Recommendations to improve the health of Vancouver's street trees surrounded by hardscape

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Urban forestry isn't a new practice and the author would like to acknowledge and recognize the long-standing maintenance and planting of trees by Indigenous peoples in British Columbia, long before settlers adopted the term 'urban forestry' we use today. As a white academic, the author is responsible for educating other settlers on the history of land management prior to colonization, making spaces for Indigenous voices in institutions where they have historically been marginalized, and working to reframe the ways plants are botanically taught and represented. The author invites you to read ***Plant Management Systems of British Columbia's First Peoples*** (2014) by Nancy Turner, Douglas Deur, and Dana Lepofsky to learn more about Indigenous tree management in British Columbia.

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EXECUTIVE SUMMARY

With most of the world's population living in cities, trees are critical green assets to increase the livability of urban areas in a changing climate while accommodating continuing densification. Within urban streets, municipalities often plant trees in the public realm which must tolerate limited growing space not experienced by trees growing in the unrestricted soils of parks and within native forests. Built 'grey' infrastructure (sidewalks and roadways) and 'green' infrastructure (trees) are in direct competition for space in the street right-of-way on top of the increased pressure of climate change. Within the constraints of the built environment, the typical average life expectancy of an urban tree is between 19-28 years, and trees only make significant carbon mitigation returns when they reach mature age (Turner-Skoff & Cavender, 2019; Roman & Scatena, 2011). Urban street trees struggle to live long enough to provide enough benefits to store substantial carbon. While growing the urban forest is a desired outcome, the walkability and condition of sidewalks can often be in direct conflict with the roots of trees as they attempt to obtain available water and nutrients, resulting in damaged hardscapes and increased costs to repair sidewalks and streets.

This report explores methods to improve the health of existing and new street trees in hardscape infrastructure in Vancouver through evaluation of research, comparison of peer municipal practices and case studies, and analysis of current city trends. Recommendations are provided for Vancouver's existing design and management standards and specifications for trees in hardscaped areas. Three objectives of the project include providing recommendations for below and at-ground practices to:

- Improve the overall health and longevity of **existing street trees** surrounded by hardscape while maintaining sidewalks in good, accessible condition;
- Situate **newly planted street trees** for success around hardscapes; and,
- Identify the impacts of **current sidewalk and boulevard design** on existing street tree health with focus on areas of low canopy cover.

Key findings

- Vancouver's current minimum standard boulevard width is smaller compared to other municipalities;
- Vancouver's tree selection list is the least extensive compared to other municipalities; and
- Vancouver's Standard Drawings pertaining to street trees and tree pit design are limited in comparison to other municipalities.

Several case studies and data analysis, alongside interviews with staff, provide a snapshot view of what is currently working and a map of potential locations to explore for planting site retrofitting based on equitable target areas. Key findings from the data analysis include:

- Street trees planted in tree cutouts (pits) have higher mortality rates than other planting locations
- Smaller boulevard widths are associated with more trees heaving sidewalks
- Street trees planted in cutouts have less mature and old trees compared to other planting locations such as grass boulevards

Finally, a list of recommendations the City of Vancouver can take based on six key goals is provided including:

- Increasing the standard boulevard width for new boulevards with street trees from **1.2 meters to 2 meters**;

- Targeting tree pit retrofitting, sidewalk repair efforts, and future green rainwater infrastructure initiatives in **areas of low canopy**, particularly in areas with **disproportionately impacted populations**;
- Requiring appropriate **soil volume** must be achieved before planting a new street tree; and
- Consideration of an **'Adopt-a-tree-pit" pilot-project** for assistance in tree pit maintenance.

While urban densification and climate change continue to place pressures on growing an urban forest that can sustain future populations, there are cost-effective actions that can be taken to maintain walkable and safe streetscapes while providing conditions to grow healthy and long-lasting street trees that live beyond the 19-28 year average age.

GLOSSARY

Buttress root - species specific roots that form at the ground surface to stabilize a shallow-rooting tree species.

Engineered soil ('structural soil') - Soil utilized often under sidewalks and/or utilities to create additional growing medium for tree roots while providing structural support for the sidewalk using a mix of compacted gravel and soils.

Green rainwater infrastructure (GRI) - a suite of rainwater management tools utilizing both engineered and nature-based solutions to protect, restore, and mimic the natural water cycle (City of Vancouver, 2019)

Grey infrastructure – human engineered infrastructure for water resource such as water and wastewater treatment plants, pipes, pump stations, and detention tanks (City of Vancouver, 2019).

Hardscapes – environments with many surfaces that water and other liquids cannot pass through (City of Vancouver, 2019).

Permeable - surface allowing water to pass through (e.g. uncompacted soil). Opposite is 'impermeable' (e.g. concrete sidewalk).

Soil porosity - the percentage of open space between particles of soil. The higher a soil's porosity, the higher proportion of open space in a soil, enabling water and air to flow through. Compacted soils have a low soil porosity, limiting water and air movement.

Urban forest - System of trees in cities, suburbs, towns, and other urbanized areas, including public and private lands, spanning street trees and residential yards as well as highly designed and natural parks (Miller et al., 2015).

Summary of conditions that have allowed trees and sidewalks to thrive in Vancouver

Plant drought-tolerant species with no buttress roots

Maximize boulevard width

Maximize soil volume below-ground using Engineered soils

Maintain a strict watering schedule

Remove tree grates and panels before maturity

Limit asphalt fill in the tree pit

Provide mulch for young trees

Utilize permeable sidewalk materials around heaving roots

Minimize root pruning and reroute sidewalk where possible

Implement trees in GRI systems

Maintain surface porosity while limiting surface compaction

Reroute curbs by installing mid-block bump-outs

30% canopy cover was found to reduce premature deaths from heat by 1/3rd. Vancouver's current canopy cover city-wide is 23%.

