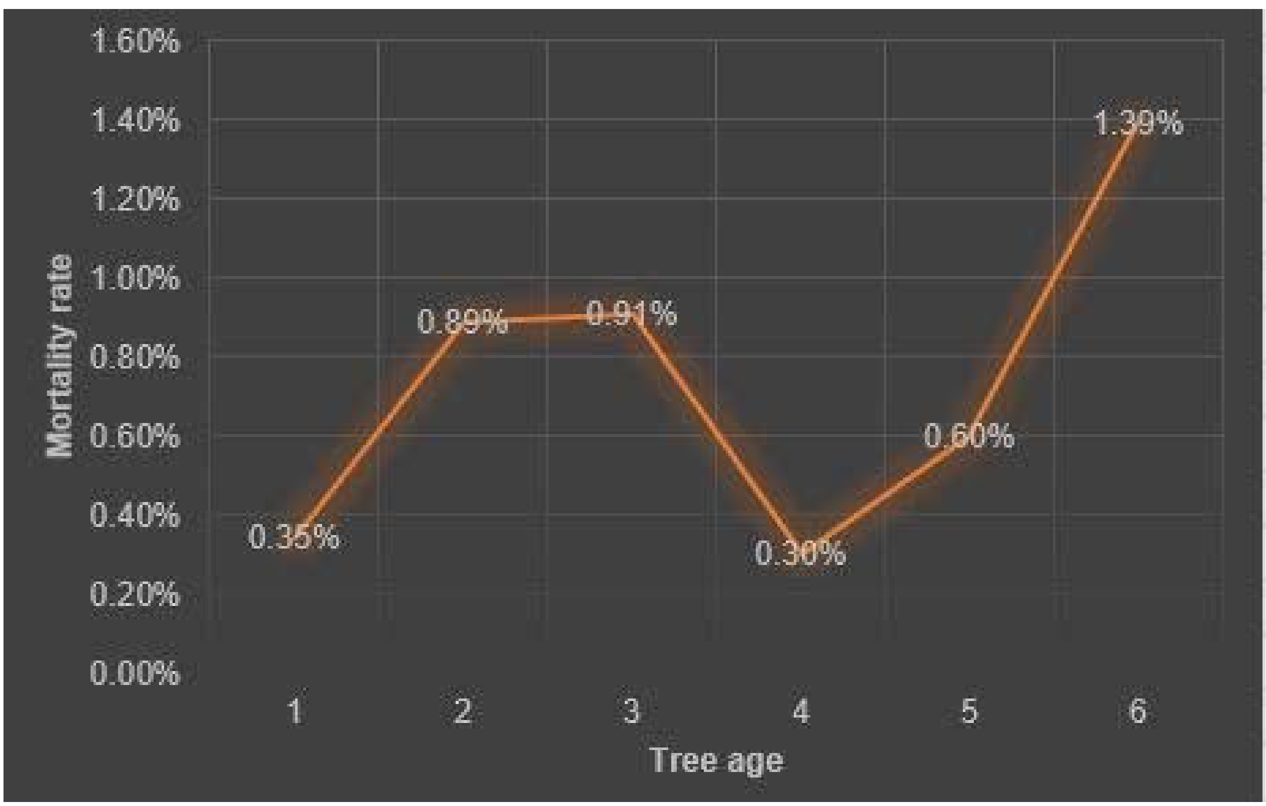


Figure 1: tree mortality rate by age (2013-2018)

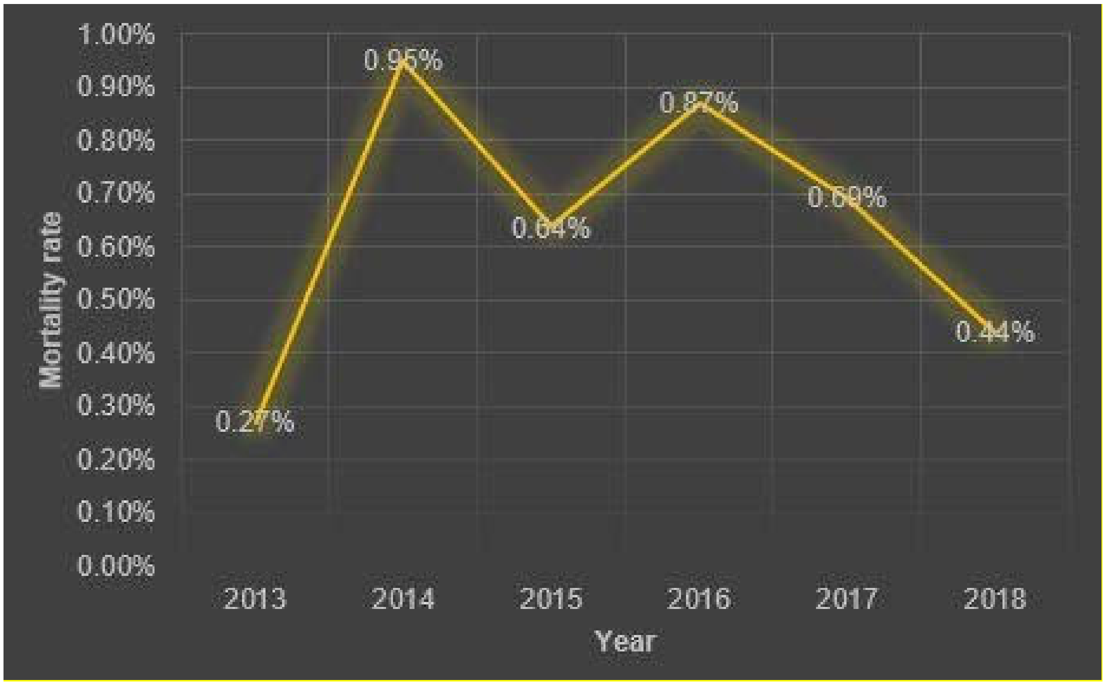


Figure 2: tree mortality rate by year (2013-2018)

The survival rate of selected trees that were planted in 2013 and 2014 is calculated by dividing the number of living trees in 2017 and 2018 by the number of living trees in 2013 and 2014. Figure 3 shows that the survival rates after five years of all selected trees planted in 2013 and 2014 are 97.26% and 95.82% respectively; the average is 96.54%. Looking at Figure 4, it is noticeable that PRUYAK, ACER, and CABEFA are the three top ranking tree species for survival rate. The average survival rates after five years are 98.81%, 97.49%, and 97.17% respectively.

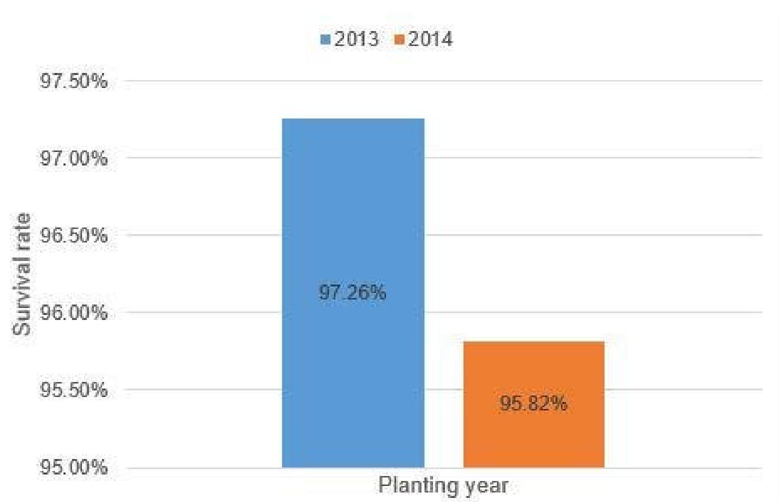


Figure 3: total tree survival rate planted in year 2013 and 2014 within five years

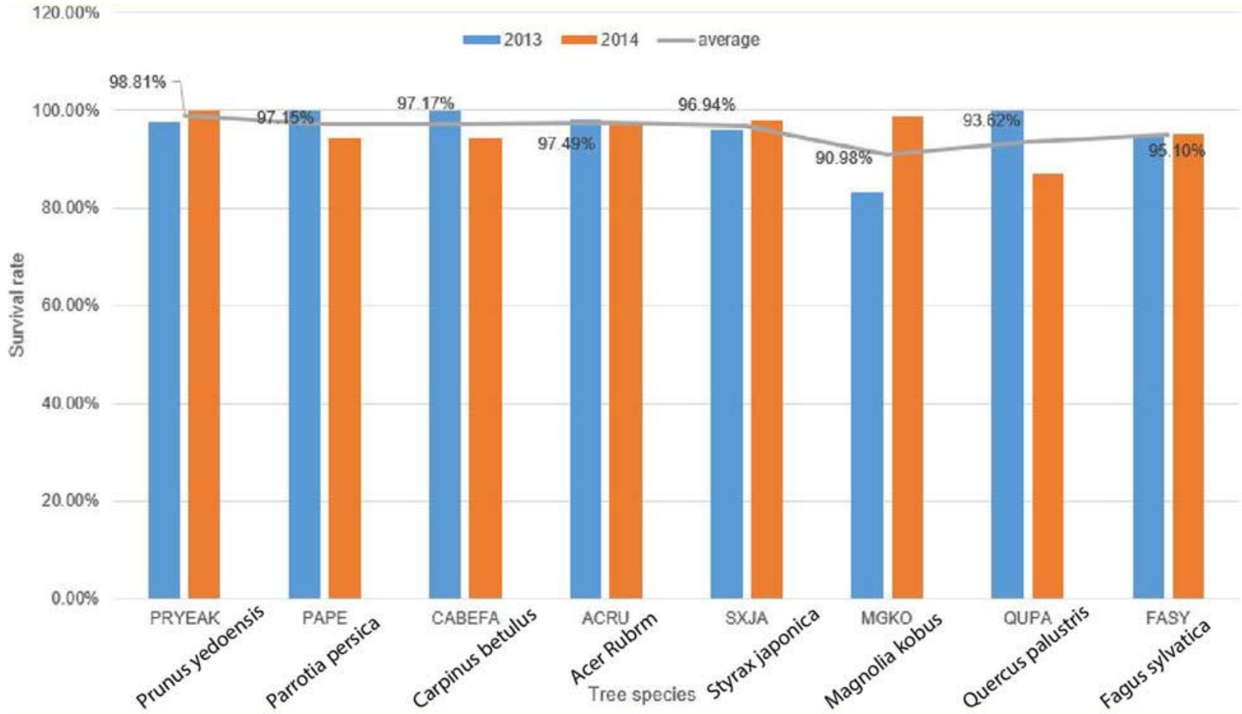
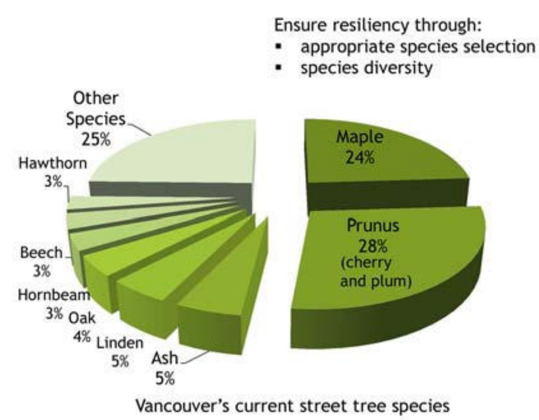


Figure 4: total tree survival rate by species planted in year 2013 and 2014 within five years

According to a Figure 4, among the selected tree samples, *Prunus yedoensis, Acer rubrum,* and *Carpinus betulus* ranked among the best for hardiness in tree establishment under Vancouver's current climate conditions. Although *Prunus yedoensis* and *Acer rubrum* have the highest survival rates, they are overrepresented according to Vancouver Park Board's standards for diversity. Based on the 30-20-10 tree planting rule (Tehandon, 2017), 30% of trees or fewer should be from the same family, 20% of trees or fewer should be from the same genus, and 10% of trees or fewer should be from the same species. This principle effectively limits unchecked disease outbreaks and severe economic losses from disease by enriching the biodiversity in nature. Since the percentage of *Prunus* and *Acer* planted in Vancouver already surpasses the 20% genus limitation, the more ideal species to be selected for future plantings would be *Parrotia persica* and *Carpinus betulus*.



Study 2: tree removal cause validation

4.1 Methodology

This part of the report aims to identify current removal causes, such as watering stress, and their potential adverse effects. Based on the past inventory database[1], 182 young public trees are recorded to be removed. 103 trees were selected in this study for field validation. The selection process identified opportunities for avoiding, mitigating or minimizing human and non-human impacts. Photos were taken of all stressed trees. They can be accessed via the link below for reference: https://www.dropbox.com/sc/nhe7v1qe49576z0/AADvOpj0gol5Up2Fi7JrZQpwa

4.2 Results

Causes of mortality were generally divided into nine categories: basal damage, water stress, vandalism, construction operations, poor planting practices, pathogen and insect damage, MVA (motor vehicle accidents), death from unknown causes, and bad data (unhealthy and already removed trees). Examples are shown below:

- Basal damage includes mower machine and vehicle damage, damage from forest wildfire, and any other factors that contribute to root trunk injury;
- Water stress is associated with symptoms such as small, wilting, and discolored leaves, sparse tree canopy crown, pearling bark, etc.;
- Vandalism is human action involving deliberate damage to trees;
- Construction damage can cause physical injury to the trunk and crown by root cutting, soil compaction, smothering roots by adding soil, and exposure to elements;

(*The diagnosis is conducted through visual inspections. One disadvantage of this method is that a tree's underground root system may be disregarded.)

- Poor planting occurs when a tree is planted using incorrect practices or is established in unsuitable soil;
- Pathogen problems observed in sample trees are shown in Table 2;
- Motor vehicle accidents result in trunk wounds as stress symptoms.

The rest of the sample trees look healthy or have been removed or replaced.

---

[1] For excel sheet of young stressed trees that are going to be removed within the past five years, refer to

https://drive.google.com/file/d/14A0u2O9wlc-HGFriCGuU1IA5uSrsTzi7/view?usp=sharing

Figure 5a: vandalism

Figure 5b: water stress

Figure 5c: pest and disease (Anthracnose)

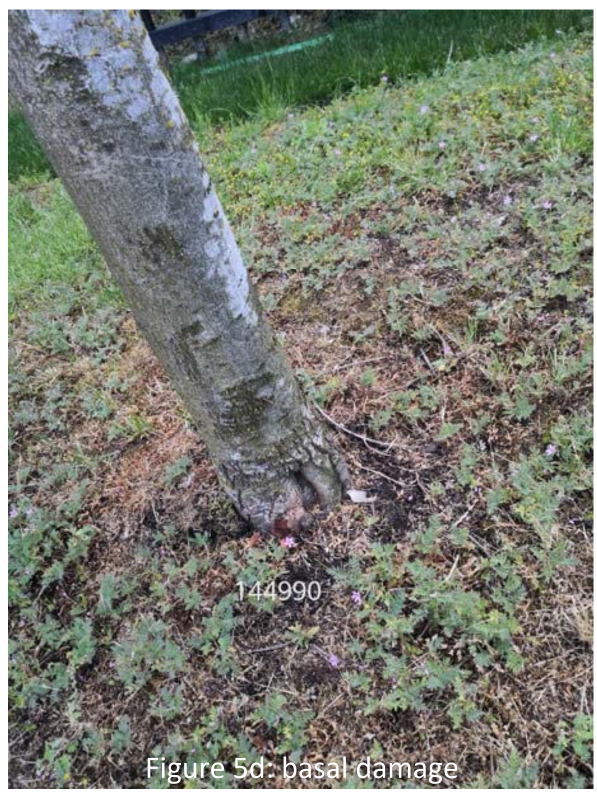


Figure 5d: basal damage

Figure 5e: construction damage

Figure 5f: pest and disease (pest trellis rust)

Figure 5g: poor planting

Figure 5h: root collar stress

Pest and diseases	Common hosts in the sample pool
Anthracnose	Cornus
Verticillium wilt	Acer/ Magnolia
Aphid	Tilia euchlora/ Liriodendron tulipifera
Pear trellis rust	Pyrus
Apple scab	Malus

Table 2: reoccurring pests and diseases found in the survey trees

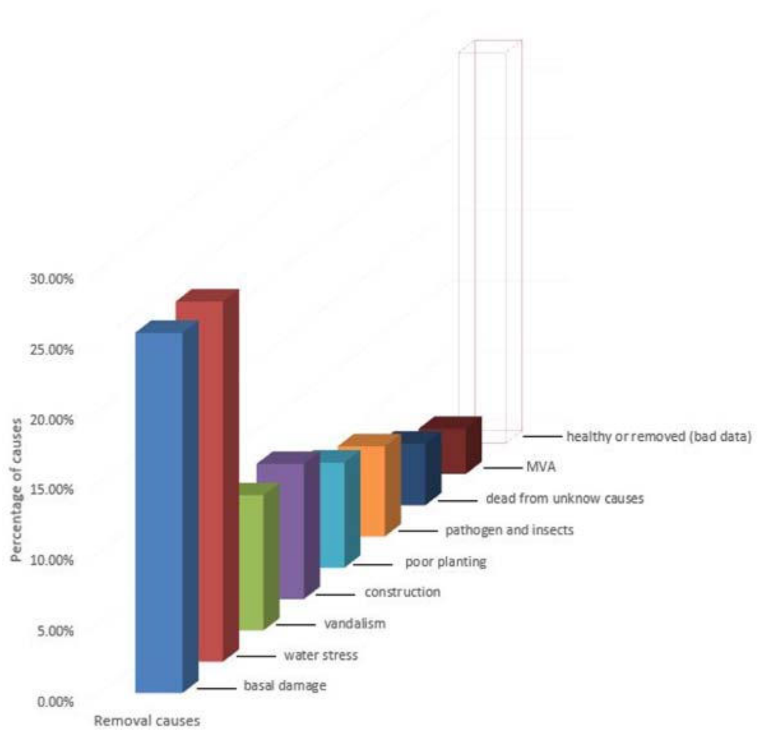


Figure 6: Vancouver young public tree mortality tree causes

Figure 6 compares various removal causes of park and street trees in Vancouver during the last five years. Basal damage and water stress are the top two reasons causing tree death, each contributing 26% of total tree mortality. Following basal damage and water stress, the third and fourth major causes of tree mortality are vandalism and construction damage, which are less prevalent but still significant.

4.3 Discussion and recommendations

1. Basal injury

Young trees are more vulnerable to disturbances and have higher mortality rates for 2-3 years after planting. This is probably caused by mower machine damage to the root collars when the first year of organic mulch has been decomposed into soil. Young trees can be damaged in their basal areas by grass mowers or string trimmers operated by homeowners or landscape workers. Four solutions can help to resolve this problem:

a. Tree guards

Tree guards are made of a durable high-density and light-weight polyethylene material, firmly placed at the base of a tree. Tree guards are designed to prevent tree trunk damage from animals, string trimmers, and mowers. They protect the trunk while allowing nutrients to be adequately uptaken by young trees (Century Products, 2014). A tree guard should be loose and regularly maintained after a few years of installation so that the root collar is free to grow.

b. Mulch

Organic mulch is a layer of material usually mixed with bark chips, pine needles, and nut shells. It is often applied to the surface of the soil to support young tree establishment. Proper tree mulching starts about 3 to 6 inches from the trunk and continues outward in all directions for at least 3 feet. It acts as a natural barrier to prevent mower machines from hitting tree trunks.

Mulch provides other benefits such as enhancing soil fertility and biology, improving soil structure, reducing evaporation to moderate soil temperature, limiting weed competition and mitigating soil compaction. However, after 1-2 years of tree establishment, mulch is completely decomposed into the soil, and the barrier functions no longer exist. Regular application of mulch needs to be included in tree management plans so that young trees access these benefits and have a higher chance of success in growing up healthy.

c. Bedding plant and ground cover

Where mowing damage is not wanted, low-growing shrubs and perennials can be planted around the tree root collar, and they require less maintenance than grass. Additionally, unlike grassy peat (thatch) that prevents nutrient infiltration, bedding plants provide habitat for pollinators and facilitate ecosystem balance. Based on soil conditions, sunlight and other preferences, a grass lawn can be replaced with perennial ground covers such as *Trifolium repens* to reduce the need to mow lawns.

Figure 7: street garden example

2. *Water stress*

Newly planted trees require at least 12 months to establish root systems, and they need regular watering over that period (Craul, 1992). A regular watering schedule, along with supplemental watering in dry seasons, can prevent wilting and allow the plant to grow up well. Water bags, water pods, and drip irrigation systems are efficient methods to ensure water infiltration into soil for longer periods compared to sparkling irrigation (Harris & Matheny, 2004). Organic mulches also work well to reduce evaporation.