INTRODUCTION

30% Canopy Cover by 2050

Canopy cover is the measure of a tree's crown when viewed from an aerial 'bird's-eye' view and is one metric that can help cities set planting targets. In 2020, Vancouver's current canopy cover was just 23% and the City has set a target to grow the urban forest to 30% by 2050. 30% has been observed as a global benchmark for cities, adopted by Seattle and similar (33%) in Portland, Oregon. One recent study found a canopy cover of 30% can reduce premature deaths from the urban heat island by 1/3rd (Barcelona Institute for Global health, 2023).

Highly impermeable areas and heavily built infrastructure are typically associated with less canopy cover; in 2018, half of Vancouver's city blocks were found to exceed 50% impermeability and once impermeability exceeds 50%, tree canopy typically averages less than 10% as observed in eastern portions of the city (City of Vancouver, 2018). In April 2023, the Vancouver Park Board set a strategy to plant 100,000 trees by 2026; however, easily planted sites in streets are falling short and many existing sites are surrounded by hardscapes, conflict with underground infrastructure, and are limited by soil volume (Chan, 2023). To plant more trees in these challenging areas, unique design solutions are required to grow a large, mature, and healthy urban forest.

Who is involved?

Many actors across numerous City departments are responsible for the health of the urban forest at various steps of a tree's life. Vancouver's Engineering Services department oversees public street design, including development approval. The Planning, Urban Design, and Sustainability department is involved where new development requires a tree removal permit application. Within the Vancouver Board of Parks and Recreation (VBPR), the Planning and Development department is tasked with fulfilling goals from guiding policies such as the Urban Forest Strategy, whereas the Operations and Engineering Department is responsible for the operations and management of the urban forest. Figure 1, adapted from Cindy Cheng's *Growing a resilient and equitable urban forest report* (2019), outlines the departments and shared responsibilities of the urban forest.

Figure 1. Departments responsible for Vancouver's trees and sidewalks in the right-of-way

How are trees and sidewalks regulated?

A series of policies, research, standards, and specifications are in place to help regulate the public urban forest and streetscape in Vancouver. This project focuses on publicly owned City trees and sidewalks in the street right-of-way (ROW). Figure 2 illustrates the guiding, supporting, and informing policies and standards pertaining to trees in the ROW that specifically informed this project.

POLICIES THAT GUIDE	*Urban Forest Strategy* *Equity Framework* *Climate Change Adaptation Strategy*
POLICIES & RESEARCH THAT SUPPORT	*Climate Emergency Action Plan* *Transportation 2040* *Rain City Strategy* *Rethinking Street Pavement Rehabilitation Practices to Support the Urban Forest* *Growing an equitable and resilient urban forest*
STANDARDS & SPECIFICATIONS THAT MANAGE	*Standard detail drawings* *Construction Specifications* *Engineering Design Manual*

Figure 2. Policies, research, standards, and specifications that regulate the urban forest and streetscape in Vancouver.

GUIDING

Urban Forest Strategy (2018)

Vancouver's Urban Forest Strategy is a guiding policy that highlights key data findings on the state of the urban forest to provide goals, strategies, and actions to create a healthier urban forest that can sustain generations. Actions most relevant to this study include:

- **Action 21** – Update the Street Tree Guidelines for the Public Realm to reflect best practices and set targets for soil volume to support healthy mature trees
- **Action 14** – Update tree selection guidelines to reflect the city's goals for climate adaptation, rainwater management, food production, biodiversity, and reconciliation

In addition, the Strategy calls for a need for innovative solutions including:

- Installation of new planting cutouts in predominantly paved areas of City
- Integration of trees into GI assets to offset stormwater peak flows
- Conversion to species better suited to climate change and abiotic stressors
- Identification of cross-departmental synergies and collaboration

Equity Framework (2021)

The City's Equity Framework highlights neighbourhoods with higher populations of equity-denied groups often have access to less canopy cover and a higher coverage of impervious surfaces. The vision for an equitable city is: "*We envision a city where those who are most marginalized are not excluded from care and opportunity for flourishing, rather, they are systemically prioritized for it*."

Climate Change Adaptation Strategy (2021)

Preserving and growing the urban forest will contribute to both climate change mitigation and adaptation with research showing the urban forest can dramatically reduce regional temperatures. The Strategy acknowledges a few key objectives and actions supporting this project including:

- Objective 5.2 - increase the long-term health and vigour of urban forests, green spaces and trees
- Ensure species and location selection criteria in the landscape guidelines reflect future climate projections and any Urban Heat Island Effect mapping

SUPPORTING

Climate Emergency Action Plan (2019)

The Plan sets a key target to reduce the City's carbon pollution by 50% by 2030 and to become carbon neutral by 2050. Growing healthy, mature trees, will work to store and sequester carbon as a part of the plan.

Transportation 2040 (2019)

Transportation 2040 is Vancouver's long-term strategic vision, guiding land use decisions and public investments. It sets several key actions relevant to street trees to provide a blueprint for improved pedestrian realm design. Key action W 1.6.2 states:

"Explore opportunities to improve local ecology when designing and (re)building streets and other rights-of-way, for example by improving wildlife habitat and stormwater management, restoring native flora, increasing the ***number, size, and health of street trees,*** *and daylighting lost streams."*

Rain City Strategy (2019)

The Rain City Strategy is the City's initiative for green rainwater infrastructure and rainwater management with the goals of improving and protecting water quality, increasing resilience through sustainable water management, and enhancing livability by improving natural and urban ecosystems. The initiative recognizes trees as critical for absorption of rain and a key element of green rainwater infrastructure (such as rainwater tree trenches), which provides larger soil volumes and more reliable sources of water for healthier and more mature trees.

Rethinking Street Pavement Rehabilitation Practices to Support the Urban Forest (2022)

This report by a previous Sustainability Scholar explores the relationship between street and sidewalk pavement rehabilitation to recommend a strategy to depave heavily impervious areas across Vancouver. The report identifies streets in need of rehabilitation or replacement and provides several key recommendations.