Residents are encouraged to water street trees in front of their houses when they irrigate their gardens. In locations where plants are not drought-tolerant, or soil erosion is severe, active harvesting systems can be applied to collect, store and reuse water for spring and summer (Harris & Matheny, 2004). An active harvest system combines rain barrels and pumps to distribute water when it is required most (Diamond Head, 2016). When turf or other small plants are irrigated, however, care must be taken so that trees are not over- or under-watered.

Container-grown and B-in-B plants, both deciduous and evergreen, require rather frequent watering. On the other hand, deciduous trees that are planted bare root and thoroughly watered at planting or afterward should not need irrigation until 2-4 weeks after growth begins. Over-watering during this time can endanger root growth and function (Craul, 1992).

3. *Vandalism*

In places that have higher vandalism rates such as the east downtown area, larger mature trees are better choices than small young seedlings, since their vitality is less impacted by the breaking of branches. In other neighborhoods of Vancouver, seedlings that have a caliper of over 7 cm are encouraged, to prevent potential vandalism. It is also necessary to prune the lowest tree branches at least 2.5 meters above the ground, to where the height is beyond the reach of hands.

4. *Construction damage*

1) Principles

Barriers such as fences, curbs, and planting containers must be erected to protect trees from mechanical injury above ground or underground (in critical root zones*). Minimum tree protection zones (two meters from tree center) should be set to protect permeable surfaces for root growth.

2) Enforcement and education

Tree protection principles during the construction periods should reviewed not only by arborists, but more importantly, by developers and house owners who can be educated to understand. Additionally, the city needs to find better ways to conduct enforcement programs. For instance, if trees are likely to be damaged by construction, operations based on diagnoses, fines or replacement of new trees are required to compensate for the losses.

4.4 Cost analysis

$$\frac{\text{Sample removal causes}}{\text{Sample size}} = \frac{\text{Total number of trees stressed from certain causes}}{\text{Total trees that are going to be removed}}$$

Sample size: 103

Total trees that are going to be removed: 182

Figure 8a: the equation to calculate number of trees stressed from certain causes (2013-2017)

Young tree removal costs: CAD 150 per tree

Tree establishment costs: CAD 500 per tree

(purchase + installation + first year watering)

Removal causes	# of removed trees	Removal costs	Replanting costs (establishment)	Total costs
Basal damage	42	$6,300	$21,000	$27,300
Water stress	42	$6,300	$21,000	$27,300
Vandalism	16	$ 2,400	$8,000	$10,400
Construction damage	16	$ 2,400	$8,000	$10,400
Poor planting	12	$1,800	$6,000	$7,800
Pests& Pathogens	10	$1,500	$5,000	$6,500
Dead from unknown causes	7	$1,050	$3,500	$4,550
Motor vehicle accidents	5	$750	$2,500	$3,250
Total	150	$22,500	$75,000	$97,500

Figure 8b: total estimated costs of replacing stressed trees recorded in the datasheet (2013-2017)

Study 3: Bio-mediation soil treatment

Stakeholder consultation was conducted to further understand a variety of tree treatment products, as well as their recommendations for future use. As most tree experts suggested, when applying fertilizer or pathogen control products, we should choose the option that has the most effective integrated tactics and the least detrimental impacts on landscape ecosystem. One way to boost young tree establishment and soil structure is bio-mediation treatment, through which we can remove the hands of humans in the management of green space in an eco-efficient manner.

4.1 What can Acclim8TM do?

Acclim8TM, a product that has been tested in labs and in numerous cities, claims to improve the water-nutrient capacity of trees, and to increase the amount of available nutrients in the soil, by adding soluble organics and minerals, carbohydrates, plant extracts with patented organics and minerals. It is specially designed to help catalyze natural bio-geochemical processes in compacted-low organic matter soils. Through facilitating the creation of a microbial appropriate root zone in soils, the natural process helps increase the water and the nutrient holding capacity of a tree, and promotes nutrient production in a way that is superior to using short-term fertilizers alone. A microbial appropriate root zone in landscape soils is the key to long-term plant health and ecological sustainability.

According to a Kwantlen Polytechnic University study (2014), there are positive probiotic and prebiotic effects on soil food web microbes. After applying Acclim8TM, the growth of beneficial soil bacteria, fungi, nematodes, and major nutrient cycling protozoa were stimulated, which led to 144% greater shoot development and significant increases in height, spread, and root mass. The microbes also occupy space in the soil and they out-complete for resources in the soil, keeping diseases at bay.

Acclim8TM also contains the significant component STV (the Phosphates Steric Transport Vehicle), which facilitates phosphorus absorption and penetration in the soil. STV shields the phosphate ion and combines with metal ions in the soil solution that interfere with phosphate availability. Research done by PENET Group and different cooperators over the last 16 years has shown that STV-Phosphate is three times more efficient than 10-34-0 or 0-52-0 in delivering phosphorus to plants. Analysis of phosphate movement in soil has shown that the STV-Phosphate complex can move up to 12’’ (subsoil) into the soil profile whereas the naked phosphate ion rarely moves deeper than 2’’. By improving nutrients and mineral availability in the subsoil, tree roots will have greater stability and performance, with no competition from surface shrubs and grasses.

Acclim8TM was not specifically meant to help trees thrive or to decrease transplanting shock, but more importantly, it can be applied at a cost neutral basis by reducing tree mortality rate. Money spent on replacing dead trees with new trees can be spent on maintaining existing trees. It is very likely to see positive results and save $ 1000 on tree replacement costs. The program will pay for itself.

4.2 Experiment design

In this experiment, the Acclim8 Tree Health Formula (soluble pucks) are specifically designed for Treegator Watering Bags (Figure 9). According to Figure 10, each 100g Puck contains soil probiotic microbial inoculant, soil prebiotic root exudation technology, and patented mineral chelation technology.

The control plot study test took place in August 2018. The product (one puck of Acclim8TM) will be distributed to the test trees in different parks and streets every ten days, up to three times. There are 68 test trees that will be given Acclim8TM soluble pods, and 77 control trees that will not be given Acclim8TM. The selected trees for this pilot project are in different microcosm throughout the city. They are the most vulnerable to disturbances and require the most help.

Figure 9: soluble pucks designed for Treegator Watering Bags

Each 100g Puck Contains:

Soil Probiotic Microbial Inoculant:	2000 µg/g Beneficial Fungi 1500 µg/g Beneficial Bacteria 100,000 MPN/g Beneficial Soil Protozoa
Soil Prebiotic Root Exudation Technology:	Plant extracts, Sea kelps, Carbohydrates and Organic acids
*** Patented Mineral Chelation Technology:**	3 - 6 - 4 + 0.8S Mineral balance. * Los Alamos National Laboratory showing 26 week delayed phosphorus fixation in soils. * Rikken Institue of Japan showing 25% improved phosphorus uptake

Figure 10: Acclim8 Tree Health Formula components

The test and control trees on streets, used for pair comparisons, will be in close proximity to each other to rule out differences in location, ages and species as being causes for changes to the trees. The sample trees in parks, used for pool comparisons, are of random species, but vigour (leaf color, leaf size, crown density) will be recorded quantitatively to compare growing conditions.

Data will be recorded for the control and test trees one day before the first application of Acclim8TM begins. The data collection will include tree serial number/GPS location, code, species, age, height, twig growth, signs of disorders, and a picture of each tree (taken 5m away from the tree and facing north). A measuring stick, as a reference object, will be used to compare tree scales (Figure 11).

After each application of Acclim8 is completed, the same data plus mortality rates and obvious biotic or abiotic problems will be recorded again. We look forward to comparing next year's study results with this year's results. The Vancouver Park Board is still in the process of figuring out how Acclim8TM will affect growth conditions for young trees. This can be determined only if future research is done in the year to come.

- Tree photos (first year) are saved in https://www.dropbox.com/sh/o8uv5v20epgjj10/AABmsw6yCCgc7F2DDzzKLUa3a?dl=0

- Inventory data of test trees (first yearyo) are saved in https://docs.google.com/spreadsheets/d/1wFRBp2tYWGMCzXWXb8dan7q4h-O-ndKTF1bBVJBnhdc/edit?usp=sharing

- Appendix C & D: street tree and park tree work sheet for the second/ third year

Figure 11: treated trees and a reference measuring stick

Limitations and Next steps

- The study looked at the mortality rate of young park and street trees. The results were very positive; however, because the sample trees I selected were all hardy species that are frequently planted, the findings may not completely reflect overall young tree conditions.

- In terms of tree removal causes, total sample size might be small for high statistic validity. Almost 30% of trees in the sample were either removed, replaced or looking healthy, which significantly reduced the working efficacy and produced limitations in interpreting findings. Additionally, the financial analysis of tree replacement costs was not strictly accurate because a great number of young trees stressed were not recorded in the Vantree data sheet.

- The soil bio-mediation treatment study is a new field to explore. It is likely that there are still numerous gaps in the knowledge base that need to be filled. Additionally, since trees have low cycling speed, their reactions to the soil products will not display until the second year. The next step would be bridging a good connection with following research.

Suggestions for future research:

- For urban forestry research teams, the study of bio-mediation treatment should be continued, and the same data recording methods should be followed. A larger sample of trees (e.g. new species that might be able to adapt to future climate change) can be selected for mortality rate analysis.

- For the Vancouver Park Board, a more comprehensive framework should be created to encourage retention of existing trees and to discourage tree damage. A system of payments for basal damage, construction and vandalism is suggested. Also, the street/park tree management plan might be updated regarding tree establishment.

- Although the mortality rate is low, Vancouver Parks Board should continue to experiment with planting other species in the interests of enhancing population level diversity.

- For local environmental organizations and community members, effective and engaging residential local tree programs can be designed and delivered, through which residents are educated in protecting existing young trees, and are empowered in street tree watering or street garden maintenance.

Conclusion

A rigorous tree mortality analysis plus the practices I have suggested will be necessary to support the ambitious tree planting targets set out in the Greenest City 2020 Action Plan, which seeks to place 150,000 new trees across the city. Through the young tree mortality analysis, the five year survival rate (96.54%) of eight selected trees is reasonably good.

Along with peer reviews of earlier tree management plans, data-driven experiments and feedback from related stakeholders, this report can help the Vancouver Park Board's to optimize treatments to ensure establishment of young ornamental trees planted along streets and parks.

New scholars can continue to improve research regarding Vancouver's soil treatment which is a work in progress. Maybe one day the results can be used by the City of Vancouver and the UBC research team as an independent and optimized young city tree management kit.

We also have an opportunity to take advantage of the enthusiasm and momentum generated by the creative capacities of different stakeholders to learn more about tree establishment stress, and to increase the survival rates.

For my part, I can definitely say that I have enjoyed working on the Greenest City Scholar research project. It has been a valuable learning experience and meeting many dedicated people, including mentors, colleagues, and so forth, has been inspiring.

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Appendix A: annual mortality rate by selected tree species

ACRU

address	street	NB	Cell	species	Plant year	DBH (before)	remove year	DBH (after)	cause	serial
3,253.00	W 22ND AV	10	7	ACRUAF	11-13-2013	3	02-18-2014	3	R-UTILITIES	161890
5,351.00	CAMOSUN ST	10	3	ACRUAF	11-12-2013	3	12-11-2017	3	R-DEAD	244277
1,878.00	NANAIMO ST	5	4	ACRUOG	12-06-2013	3	03-19-2018	3	R-DEAD	247264
4,956.00	KNIGHT ST	15.00	5.00	ACRUBH	02-17-2014	3	12-15-2014	3	R-MVA	247256
4,932.00	KNIGHT ST	15.00	6.00	ACRUBH	2014-02-17	3	2015-01-08	3	R-DEAD	247255
6,641.00	BROOKS ST	22.00	4.00	ACRUOG	2014-01-09	3	01/28/2015	3.00	R-DEAD	247679
7,580.00	ST. GEORGE ST	20.00	6.00	ACRUOG	03-03-2014	3	08-10-2016	3	R-DEAD	247848
277.00	THURLOW ST	1.00	7.00	ACRUBH		3	12-01-2017	3	R-DEAD	247502
301.00	NELSON ST	1.00	3.00	ACRUBW	2014-03-07	5	09-29-2017	5	R-DEAD	249107
3,504.00	E 27TH AV	16.00	2.00	ACRUBH	2015-01-20	3	03-30-2016	3	R-DEAD	249999
2,426.00	W 20TH AV	11.00	5.00	ACRUAF	2016-02-11	3	02-10-2017	3	R-DEAD	252749

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	104	104	0	103	0.96%	103	0	103	0	102	0.97%	101	0.98%	0.49%	98.06%
2014	195	194	0.005	192	1.03%	191	0.52%	189	1.05%	189	0	X	X	0.62%	96.92%
2015	115	115	0.009	114	0	114	0	114	0	X	X	X	X	0.22%	
2016	157	157	0	156	0.64%	156	0	X	X	X	X	X	X	0.21%	
2017	70	70	0	70	0	X	X	X	X	X	X	X	X	0	
2018	60	60	0	X	X	X	X	X	X	X	X	X	X	0	

QUPA

street	NB		Cell	species	DBH	plant year	cause	remove year	serial
33.00	W PENDER ST	1.00	2.00	QUPA	3.00	01-28-2014	R-DEAD	12-19-2014	249066
1,610.00	E 4TH AV	4.00	5.00	QUPAGP	3.00	03-26-2014	R-DEAD	07-07-2015	243362
1,997.00	OMMERCIAL DRIV	4.00	23.00	QUPAGP	3.00	03-31-2014	R-DEAD	01-06-2015	243498
1,604.00	E 4TH AV	4.00	1.00	QUPAGP	3.00	03-26-2014	R-DEAD	03-02-2016	243225
1,534.00	E 4TH AV	4.00	6.00	QUPAGP	3.00	03-28-2014	R-DEAD	01-22-2016	244109
1,536.00	E 4TH AV	4.00	2.00	QUPAGP	3.00	03-28-2014	R-DEAD	03-02-2016	244110
2,881.00	ADANAC ST	5.00	3.00	QUPAGP	3.00	03-17-2015	R-STORM	06-15-2015	248101
2,875.00	ADANAC ST	5.00	3.00	QUPAGP	3.00	03-17-2015	R-DEAD	01-12-2016	248102
2,861.00	ADANAC ST	5.00	4.00	QUPAGP	3.00	03-16-2015	R-DEAD	01-12-2016	248104
2,823.00	ADANAC ST	5.00	4.00	QUPAGP	3.00	03-16-2015	R-DEAD	01-12-2016	248109
2,821.00	ADANAC ST	5.00	5.00	QUPAGP	3.00	03-16-2015	R-DEAD	01-12-2016	248110
595.00	W 27TH AV	13.00	22.00	QUPAGP	12.50	04-14-2015		07-13-2016	251660

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	27	27	0%	27	0%	27	0%	27	0%	27	0%	27	0%	0%	100.00%
2014	47	46	2.13%	44	4.35%	41	6.82%	41	0%	41	0%	X	X	2.66%	87.23%
2015	49	48	2.04%	43	10.42%	43	0	43	0	X	X	X	X	3.12%	
2016	2	2	0	2	0	2	0	X	X	X	X	X	X	0	
2017	3	3	0	3	0	X	X	X	X	X	X	X	X	0	
2018	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

PRYEAK

Address	Street	NB	Cell	Species	DBH	plant year	DBH	remove year	Serial
4,044.00	W 16TH AV	10.00	28.00	PRYEAK	5.00	10-31-2013	R-DEAD	03-27-2018	71191

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	42	42	0	42	0	42	0	42	0	42	0	41	2.38%	0	97.62%
2014	43	43	0	43	0	43	0	43	0	43	0	x	x	0	100%
2015	39	39	0	39	0	39	0	39	0	X	X	X	X	0	
2016	66	66	0	66	0	66	0	X	X	X	X	X	X	0	
2017	48	48	0	48	0	x	x	X	X	X	X	X	X	0	
2018	10	10	0	x	x	X	X	X	X	X	X	X	X	0	

CABEFA

street	NB		Cell	species	DBH	plant year	cause	remove year	serial
855.00	W 59TH AV	19.00	13.00	CABEFA	3.00	12-04-2014	R-DEAD	12-04-2014	244353
7,350.00	LAUREL ST	19.00	16.00	CABEFA	3.00	12-04-2014	R-DEAD	12-04-2014	244356
7,350.00	LAUREL ST	19.00	17.00	CABEFA	3.00	12-04-2014	R-DEAD	12-04-2014	244361
1,150.00	E KENT AV SOUTH	20.00	4.00	CABEFA	3.00	04-12-2016	R-DEAD	04-12-2016	254943
360.00	NORTHERN ST	3.00	3.00	CABEFA	3.00	02-17-2016		11-28-2017	254316

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	7	7	0	7	0	7	0	7	0	7	0	7	0	0	100.00%
2014	53	50	5.66%	50	0	50	0	50	0	50	0	X	X	1.13%	94.34%
2015	32	32	0	32	0	32	0	32	0	X	X	X	X	0	
2016	115	114	0.87%	113	0.88%	113	0	X	X	X	X	X	X	0.58%	
2017	35	35	0	35	0	X	X	X	X	X	X	X	X	0	
2018	8	8	0	X	X	X	X	X	X	X	X	X	X	0	

MGKO

Address	Street	NB	Cell	Species	DBH	plant year	cause	remove year	Serial
2,101.00	W 5TH AV	8.00	6.00	MGKO	3.00	11-14-2013	R-DEAD	05-29-2017	245330
2,006.00	W 46TH AV	17.00	20.00	MGKO	3.00	01-22-2014	R-DEAD	05-10-2016	247054

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	6	6	0	6	0	6	0	6	0	5	16.70%	5	0.00%	0	83.33%
2014	73	73	0	73	0	72	1.40%	72	0	72	0	X	X	0.27%	98.63%
2015	19	19	0	19	0	19	0	19	0	X	X	X	X	0	
2016	36	36	0	36	0	36	0	X	X	X	X	X	X	0	
2017	10	10	0	10	0	X	X	X	X	X	X	X	X	0	
2018	31	31	0	X	X	X	X	X	X	X	X	X	X	0	

Address	Street	NB	Cell	Species	plant year	plant year	cause	remove year	Serial
936.00	GRANVILLE ST	1.00	2.00	FASY	3.00	10-15-2013	R-DEAD	11-08-2013	248216
68.00	W CORDOVA ST	1.00	2.00	FASYDW	3.00	10-21-2013	R-DEAD	02-05-2014	233729
74.00	W CORDOVA ST	1.00	5.00	FASYDW	3.00	10-21-2013	R-DEAD	04-11-2014	247060
698.00	W HASTINGS ST	1.00	10.00	FASY	3.00	10-24-2013	R-FAILURE	04-20-2015	248210
128.00	W CORDOVA ST	1.00	7.00	FASYDW	3.00	10-21-2013	R-DEAD	03-18-2015	247744
7,201.00	HEATHER ST	18.00	6.00	FASY	3.00	12-04-2013	R-DEAD	04-22-2016	248013
7,201.00	HEATHER ST	18.00	5.00	FASY	3.00	12-04-2013	R-VANDAL	02-08-2018	248012
7,101.00	HEATHER ST	18.00	6.00	FASY	3.00	12-04-2013	R-VANDAL	02-08-2018	248019
68.00	W CORDOVA ST	1.00	2.00	FASYDW	3.00	02-05-2014	R-DEAD	04-14-2014	249189

1,095.00	E 62ND AV	20.00	9.00	FASY	3.00	03-24-2014	R-DEAD	03-14-2016	248284
1,280.00	RAYMUR AV	3.00	10.00	FASYAS	11.00	04-09-2014	R-DEAD	12-14-2016	249397
3,678.00	MAXWELL ST	15.00	14.00	FASYDP	3.00	03-03-2014		03-31-2017	247299
4,985.00	RINCE ALBERT S	15.00	2.00	FASYDW	3.00	01-08-2015	R-DEAD	04-05-2016	249916
5,059.00	RINCE ALBERT S	15.00	2.00	FASYDW	3.00	01-08-2015	R-DEAD	04-05-2017	249922
120.00	W CORDOVA ST	1.00	4.00	FASYDW	3.00	03-17-2015	R-ENG	03-31-2017	250940
108.00	W CORDOVA ST	1.00	2.00	FASYDW	3.00	03-15-2015	R-ENG	03-31-2017	251495
136.00	W CORDOVA ST	1.00	2.00	FASYDW	3.00	03-18-2015	R-ENG	03-31-2017	251496
136.00	W CORDOVA ST	1.00	1.00	FASYDW	3.00	03-19-2015	R-ENG	03-31-2017	251497
128.00	W CORDOVA ST	1.00	7.00	FASYDW	3.00	03-18-2015	R-ENG	03-31-2017	253662
1,095.00	E 62ND AV	20.00	9.00	FASYAT	3.00	03-14-2016	R-DEAD	05-23-2017	253084
4,396.00	PERRY ST	15.00	1.00	FASYTC	3.00	04-18-2016	R-DEAD	07-28-2017	250105
3,404.00	PANDORA ST	5.00	10.00	FASYDG	3.00	04-04-2016	R-DEAD	03-19-2018	252598
3,404.00	PANDORA ST	5.00	11.00	FASYDG	12.00	04-04-2016	R-DEAD	03-19-2018	252600
3,404.00	PANDORA ST	5.00	8.00	FASYDP	3.00	02-24-2016	R-DEAD	03-19-2018	252584
3,404.00	PANDORA ST	5.00	11.00	FASYDP	3.00	02-24-2016	R-DEAD	03-19-2018	252599