Growing an equitable and resilient urban forest (2019)

This report by a previous Sustainability Scholar supports the Vancouver Board of Parks and Recreation to provide a proactive plan with gaps and recommendations to increase canopy cover alongside equitable access to green space for residents of the Downtown Eastside.

MANAGING

Standard detail drawings (2019)

Vancouver has a set of general detail drawings specific to street trees that outline construction standards for utilities, sidewalks, and roads adjacent to trees. Drawings most applicable to the design and construction related to street trees include:

- G9.2 - Backfill Engineered Soil
- G10.2 - Tree four-piece tree surround

- G11.3 - Planting median planting
- G11.2 - Planting shrub and ground cover planting
- G11.1 - Planting grass area seeded

Vancouver is currently developing a process to provide standard Engineered soil details for general use along streets alongside construction methods for installing Engineered soil for tree pits.

Construction Specifications (2019)

To facilitate standard practice across the city for both City personnel and contractors, Vancouver's Construction Specifications provide standard practices for both planting area construction as well as tree planting. The specifications include stock acquisition, planting methods, watering and mulching, use of engineered soil, tree grates and root barriers, and tree pit establishment.

Engineering Design manual (2019)

For both capital projects and contracted private development where public trees are involved, Vancouver's Engineered Design manual outlines standards for design practices including utilities setbacks and clearances, species selection, tree placement, soil volume, street horticulture, and growing medium.

Where are trees planted in the right-of-way?

Tree planting in hardscaped rights-of-way can be divided into two major classifications for the purpose of this report (Figure 3) including:

(1) Grass boulevards

(2) Tree cutouts (or tree pits)

Typically, grass boulevards are in lower pedestrian foot-trafficked areas such as residential streets and include a lawn boulevard with open soils. Tree cutouts are installed in highly constructed built environments which see a large pedestrian footprint where trees are typically situated within a concrete panel surround, metal grate, or open pit. Cutouts are either continuous and connect soil volume between trees or are closed, providing only growing material for a single street tree. While planting requirements must follow the City's Construction Specifications and Engineering Design Manual, Streetscape design guidelines are provided for 26 key areas of the city to further determine standard planting requirements and for all city areas, sidewalk and landscape guidelines are provided for commercial, lane, and residential areas.

For the purpose of this report, recommendations apply to trees and adjacent sidewalks in both grass boulevards and tree cutouts. Both site designs are required under different conditions in the urban forest and must contend with limitations from underground utilities, above-ground infrastructure, and limited soil volumes.

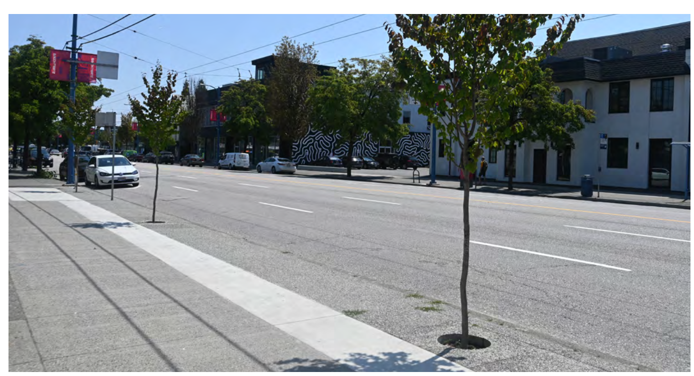


Figure 3. Trees in grass boulevards (left) and located in cutouts (or tree pits) (right)

Visualizing constraints of trees in hardscapes

Street trees surrounded by hardscapes are planted in a variety of limited site conditions and vary in successes of the below and at-ground design including the surrounding sidewalk, surface treatment, and availability of rootable soil volume. The images below introduce typical tree planting site conditions and practices limiting tree health and sidewalk condition in Vancouver, to be discussed throughout the report.

Limited soil volumes

Mature trees can cause significant sidewalk panel lift as roots attempt to access water and nutrients.

Sidewalk heaving

Temporary asphalt fill is typically used to address sidewalk heaving and trippable hazards caused by root lift.

Narrow boulevards

Small boulevards under the current minimum 1.2 meter boulevard requirement limit room for new plantings.

Tree pit maintenance

Weeds compete with a newly planted tree for water and nutrients in a four-paneled tree pit cutout design.

Compacted soils

Without a surface treatment in a high-pedestrian area, soils can become heavily compacted.

Poor drainage

Drainage challenges can impact the health of a tree. Heavily compacted soils can lead to decreased water filtration.

Surface repairs

As trees outgrow pits, surface repairs are often costly and can pose a tripping risk for pedestrians.

Regular inspection

Permeable surface treatments require cleaning and maintenance to ensure porosity is maintained.

LITERATURE REVIEW

Introduction

Street tree planting is a long-standing practice, occurring in the earliest of urban cities as a form of green infrastructure (Thuring, 2016). One of the earliest known examples dates to 618-907 AD during the Tang Dynasty in China where planting fruit trees beautified streets and walls (Schafer, 1962). While most of the world now lives in urban areas, street trees are an essential asset for mitigating the impacts of climate change intensified in cities today (Konijnendijk, 2023). With the COVID-19 pandemic, the value and associated mental and physical benefits of urban trees and greenspaces has gained popularity in the public realm with a study finding an overall global increase in the appreciation of urban green spaces during the pandemic (Weinbrenner et al., 2021).

Over the last decade, a large body of urban forest research is interested in the impacts of the urban forest on human mental and physical health and the requirements to grow healthy trees is well-known; however, research to improve urban tree health in hardscaped areas remains limited. Throughout the literature, a series of practices were identified to improve the design of hardscapes and planting practices to maximize the health and longevity of trees while mitigating damage to the streetscape. To increase the body of research, municipalities can begin to adopt bold new practices alongside partnership with researchers to explore the effect on tree health and longevity (Jim, 2019).