FASY

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	100	99	1.00%	97	0	95	0	94	0	94	0	92	2.13%	0	94.85%
2014	86	85	1.16%	85	0	85	0	83	2.35%	82	1.20%	X	X	1.16%	95.35%
2015	84	84	0	83	1.20%	77	7.22%	77	0	X	X	X	X	2.10%	
2016	46	46	0	44	4.30%	40	9.10%	X	X	X	X	X	X	4.50%	
2017	63	63	0	63	0	X	X	X	X	X	X	X	X	0	
2018	102	102	0	X	X	X	X	X	X	X	X	X	X	0	

Address	Street	NB	Cell	Species	DBH	plant year	remove year	Serial
1,307.00	W 41ST AV	12.00	8.00	SXJA	3.00	11-13-2013	03-27-2018	84884
1,850.00	WHYTE AV	8.00	4.00	SXJASC	4.00	01-13-2014	12-09-2014	246970
1,996.00	TRUTCH ST	8.00	6.00	SXJA	3.00	02-04-2015	02-04-2015	249370

SXJA

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	26	26	0	26	0	26	0	26	0	26	0	25	3.84%	0.64%	96.15%
2014	44	43	2.27%	43	0	43	0	43	0	43	0	X	X	0.45%	97.73%
2015	46	45	2.17%	45	0	45	0	45	0	X	X	X	X	0.54%	
2016	64	64	0	64	0	64	0	X	X	X	X	X	X	0	
2017	26	26	0	26	0	X	X	X	X	X	X	X	X	0	
2018	42	42	0	X	X	X	X	X	X	X	X	X	X	0	

Address	Street	NB	Cell	Species	plant year	Date	cause	Date	Serial
2,020.00	ARBUTUS ST	8.00	23.00	PAPEVN	3.00	05-06-2014	R-VANDAL	11-17-2014	141133
3,188.00	W 41ST AV	17.00	9.00	PAPEVN	3.00	11-12-2014	R-DEAD	02-26-2015	247669
2,802.00	E 21ST AV	16.00	13.00	PAPE	3.00	01-07-2014	R-DEAD	05-09-2016	243084
75.00	W BROADWAY	6.00	21.00	PAPEVN	3.00	03-04-2014	R-DEAD	11-09-2016	249138
2,706.00	E 3RD AV	5.00	8.00	PAPEVN	3.00	11-12-2014	R-DEAD	01-31-2018	250334
2,706.00	E 3RD AV	5.00	10.00	PAPEVN	3.00	11-12-2014	R-DEAD	01-31-2018	250335
2,706.00	E 3RD AV	5.00	12.00	PAPEVN	3.00	11-12-2014	R-DEAD	01-31-2018	250336
2,703.00	VENABLES ST	5.00	21.00	PAPEVN	4.50	01-19-2015	R-DEAD	06-16-2015	250164
2,064.00	W 36TH AV	12.00	2.00	PAPE	3.00	12-10-2015	R-DEAD	01-29-2016	243833
859.00	W 48TH AV	18.00	5.00	PAPE	3.00	12-04-2015	R-DEAD	03-22-2016	252839
2,008.00	W 41ST AV	17.00	22.00	PAPEVN	3.00	01-17-2015	R-DEAD	12-09-2016	251366
860.00	DRAKE ST	1.00	2.00	PAPEVN	3.00	04-28-2015	R-DEAD	05-25-2017	251981
833.00	SEYMOUR ST	1.00	2.00	PAPEVN	3.00	03-15-2016	R-DEAD	05-25-2017	251800
400.00	W GEORGIA ST	1.00	21.00	PAPEVN	3.00	03-15-2016	R-HAZARD	09-18-2017	252284

PAPE

motality rate by year

	planted	year1	motaility rate	year2	motaility rate	year3	motaility rate	year4	motaility rate	year5	motaility rate	year6	motaility rate	average	survival rate (5Y)
2013	57	57	0	57	0	57	0	57	0	57	0	57	0	0	100.00%
2014	105	105	0%	104	0.95%	102	1.92%	102	0%	99	3.03%	X	X	1.20%	94.29%
2015	133	132	0.75%	129	2.27%	128	0.78%	128	0	X	X	X	X	0.95%	
2016	192	192	0%	190	1.04%	190	0	X	X	X	X	X	X	0.35%	
2017	58	58	0	58	0	X	X	X	X	X	X	X	X	0	
2018	29	29	0	X	X	X	X	X	X	X	X	X	X	0	

Species code	**Scientific name**	**Common name**
PRYEAK	*prunus yedoensis*	Japanese flowering cherry
PAPE	*Parrotia persica*	Persian ironwood
CABEFA	*Carpinus betulus*	Common hornbeam
ACRU	*Acer rubrum*	Red maple
SXJA	*Styrax japonica*	Japanese snowbell
MGKO	*Magnolia kobus*	Magnolia
QUPA	*Quercus palustris*	Pin oak
FASY	*Fagus sylvatica*	European Beech

Name list of selected trees

Appendix B: tree removal and mortality cause working sheet

serial #	former species	personal damange				construciton damage	abiotic				water stress union disoder	biotic (pest)	notes
		basal damage	vandalism	poor planting	MVA		thing/small canopy	Wilted or scorched leaves	dead or broken branch	CRACK		leaf spot/ blight/ holes	
158313	ARISTOCRAT PEAR	X											
141369	EASTERN REDBUD				X								
141410	EASTERN REDBUD	X											
140355	EASTERN REDBUD			X			X						
140512	EASTERN REDBUD	X					X						
161921	SNOWBIRD HAWTHORN												healthy
107581	PACIFIC SUNSET MAPLE	X											
144990	PACIFIC SUNSET MAPLE	X											
233492	PYRAMIDAL EUROPEAN HORNBEAM		X										cown is vigorus
249328	GREEN PILLAR PIN OAK												removed
138616	CHANTICLEER PEAR			X								x	naturally occurring disease (Pear Trellis Rust)
234762	CHANTICLEER PEAR			X			X	X	X				
254827	DAWN REDWOOD						X	X	X				
253646	DAWN REDWOOD						X	X	X				
254829	DAWN REDWOOD												
254830	DAWN REDWOOD												recovering itself
249201	JAPANESE STEWARTIA										X		100% dead
249222	JAPANESE STEWARTIA												healthy
161659	EMERALD QUEEN NORWAY MAPLE												removed
88880	GREEN PILLAR PIN OAK	X											
257468	GREEN PILLAR PIN OAK												healthy
211504	CHINA GIRL DOGWOOD											X	
252377	EUROPEAN BEECH		X						X		X		100% dead
231825	PRINCETON GOLD MAPLE												Pruning wound but look healthy
233570	EDDIES WHITE WONDER DOGWOOD									X	X	X	athranose
251406	GREEN PILLAR PIN OAK												removed
69360	VANESSA PERSIAN IRONWOOD										X		completed dry, location is across the road
11274	JAPANESE SNOWBELL	X							X				
234104	JAPANESE SNOWBELL												there's a eastern red bud that is dead
252091	KINDRED SPIRIT OAK					X							
251767	AMERICAN HORNBEAM					X							
251644	AMERICAN HORNBEAM					X	X						
251645	AMERICAN HORNBEAM					X							
251781	AMERICAN HORNBEAM					X							
255686	NIGHT PURPLE LEAF PLUM						X			X	X		
255687	NIGHT PURPLE LEAF PLUM											X (hole)	
249923	APPLE SERVICEBERRY			X			X	X					
249924	APPLE SERVICEBERRY			X			X	X					
249925	APPLE SERVICEBERRY			X			X	X					
33431	JAPANESE STEWARTIA	X							X				
251526	BRANDYWINE RED MAPLE	X											
227526	GINKGO OR MAIDENHAIR TREE												healthy
242877	EASTERN REDBUD	X							X				
242886	EASTERN REDBUD		X						X				
223549	BOWHALL RED MAPLE						X	X					
245809	SNOWCONE JAPANESE SNOWBELL	X							X				
248704	SNOWCONE JAPANESE SNOWBELL				X				X				
248705	SNOWCONE JAPANESE SNOWBELL	X							X				
141513	EUROPEAN BEECH		X				X	X	X				
253663	NOOTKA CYPRESS		X					X					
251233	EUROPEAN BEECH		X				X	X	X				
231586	NOOTKA CYPRESS		X					X					
251235	EUROPEAN BEECH								X		x		completed dead
243017	EDDIES WHITE WONDER DOGWOOD		X			X							
243015	EDDIES WHITE WONDER DOGWOOD					X							
230483	KATSURA TREE							X					
204265	JAPANESE HORNBEAM												replaced with big leaf maple
256492	MAGNOLIA ‘VICTORIA’	X							X				
258799	MAGNOLIA ‘VICTORIA’	X							X				gildling roots?
161938	OSAKAZUKI JAPANESE MAPLE						X	X			X		
244088	OSAKAZUKI JAPANESE MAPLE						X	X			X		
244090	OSAKAZUKI JAPANESE MAPLE						X	X			X		
166954	CRIMSON SENTRY NORWAY MAPLE		X						X		X		100% dead
216272	BOWHALL RED MAPLE		X						X		X		100% dead
243983	JAPANESE STEWARTIA						X					X	
144673	KATSURA TREE	X						X		X			
174091	KOBUS MAGNOLIA					X							
174126	MAGNOLIA ‘VULCAN’						X						
146465	ENGLISH HOLLY												there are three more big holy in front of the house
233971	KATSURA TREE												removed
180654	MAGNOLIA ‘CAERHAYS BELLE’	X							X				
207843	MAGNOLIA WADA’S MEMORY						X	X				X	
222570	FALL GOLD BLACK ASH												removed
220726	CHANTICLEER PEAR					X							
224751	GOLD LEAF BLACK LOCUST												epicormic branches (suckering on the main stem)
177145	CHINESE KOUSA DOGWOOD								X				water stress union disorder
164395	PYRAMIDAL EUROPEAN HORNBEAM												grafting
202727	TREE LILAC	X			X								MVA
247030	AUTUMN APPLAUSE ASH												removed
227011	PYRAMIDAL EUROPEAN HORNBEAM												