Challenges for trees in hardscapes

In the urban forest, street trees in hardscapes experience constrained growing conditions often resulting in more physically restricted and stressed trees that can compromise public safety, reduce the lifespan of a tree, increase maintenance required and pressure budgets, and limit benefits provided (e.g. carbon sequestration and storage) while typically favoring pedestrian movement over a tree's needs (Jim, 2017). While cities often are looking to plant new trees, locating appropriate planting areas can be difficult, as trees need to be adapted to the presence of underground utilities, setback requirements, high pedestrian volume, building shade and wind tunnels, and aboveground infrastructure, including street furniture (Metro Vancouver, 2017).

The below-ground environment of a street tree is often challenging to observe, resulting in poor soil quality, entangled and girdling roots, reduction of tree canopy size, and a decline in overall tree condition (Jim, 2019). Trees already struggling in limited soil volumes can experience further decline with one or more compounding factors including inappropriate species selection, over or under watering, disease, and vehicular damage (Minnesota Pollution Control Agency, 2023).

Urban forest equity

In recent years, cities including Vancouver are setting targets to grow equitable urban forests by planting trees in low canopy areas. Historically, tree-planting trends in the urban forest often result in less canopy cover and higher impervious cover in under-served neighborhoods, resulting in an increase in the urban heat island effect and increase in the mental and physical health challenges for the people who live in these areas (Nowak, 2022). By working together across a network of departments and through acceptance that green infrastructure, including trees, come with unknown outcomes and a certain level of uncertainty, cities can incorporate ecological science within the existing built environment to offset the impact of human cohabitation with the landscape (Thuring, 2016).

Selecting appropriate street trees

Adapting to a changing climate

Selecting the appropriate type of tree is critical to setting up a street tree for a changing climate. Hardiness zones are one standard metric used to determine appropriate tree selection based on climatic conditions across Canada (Natural Resources Canada, 2022). Vancouver's hardiness zone is projected to increase from 8 to 9 by the 2080s, resulting in a requirement for drought-tolerant trees in the future (Metro Vancouver, 2017). As part of Metro Vancouver Climate Adaptation Framework, the framework provided an urban tree list and species selection database as a guiding tool for cities based on tree species suitability for current and projected future climates. Of the 64 species currently listed in Vancouver's preferred street tree list as part of the Design Specifications, only 22% are very suitable for a changing climate and anticipated to tolerate a broad range of future sites (Metro Vancouver, 2017).

Selecting trees appropriate for urban areas

For street trees planted in dense urban areas within the Metro Vancouver region, trees should be selected that are deciduous, medium to large, provide shade from leaves, and are tolerant of drought to maximize benefits provided (Metro Vancouver, 2017). Trees species should also be favored that do not develop sizable buttress roots or aggressive root systems to mitigate the potential for tree roots to lift tree grates and damage underground utilities (Jim, 2017).

Selecting nursery stock

Selecting appropriate stock from the nursery is also critical to establishing young trees in their new planting site. A best practice is to obtain trees grown from seed and clonal stock from nurseries and to plant genetically diverse stock (Metro Vancouver, 2017).

Establishing healthy soils

Soil amendments

In heavily compacted planting sites with little topsoil, applying a soil amendment can be a cost-effective upfront strategy to improve the establishment of young trees by increasing soil nutrients, water storage capacity, soil porosity, and reducing irrigation costs by providing greater access to moisture (Metro Vancouver, 2017). Compost is an amendment used to rebuild soil horizons over time and should be in the form of high-quality mature leaves, yard waste, or food waste (Day, 2012; Smiley, 2008). A study found compost increased the soil fertility significantly for sites planted with *Styphnolobium japonica* (Japanese pagoda tree) in urban tree pits and improved soil physical characteristics when installed at a depth of ten centimeters (Qu et al., 2017). To install compost at a planting site, best practices recommend an application of a four-inch depth over compacted subsoil and testing to ensure weed seeds aren't present (Day, 2012).

In conjunction with compost, a well-researched soil amendment option is the use of biochar, a product created in the absence of oxygen through thermal degradation of organic materials like charcoal (Abrol and Sharma, 2019). In Montreal's urban forest, amending soils with biochar resulted in the greater retention of stormwater runoff contaminants, soluble trace metals, and de-icing salts for trees in tree pits when applied at a rate of 7.5% total dry weight (Sequin et al., 2018). One study found using a biochar-stone mix (termed the Stockholm system) compacted to 90% Proctor density alongside a slow-release fertilizer produced healthy trees and considered a suitable tree planting amendment (Ow et al., 2018).

Another potential soil amendment is application of artificial mycorrhizae to improve the uptake of nutrients in harsh urban environments which was found with varying results across studies to improve the growth of commonly planted street trees and ameliorate the effect of drought stress on trees, however, more research is needed (Szabo, 2014; Bainard et al, 2010).

Planting site design

Existing tree pit retrofitting

Across research from the literature review, expanding a planting pit surface can improve the health of a street tree by increasing water infiltration rates for street trees (Elliott et al., 2017; Nielsen et al., 2007). Best practices recommend expanding a tree pit as the first step to retrofit an existing tree pit (Deeproot, 2018). Where space allows, expanding the tree pit to provide at least 6 feet of adjacent pedestrian clear space is recommended, and where prohibitive, at least 8-10 feet of the tree pit can be expanded longitudinally (Deeproot, 2018). Larger tree pits are also associated with growing taller trees with larger diameters, contributing to more ecosystem services provided (Mullaney et al., 2015).

Trees can also be planted too high or too low compared to the surrounding hardscape resulting in drainage challenges and exposure of roots. Where the tree is planted too high, adjacent curbs can be raised and additional soil placed over exposed roots with use of an air spade to encourage root settlement (Deeproot, 2018). Where the tree planting is too low, best practices recommend expanding the tree pit and changing the grade gradually using free drainage soil or pea gravel (Deeproot, 2018).