245333	AUTUMN BLAZE RED MAPLE												removed
220660	EUROPEAN BEECH												removed
248235	AUTUMN FLAME RED MAPLE												removed
233139	MAGNOLIA ‘YELLOW BIRD’												removed
199603	PYRAMIDAL EUROPEAN HORNBEAM												replaced
232749	PYRAMIDAL EUROPEAN HORNBEAM												removed
253100	RISING SUN REDBUD	X							X				CRACKS at base
248162	CHINESE KOUSA DOGWOOD			X									
27456	EASTERN REDBUD												Healthy
199786	JAPANESE SNOWBELL												healthy
244920	TOBA HAWTHORN	X							X				close to the cable pole
220949	FALL GOLD BLACK ASH												removed
171504	FALL GOLD BLACK ASH												removed

X

Appendix C: bioremediation treatment control study record sheet (street trees)

Name: **Recording date:**

treated/ control	NB	address	street	cell	serial	code	species	GPS	height	condition (0dead, 1poor, 2 fair, 3 good, 4 excellent)				shoot growth	signs of diorders
										leaf color	leaf size	crown density	overall vigor		
c	14	11	PEVERIL AV	1	6177	ACGR	acer griseum								
c	14	11	PEVERIL AV	4	28637	ACGR	acer griseum								
c	14	11	PEVERIL AV	5	35922	ACGR	acer griseum								
c	14	11	PEVERIL AV	6	28693	MGKO	magnolia kobus								
c	14	25	PEVERIL AV	1	28694	ACGR	acer griseum								
c	14	25	PEVERIL AV	6	28832	ACGR	acer griseum								
c	14	37	PEVERIL AV	3	8004	ACGR	acer griseum								
t	14	45	PEVERIL AV	6	35905	ACGR	acer griseum								
t	14	45	PEVERIL AV	3	18924	MGKO	magnolia kobus								
t	14	55	PEVERIL AV	5	35919	ACGR	acer griseum								
t	14	69	PEVERIL AV	7	26387	ACGR	acer griseum								
t	14	75	PEVERIL AV	4	28621	ACGR	acer griseum								
t	14	83	PEVERIL AV	5	28695	ACGR	acer griseum								
t	14	87	PEVERIL AV	6	35899	ACGR	acer griseum								
t	16	5274	CLARENDON ST	3	245636	ACPLCO	acer platanoides								
t	16	5306	CLARENDON ST	3	245639	ACPLCO	acer platanoides								
t	16	5320	CLARENDON ST	3	245641	ACPLCO	acer platanoides								
t	16	5334	CLARENDON ST	3	245643	ACPLCO	acer platanoides								
c	16	5348	CLARENDON ST	3	245645	ACPLCO	acer platanoides								
c	16	5392	CLARENDON ST	2	245651	ACPLCO	acer platanoides								
t	16	5428	CLARENDON ST	3	245654	ACPLCO	acer platanoides								
t	16	5434	CLARENDON ST	1	245656	ACPLCN	acer platanoides								
c	16	5454	CLARENDON ST	3	245659	ACPLCO	acer platanoides								
c	16	5470	CLARENDON ST	6	253925	ACPLCO	acer platanoides								
c	16	5534	CLARENDON ST	6	245667	ACPLCO	acer platanoides								
t	16	2319	E 33RD AV	2	245933	CABEFA	carpinus betulus								
t	16	2327	E 33RD AV	7	248208	ACRUBH	acer rubrum								
c	16	2327	E 33RD AV	1	245935	CABEFA	carpinus betulus								
c	16	2341	E 33RD AV	1	245940	CABEFA	carpinus betulus								
t	16	2357	E 33RD AV	1	245944	ACRUBH	acer rubrum								
t	16	2365	E 33RD AV	1	245946	CABEFA	carpinus betulus								
t	16	2373	E 33RD AV	2	245950	ACRUBH	acer rubrum								
t	16	2393	E 33RD AV	1	245938	ACRUBH	acer rubrum								
c	16	2322	E 33RD AV	7	245932	ACRUBH	acer rubrum								
c	16	2328	E 33RD AV	3	245936	ACRUBH	acer rubrum								
c	16	2334	E 33RD AV	3	245937	CABEFA	carpinus betulus								
c	16	2340	E 33RD AV	2	245939	ACRUBH	acer rubrum								
c	16	2346	E 33RD AV	1	245941	CABEFA	carpinus betulus								
c	16	2354	E 33RD AV	1	245943	ACRUBH	acer rubrum								
c	16	2366	E 33RD AV	2	245947	ACRUBH	acer rubrum								
c	16	2374	E 33RD AV	2	245951	CABEFA	carpinus betulus								
c	16	2380	E 33RD AV	1	245953	ACRUBH	acer rubrum								
t	16	2392	E 33RD AV	7	245955	CABEFA	carpinus betulus								
t	16	2396	E 33RD AV	7	245956	ACRUBH	acer rubrum								
t	16	2404	E 33RD AV	4	245957	CABEFA	carpinus betulus								
t	16	2428	E 33RD AV	1	245961	ACRUBH	acer rubrum								
t	16	2436	E 33RD AV	2	245962	CABEFA	carpinus betulus								
c	16	2466	E 33RD AV	4	245967	ACRUBH	acer rubrum								

t	16	2480	E 33RD AV	5	245969	ACRUBH	acer rubrum								
c	21	2468	E 54TH AV	5	233497	PAPEVN	parrotia persica								
c	21	2488	E 54TH AV	5	233498	PAPEIV	parrotia persica								
c	21	2520	E 54TH AV	5	233569	PAPEIV	parrotia persica								
t	21	2536	E 54TH AV	2	233590	PAPEVN	parrotia persica								
t	21	2536	E 54TH AV	7	233601	PAPEVN	parrotia persica								
t	21	2552	E 54TH AV	3	233608	PAPEVN	parrotia persica								
c	22	3205	E 51ST AV	24	138849	ACCP	acer cappadocicum								
c	22	3205	E 51ST AV	20	139590	ACCP	acer cappadocicum								
c	22	3205	E 51ST AV	22	256391	ACCP	acer cappadocicum								
t	22	3191	E 52ND AV	12	249283	ACCP	acer cappadocicum								
t	22	3191	E 52ND AV	8	253192	ACCP	acer cappadocicum								
t	22	3191	E 52ND AV	10	254961	ACCP	acer cappadocicum								

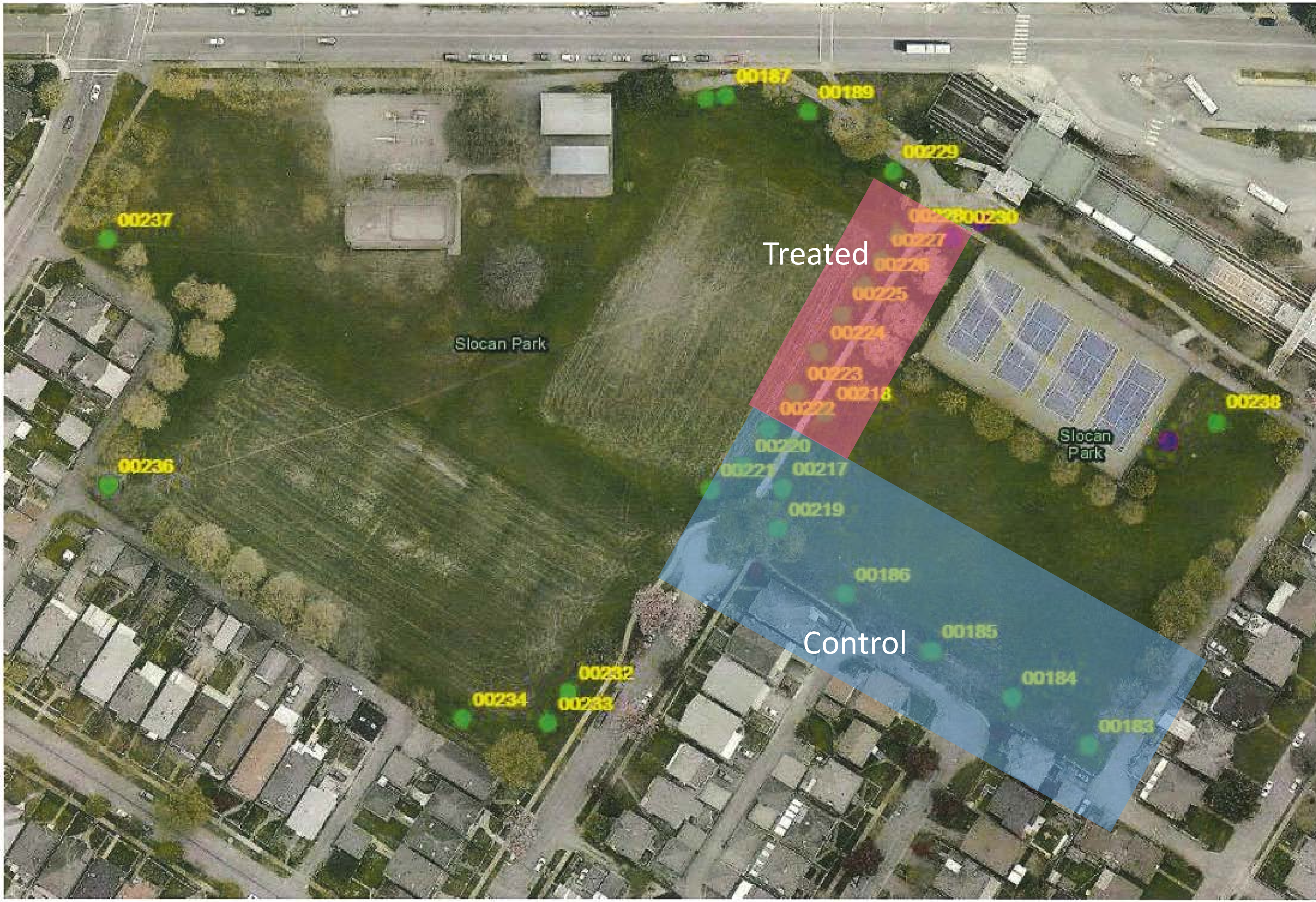
Appendix D: bioremediation treatment control study record sheet (park trees)

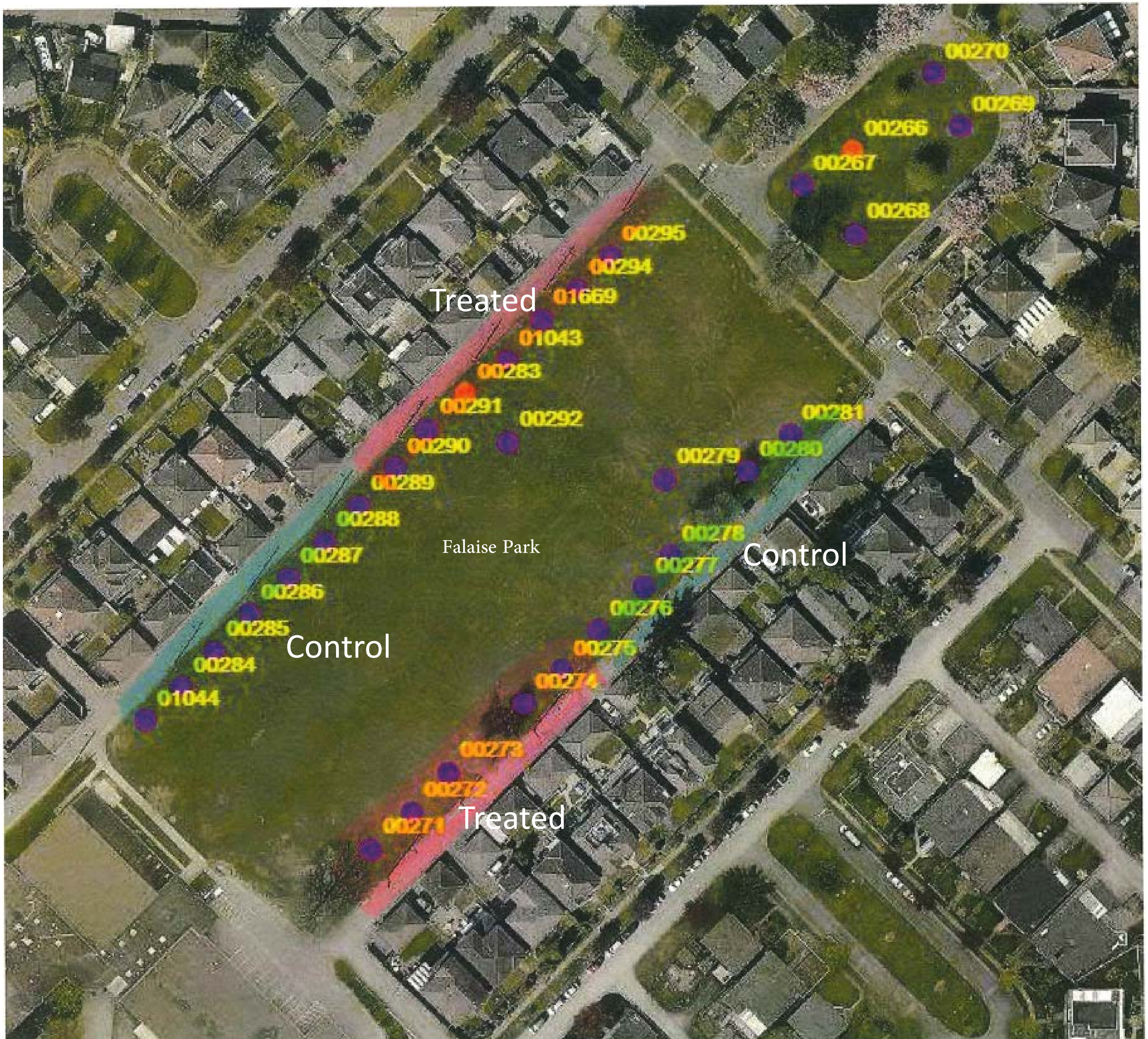
Name: **Recording date:**

park	treated/ control	No	code	species	GPS	height	condition (0dead, 1poor, 2 fair, 3 good, 4 excellent)				shoot growth	signs of diorders
							leaf color	leaf size	crown density	overall vigor		
Falaise	t	271	CRMRSB	Crataegus mordenensis								
	t	272	ACGR	Acer griseum								
	t	273	PRVIBS	Prunus virginiana								
	t	274	ACGR	Acer griseum								
	c	275	ACPABG	Acer platanoides								
	c	276	SXJA	Styrax japonica								
	c	277	CCCA	Cesas canadensis								
	c	278	PRVIBS	Prunus viginiana								
	c	279	ACGR	Acer griseum								
	c	280	ACCARS	Acer campestre								
	c	281	PRAVSK	Prunus avium								
	t	295	CCCA	Cesas canadensis								
	t	294	MGGRVC	Mognolia grandiflora								
	t	1669	PRVIBS	Prunus virginiana								
	t	1043	ACPABG	ACPABG								
	t	283	AECABR	Aesculus carnea								
	t	291	MGGRVC	Mognolia grandiflora								
	t	290	CCCA	Cesas canadensis								
	t	289	CRMRSB	Crataegus mordenensis								
	c	288	STPS	Stewartis pseudocamellia								
	c	287	PRVIBS	Prunus viginiana								
	c	286	ACGR	Acer griseum								
	c	285	MGGRVC	Mognolia grandiflora								
	c	284	SXJA	Styrax japonica								
	c	1044	PRVIBS	Prunus viginiana								
SLOCAN	t	183	ACXFAR	Acer Freemani								
	t	184	ACXFAR	Acer Freemani								
	t	185	ACXFAR	Acer Freemani								
	t	186	ACXFAR	Acer Freemani								
	t	219	ACXFAR	Acer Freemani								
	t	217	ACXFAR	Acer Freemani								
	t	218	ACXFAR	Acer Freemani								
	t	221	ACXFAR	Acer Freemani								
	t	220	ACXFAR	Acer Freemani								
	c	222	ACXFAR	Acer Freemani								
	c	223	ACXFAR	Acer Freemani								
	c	224	ACXFAR	Acer Freemani								
	c	225	ACXFAR	Acer Freemani								
	c	226	ACXFAR	Acer Freemani								
	c	227	ACXFAR	Acer Freemani								
	c	228	ACXFAR	Acer Freemani								
	c	230	ACXFAR	Acer Freemani								

ROSS	t	379	ACCARD	Acer campestre									
	t	380	ACCARD	Acer campestre									
	t	381	ACCARD	Acer campestre									
	t	382	ACCARD	Acer campestre									
	c	383	ACCARD	Acer campestre									
	c	384	ACCARD	Acer campestre									
	c	385	ACCARD	Acer campestre									
	c	386	ACCARD	Acer campestre									
	c	387	ACCARD	Acer campestre									
Memorial	t	1755	PYCACH										
	t	1683	ACGR	Acer griseum									
	t	1682	COKOST	Cornus kousa									
	t	908	ACGR	Acer griseum									
	t	909	COKOST	Cornus kousa									
	t	910	ACGR	Acer griseum									
	c	911	COKOST	Cornus kousa									
	c	912	ACGR	Acer griseum									
	c	913	COKOST	Cornus kousa									
	c	914	ACGR	Acer griseum									
	c	915	COKOST	Cornus kousa									
	c	916	ACGR	Acer griseum									
	c	917	COKOST	Cornus kousa									
	c	918	ASGR	Acer griseum									
	t	896	MGGREB	Mognolia grandiflora									
	t	895	COKOST	Cornus kousa									
	t	894	NYSY	Nyssa sylvatica									
	t	893	COKOST	Cornus kousa									
	t	892	MGGREB	Mognolia grandiflora									
	c	454	MGGREB	Mognolia grandiflora									
	c	455	COKOST	Cornus kousa									
	c	456	MGGREB	Mognolia grandiflora									
	c	457	COKOST	Cornus kousa									
	c	458	MGGREB	Mognolia grandiflora									
	t	426	COKOST	Cornus kousa									
	t	428	COKOST	Cornus kousa									
	t	429	COKOST	Cornus kousa									
	c	430	PIPUHO	picea purpurea									
	c	427	PIPUHO	picea purpurea									
	c	1041	PIPUHO	picea purpurea									

Appendix E: soil bio-mediation study area (park tree sites)