Soil surface treatments and compaction

In highly trafficked areas, tree pits are often soil sealed using impermeable concrete and asphalt to prevent compaction, soil erosion, and to avoid trash accumulation over the top of roots and replaced with the pouring of new surface sealing material and roots pruned as the tree ages. This practice can create problems for the health of trees by limiting the ability for water to infiltrate and access of oxygen to roots need as well as an organic matter deficit and poor environment for microorganisms that cycle nutrients (Jim, 2017; Jim, 2019; Metro Vancouver, 2017). One study found cement covered tree pits have the lowest rates of permeability of soil under the cement, resulting in an insufficient water supply for street trees (Zhu et al., 2021).

Soils can also self-seal when not covered by paving, organic litter, or vegetation from the rain hitting soil and compaction from trampling, resulting in reduction of water and air infiltration (Jim, 2017). One study found the most significant factor for tree pits to increase infiltration rates of water was the presence of a guard (fence) around a tree pit which typically were associated with sites built up in surface elevation, planted with a ground cover or mulch, and with a larger pit area (Elliott et al., 2017). To address challenges with soil compaction, several strategies exist including (Metro Vancouver, 2017; Jim, 2019; Jim, 2017):

- For very high pedestrian traffic areas, open tree pits should include an edging treatment such as a tree guard (fence), grate, or surface treatment that maintains permeability.
- Installing porous pavement as a soil surface treatment while having the co-benefits of providing stormwater infiltration and a structural surface, but regular inspections and maintenance are required to prevent material clogging of pores.
- An iron grate can be utilized and filled with graded gravel or pea gravel
- Where an iron grate isn't needed, graded gravel can be bonded with an epoxy resin and planted with ground cover or shrubs

Mitigating damage to sidewalks

Damage to pavement in cities can result from roots obtaining water and air under the pavement which increases maintenance costs. The literature review identified several methods to mitigate damage caused by roots lifting and heaving sidewalks which can create tripping hazards and pose risks in high-traffic areas. The methods include (Jim, 2017; Deeproot, 2018):

- A gravel sub-base should be added to reduce pavement cracking and heaving under sidewalks
- Using a cantilevered paving system (e.g., suspended paving)
- Adding a raised deck over roots if already exposed
- Where pavement has been lifted, changing the grade surrounding the tree pit with a longer grade transition, allowing the hardscape to rise over the root area and back down

Working with utilities

Underground utilities are a limiting factor for tree planting in urban environments and damage to utilities often occurs as tree roots seek out water, nutrients, and oxygen found in water and sewage utilities, however, most tree growth limitations from underground utilities can be avoided through planting site design in the early stages (Jim, 2017; Jim, 2019; Metro Vancouver, 2017). Several recommendations and innovative solutions can address the impacts of trees alongside utilities including (Jim, 2017):

- Establishing utility zones for new planting sites using a utility duct, dedicated tree zone, or utility tunnel
- If needing to trench to fix existing utility or install new utility, a trenchless technique can be utilized which installs a micro tunnel under the root envelope, ramming the old pipe
- For new line alignment, trench alignment should detour or a trenchless method should be adopted away from the root protection zone
- Install flexible root barriers around vulnerable pipes to limit root intrusion
- Abandoned utilities can be removed or relocated

General site design – soil volume and spacing

Trees in downtown areas in impermeable hardscapes generally require planting site design that is more highly engineered than trees in residential areas. Tree pits commonly experience challenges with infiltration rates where surface treatments are limiting or where materials (e.g., leaves, sediment, plant debris) are blocking the flow path and must be maintained regularly (Minnesota Pollution Control Agency, 2023). One study found tree pits that included an underdrain to mitigate excess flow to reduce waterlogged soils increased tree growth nearly double that of a standard tree planting and even in tree pits with heavy clay soils, a 90% reduction in annual runoff can be achieved (Vaugn Grey, 2018; Vaugn Grey et al., 2018).

Installing open tree pits, covered soil trenches, and utilizing passive water harvesting (i.e. rain garden tree pit, pervious paving, infiltration trenches) are all recommended as best practices for street design in downtown areas as well as providing 0.6 m3 of soil for every one m2 of tree crown at a depth of one meter of soil (Metro Vancouver, 2017; Jim, 2017). Across the United States and Canada, 37 municipalities including Vancouver have a defined minimum soil volume as part of their design standards (Deeproot, 2022). Tree size and availability for connecting soil volume (e.g., using a covered soil trench) require varying specifications as best practice including (Metro Vancouver, 2017):

Tree size	Soil volume	Spacing	Permeability
Large	45-150 m3 per tree	12-15 m	150 m2
Medium	20-70 m3 per tree	10-14 m	70 m2
Small	15-30 m3 per tree	6-9 m	30 m2

Soil volume is a primary limiting factor in restricted urban environments that creates challenges for roots as they attempt to access the water, nutrients, and air required to maintain good health. While trees in tree pits may have access to appropriate soil volumes, layers holding up pavements and infrastructure are load bearing and compacted, resulting in limited accessibility of roots of most tree species (Ow et al., 2018).

Critical to the overall structure and stability of a tree, structural roots are restricted in hardscaped sites and typically include 5-15 or more roots between 1-2 meters of the tree trunk (Day, 2010). Pronounced buttress roots at the surface can be associated with poor soils that can result in poor root anchorage and lead to sidewalk and surface treatment damage (Day, 2010). By encouraging deeper soil roots through larger soil volumes, trees can access more water and nutrients through their non-woody fine roots and avoid conflict with the pavement, ultimately reducing the cost of maintenance and risk associated with sidewalk damage (Day, 2010).

Several methods exist to expand soil volume in areas and depend on costing, installation requirements, and longevity including (Metro Vancouver, 2017; Day, 2010; Jim, 2017; Ow et al., 2018):

- Constructing root paths through narrow channels of loose soil lined with aeration mats to connect soil volume areas or to nearby green patches
- Use of suspended pavement through an uncompacted soil trench with load-bearing edges supported by a concrete paver
- Installation of soil cells holding uncompacted soil for root growth. One study by Ow et al. found tree growth in structural cells to be 37% higher than in conventional planting pits.
- Using structural soils under sidewalks – careful consideration is required as the rock component reduces the total soil volume. One study by Ow et al. found a result of healthy trees when using a structural soil blend of 80% gravel and 20% clay loam suggesting a suitable use for tree planting.
- Tree species can be selected which generate deeper root systems

Sidewalk construction

Concrete and asphalt paving can reach surface temperatures of 48-68 degrees Celsius, contributing to increased temperatures in impervious urban areas known as the urban heat island effect in the construction of streets and sidewalks (UHI) (EPA, 2012). Impervious surfaces can reduce the root growth of trees in already limited planting areas by increasing the upper soil temperatures during the daytime (Mullaney et al., 2015). Traditional paving materials have limited life spans with Portland cement lasting between 15-35 years compared to asphalt lasting only 7-20 years with cheaper associated costs (EPA, 2012). Several construction methods and planning practices exist to reduce the environmental footprint in urban areas and tree impact including (EPA, 2012; Mullaney et al., 2015; Vaugn Grey et al., 2018):

- Narrowing street widths
- Lowering parking space requirements and providing incentives to build multi-level parking over surface lots
- Utilizing permeable pavement materials for sidewalk construction including porous asphalt, pervious concrete, permeable pavers, and grid pavements. Permeable paving reduces the catchment of water required by tree pits, mitigating challenges with water retention. A deep base layer is required between the paver and soil to promote a larger water holding capacity.
- Modifying conventional asphalt pavement using an asphalt binder mixed with sand or stone to raise the reflectance
- Installing non-vegetated permeable pavements with voids allowing water to drain while maintaining structural integrity including porous asphalt, rubberized asphalt, pervious concrete, brick, or block pavers
- Providing vegetated permeable pavements using grass pavers or concrete grid pavers with plastic metal or concrete lattices to support grass or other vegetation

Street tree establishment

General soil requirements

For general soil installation requirements for street trees, best practices include (Smiley, 2008; Metro Vancouver, 2017; Day, 2012):

- A minimum soil depth of one meter with at least 30 cm of subsoil covered with 30 cm of topsoil
- Scarify the base of the soil surface between each lift to avoid compaction
- Soil pH between 5.5-6.6 for British Columbia but species dependent and should be tested prior to planting
- Utilize aeration, rip, or deep till of soil prior to planting in heavily compacted areas
- Avoid amending a soil that will be backfilled and different from the texture around the planting hole
- For balled and burlap trees, match the planting site with the soil type provided
- Limit sources of contamination during construction around soils which can change the pH of the soil (e.g., liquid concrete, limestone gravel)
- Best quality soils for planting are aggregated, firm but not compacted slightly sandy or slightly sandy/clay loam
- Topsoil should have 4-6% organic matter

Planting practices for poorly drained soils

In heavily impervious areas, young trees must contend with poorly drained soils and require different planting requirements to mitigate additional drainage challenges. The International Society of Arboriculture provides a set of planting standards for trees in poorly drained soils (ISA, 2014):

- Install a soil berm 4" high by 8" wide above root ball surface beginning at the periphery of the root ball
- Place the bottom of root ball to rest on existing or recompacted soil
- The hole to backfill soil into should be at least three times the widest dimension of the root ball
- Turn and fill in soil to reduce compaction
- Prior to mulching, lightly tamp soil around root ball in 6" lifts to brace tree. When backfilled, pour water around root ball to settle soil.
- Position the root ball surface one-quarter above grade
- Existing site soil should be added to create a smooth transition from the top of the raised root ball to finished grade at a maximum 15% slope