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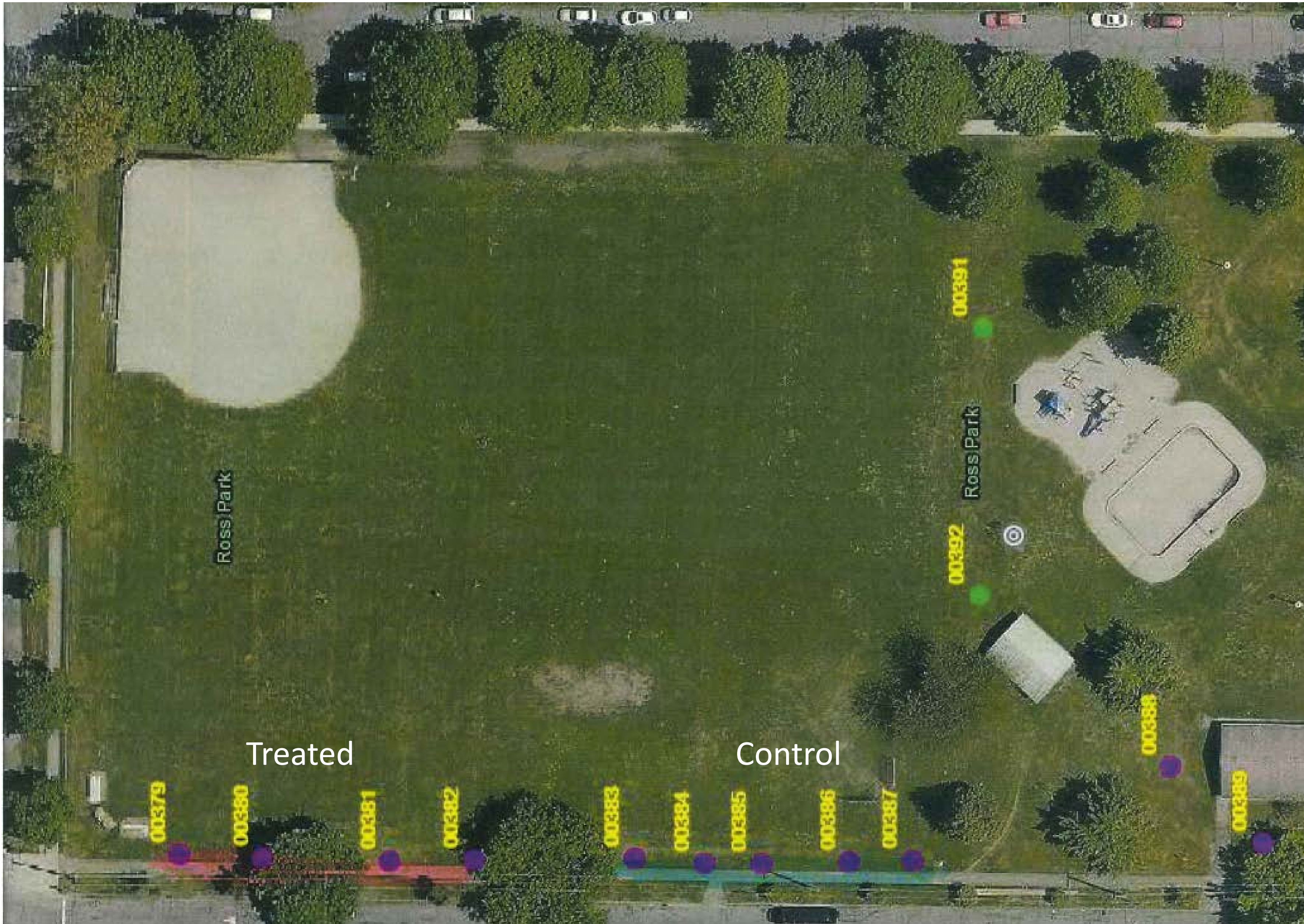
00268
00295
00294
Treated
01669
01043
00283
00291
00292
00290
00289
00288
00287
Falaise Park
00286
00285
Control
00284
01044
00281
00279
00280
00278
00277
Control
00276
00275
00274
00273
00272
00271
Treated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Ross Park
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Control
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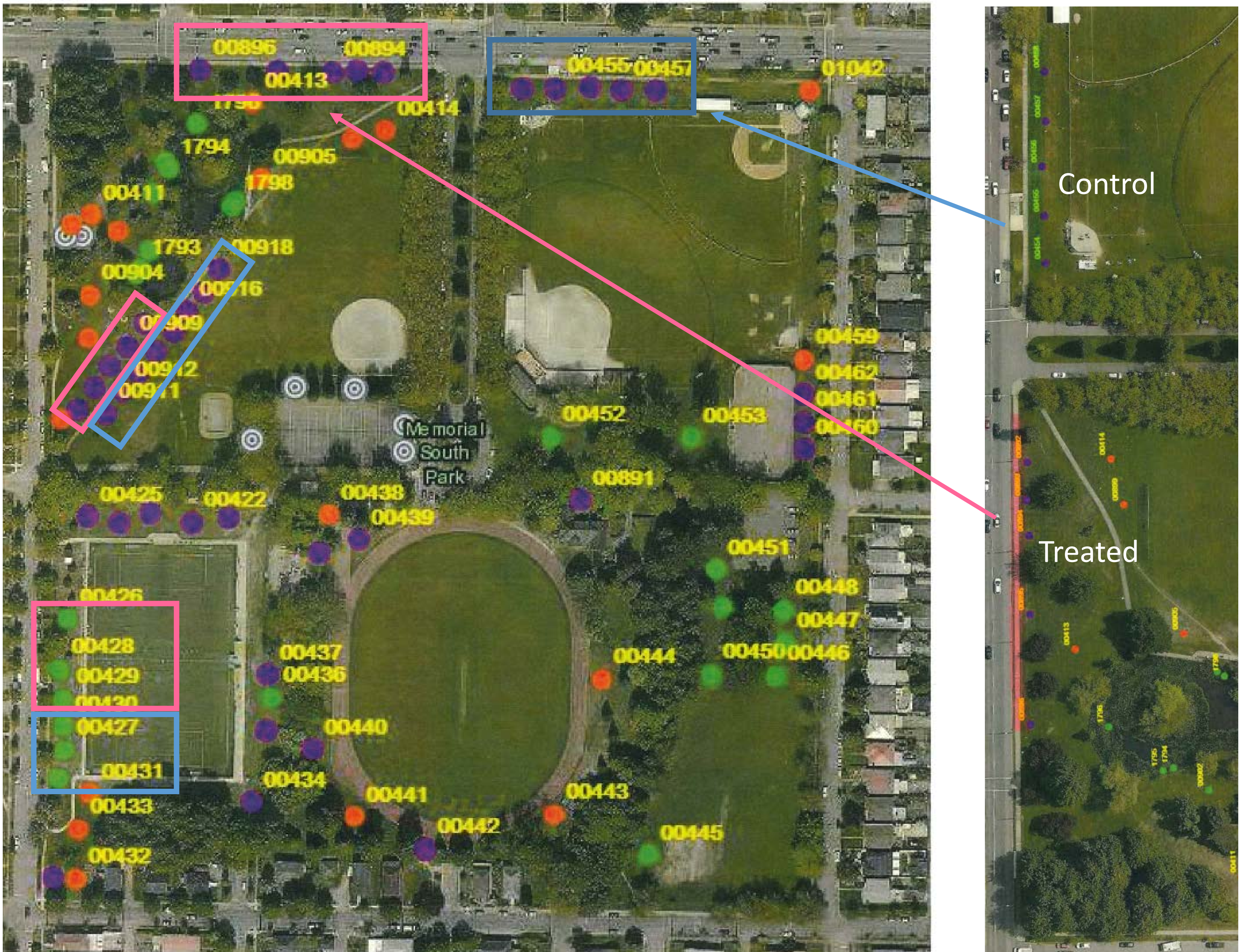
00389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00461
00452
00453
Memorial
South
Park
00891
00425
00422
00438
00439
00451
00448
00447
00426
00428
00429
00437
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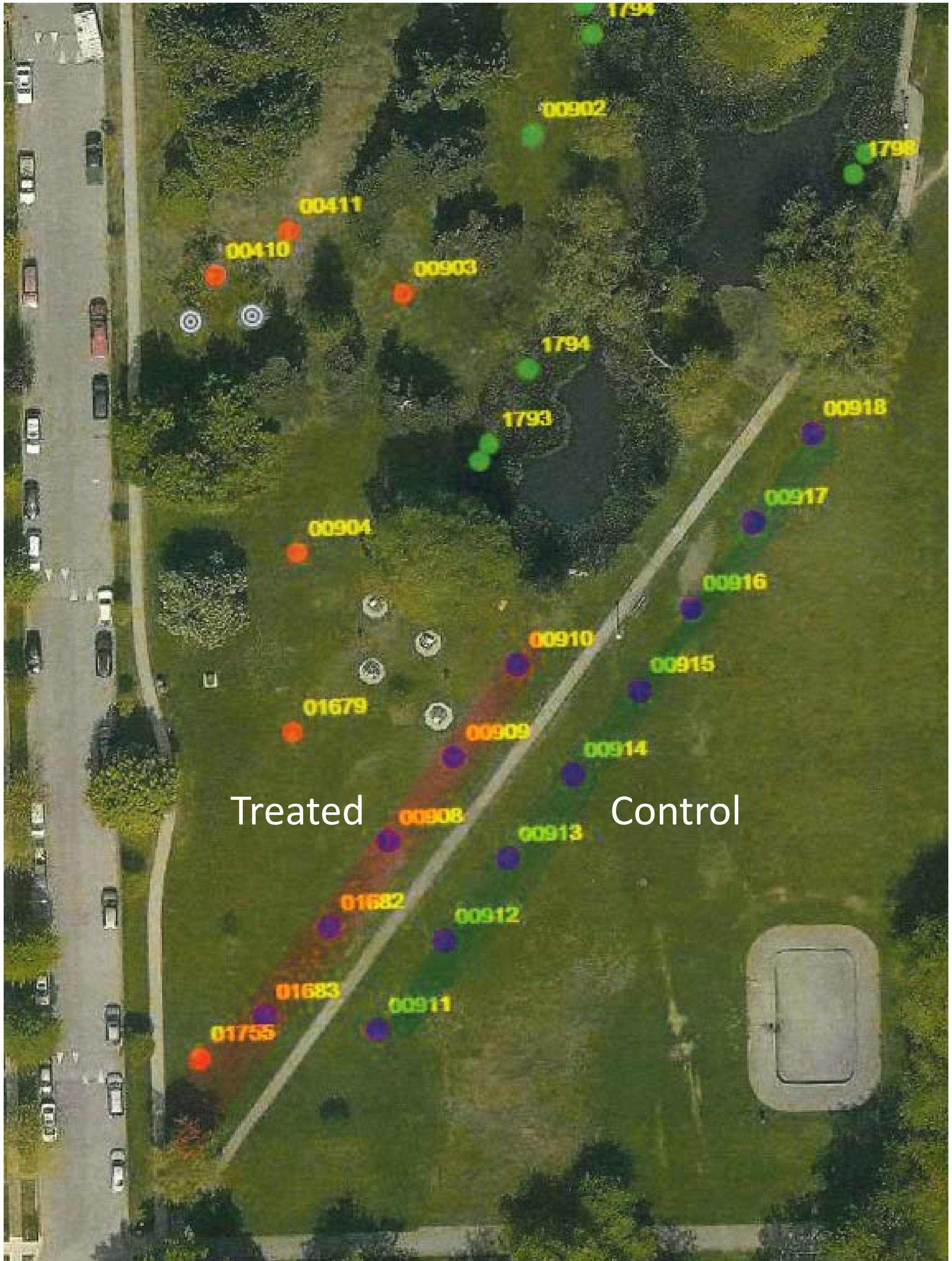
Control
Treated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00914
Treated
00908
Control
00913
01682
00912
01683
00911
01755


00425
00424
00423
00426
Treated
00428
00429
00430
Control
00427
01041
00431
00433
00432