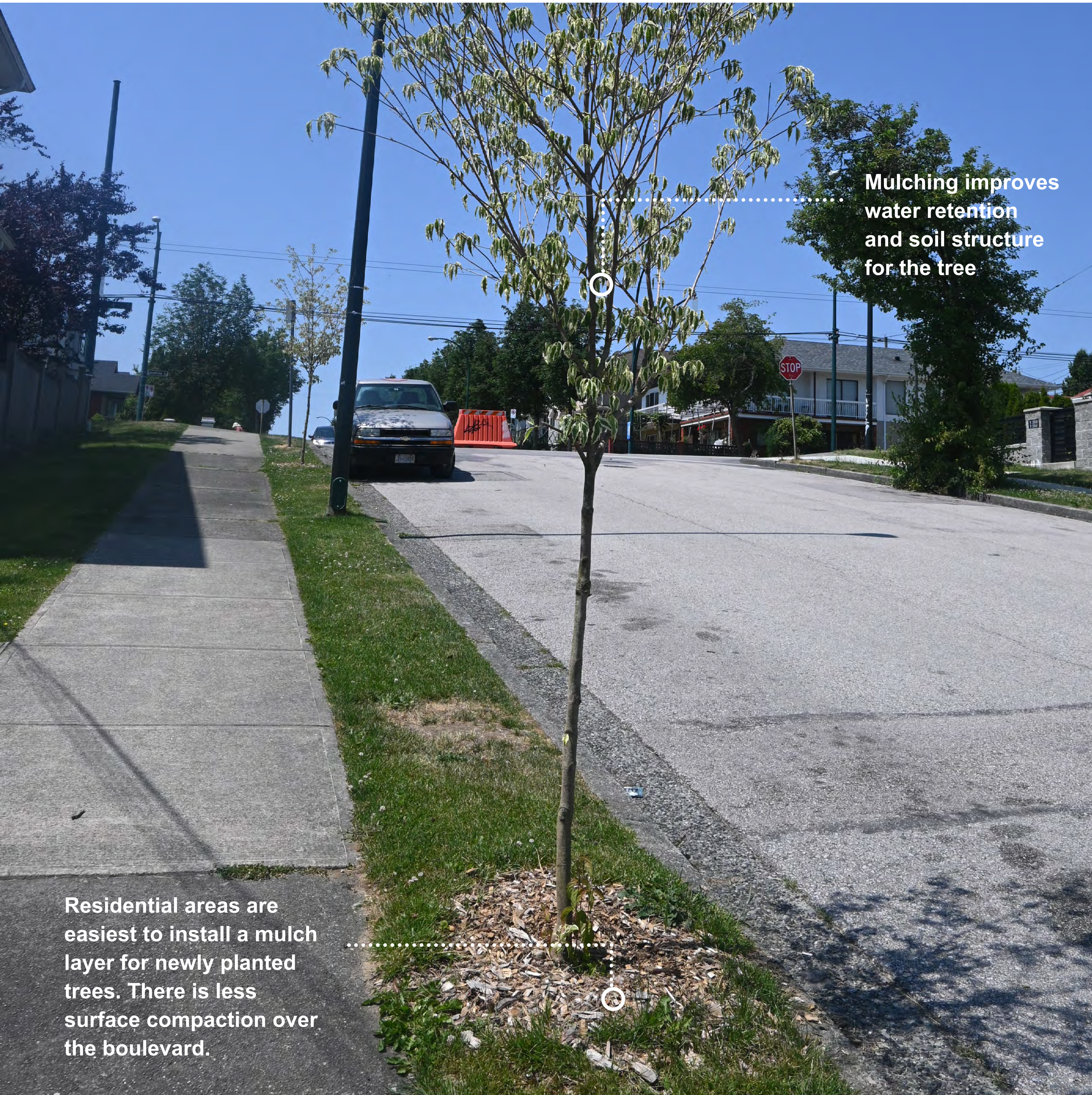
Passive versus active watering

After planting a street tree, young trees require water and supplemental watering during dry periods for the first 2-5 years of life throughout the spring, summer, and fall utilizing methods including watering bags, drip irrigation, or water pods (Metro Vancouver, 2017). Best practices recommend using potable water only in the absence of all viable alternative sources in the short term, or, in conjunction with other water efficient approaches (Markwell et al., 2020). Some cities are exploring the use of recycled water and greywater from households for tree watering in certain contexts (Markwell et al., 2020).

To reduce the reliance on potable water systems, passive systems are a preferred option and typically take the form of green infrastructure, including bioretention tree pits, permeable hardscapes, and infiltration tree trenches, designed to collect, store, and reuse rainwater for trees (Metro Vancouver, 2017). One study found street trees receiving stormwater grow larger and in the short term, trees have the potential to be effective at mitigating stormwater runoff when planted in biofiltration systems (Denman, 2016).

Mulching

To improve the soil structure and water retention capacity, best practices recommend young trees are provided with a four-inch layer of mulch around the root zone with no more than one inch on top of the root ball (ISA, 2014; Metro Vancouver, 2017). Adding organic mulch alongside young tree planting is relatively easy in grass boulevards and for tree pits, added where no tree grate is present and planted with a ground cover or shrubs in larger cutouts where maintenance allows (Jim, 2017). One New York study found higher infiltration rates in street tree pits associated with trees provided with mulch alongside a larger pit area, built-up surface elevation, and ground cover plantings (Elliott et al., 2017).



PEER MUNICIPALITY REVIEW

Background

The following document summarizes key findings from a peer review of four urban cities and one urban country. The peer locations were selected based on their robust urban forest management plans, strategic canopy cover targets, and diversity of global proximity – this resulted in the selection of Seattle, Toronto, Melbourne, and the country of Singapore for comparison with Vancouver. While Singapore stands out as an urban country, it was selected for its management of urban forest on boulevards through the National Parks Board and was selected for ambitious policies and unique management system. Vancouver's canopy cover goal is to achieve 30% canopy cover by 2050 up from its current 23%. Other cities were selected for their ambitious canopy cover targets including:

- Seattle has a canopy cover target of 30% by 2037 while it currently sits at 28%
- Toronto has a canopy cover target of 40% by 2040 with a current canopy cover of 28%
- Melbourne has a canopy cover target of 40% by 2040 with a current canopy cover of 22%
- Singapore has no target set but aims to plant one million trees by 2030 and has a current roughly estimated canopy cover of 29%
- Berlin has no target set or canopy cover estimate but has over 430,000 trees in their street network, averaging 80 trees per kilometer of street

This peer review analyzes the most relevant policy documents pertaining to boulevard tree planting and design practices including specifications and practices for the general categories of spacing and soil requirements, tree selection, understory planting practices, growing medium, planting practices, tree pit design, and mulching and watering. Due to external access of information and availability of online resources, assumptions are made on up-to-date resources with limitations in the breadth of available resources for each municipality. The following section presents key findings for each general category. More detail can be found in the Appendix.

Key findings

Planting site

Tree placement

Of the peer municipalities who detail tree spacing standards, distances were relatively similar. Vancouver requires 9-11 meter spacing for large trees, 8-10 m for medium, and 7-10 m spacing for small and columnar trees. Seattle has slightly larger spacing requirements for large and medium trees including 35-40 feet for large trees (approximately 10-12 meters), 30-35 feet for medium trees (approximately 9-11 meters), and 20-25 feet for small trees (approximately 6-8 meters). Melbourne requires similar spacing at 10-12 for large trees and 6-10 meter spacing for small or medium trees. Toronto sets a general spacing requirement of 8 meters and no spacing standard was found for Singapore.

Both Vancouver and Melbourne specified a guideline to select and place species to maximize canopy cover, favoring large mature trees over small sized trees with Vancouver ultimately aiming to close canopy cover after 20 years in high-density locations.

Soil volume

Three of the peer-reviewed municipalities set minimums for soil volume. Vancouver has the most detailed requirements of 30m3 for large, 20m3 for medium and columnar, and 10m3 for small trees in Vancouver with smaller requirements for trees in shared tree pits. Toronto takes a simpler approach with a larger minimum volume for small trees, outlining 20-30m3 per tree. Melbourne has the smallest requirements as less than 9.5m2 for small, 9.5-18.5 m2 for medium, and 18.5 m2 for large trees. Berlin has the largest minimum soil volume requirements of 36 m3 for large tree, 24 m3 for medium trees, and 12 m3 for small trees. The standard soil depth was at least one meter across municipalities with Berlin extending the requirement to 1.5 meters deep.

Minimum boulevard widths vary by municipality. Vancouver and Melbourne have the smallest boulevard widths at 1.2 meter minimums. Seattle and Toronto have 1.5 meter minimums. Singapore requires a 2-3 meter minimum 'green buffer' for new developments and for other planting along roadside, require a 1.2 meter minimum with no underground utility presence. Berlin has the largest required minimum of 3 meters.

Clearances and utilities

Clearances of trees to adjacent above and below ground infrastructure were found in nearly all municipal specifications (Figure 4). Vancouver is notably the only municipality reviewed found to have setbacks of trees and building awnings.

For utility requirements, a few municipalities took unique approaches. Toronto recommends designers approach utility owners during the preliminary design stage regarding allowable horizontal and vertical offsets between soil trenches including soil cells, root balls, and other trench components crossing utilities. Singapore takes a unique approach in their layout requirements for developers by requiring a section of the boulevard as a utility 'service verge' adjacent to a 'tree planting verge' which provides additional planting space and minimizes conflicts during the planning phase. Seattle provides detailed clearances for trees and above and below ground utility and infrastructure clearances through a detailed drawing.

HOW DOES VANCOUVER MEASURE?

Vancouver outlines utility clearances in their Design Specifications and provides detailed setbacks for building awnings. More clarification around the process of involving utilities and specifications on utility protection and trenching as well as clear drawings of utility setbacks could mitigate long-term conflicts between trees and utilities and provide solutions in plantable areas limited by existing utility infrastructure.

Figure 4. Vancouver has detailed specifications for tree clearances from utilities including a two meter clearance from water mains.

General pit recommendations

Berlin is unique by mandating if specifications cannot be met in extreme locations, the root area must be enlarged and site conditions improved. Measures to address these limited conditions include:

- Creating deeper tree pits up to 2.5 meters
- Extending root space under traffic areas such as parking lanes, foot paths, and squares
- Encouraging aeration by creating root ditches with an open-pored mineral mix

Melbourne is more relaxed in their recommendations by generally recommending curb extensions, structural soil, use of porous or permeable pavement, and use of tree pit curb inlets to enable passive irrigation; their focus lies more on the utilization of bioretention tree pits and away from containerized trees which they detail should be used as last resort.

Toronto employs multiple techniques with their tree pit design including utilization of soil cells throughout the city where more volume is desired and recommends stormwater tree trenches utilized along soil cells with permeable pavement. Three planting area conditions are outlined including a raised open pit with concrete, stone, and metal surround, at-grade open pit with metal fence, and an at-grade covered pit with grate. The city continues to trial new improvements to their tree pit designs.

Singapore takes a proactive approach in utility installation for their tree pits by specifying a service verge adjacent to their tree planting verge.

Tree grates

All municipalities except for Singapore were found to have detailed specifications on tree grates. In Vancouver, specific tree grate vendors are outlined for special planning areas Downtown but the standard city-wide tree pit grate is a four-piece concrete surround, placed a minimum of 300 mm from the curb and 1.2 meter minimum in a boulevard. Seattle favors iron framed tree pits and notes top of grate must be flush with the top of the adjacent sidewalk.

Toronto has the most details and designs provided but holds preference for open, raised, or tree fence options to in-ground or grated tree openings. In constrained spaces, flush tree grates are preferred but maintenance and growth must be factored into design and grates are to be easily lifted and removed. Melbourne only requires bioretention tree pits to use removal concentric rings made of steel and fiber-reinforced polymer but does not have specifics outside of GI systems. Berlin is unique in providing detailed maintenance practices for pit cleaning where tree grates are to be cleaned at least four times a year manually.

Tree guards

Tree guards are not specified for use in Vancouver, though they are found in small areas of the city, Tree guards have been adopted in specifications for Melbourne and Berlin where areas are particularly vulnerable to vehicular damage or vandalism. Berlin specifies a tree guard must be at least 70 cm in height and protection from dog urine provided by slats at the foot of the tree trunk. Melbourne notes that tree guards should only be used when necessary and should be removed when trees have outgrown their capacity.

Surface treatments

Four of the six municipalities outlined general requirements for surface treatments. Vancouver utilizes surface treatments, typically using crushed gravel in hard boulevards, but does not have specifications detailing requirements. Seattle specifies a flexible porous surface treatment with topdressing required in drawings to a minimum depth of two inches. Melbourne and Berlin specify use of gravel with Melbourne specifying use of 50 mm compacted granitic gravel on a short-term basis with permeable pebbles preferred with an epoxy mix. Singapore is simple in using grass in unsealed tree pits with loose paved slabs.

Tree selection

General criteria for selection

Municipalities were found to favor large trees overall, with Seattle expanding to plant only small and columnar trees if space is limited. Toronto was found to generally favor large native trees as plantings. Vancouver, Melbourne, and Berlin list criteria for selecting adaptable trees in their cities (Table 5).

Table 5. Comparison of criteria of adaptable trees for selection

Vancouver	Melbourne	Berlin
• Compatibility with local growing conditions • Adequate space to reach natural form at maturity • Branch failure or wind-throw resistance • Pest resistance • Freedom from significant nuisance problems • Low maintenance	• Drought tolerance • Heat tolerance • Wind tolerance • Longevity • Pollution tolerance • Pathogen and pest susceptibility and manageability • Allergen potential • Shade cast • Maintenance required • Tree litter	• Large list of specific criteria applicable to selection of tree species.

Stock acquisition

Vancouver bases their stock acquisition based on the Canadian Nursery Landscape Association Canadian Standards for Nursery Stock with a general preference for trees grown in the Pacific Northwest USA, requiring balled and burlapped or trees in wire baskets. Seattle allows bare root and container planting, specifying trees in containers must be vertically cut and girdling roots loosened while delineating a planting period between October 1st and April 30th. Melbourne conforms to the Australian Standard for Tree Stock for Landscape Use and generalizes trees are to be in good form, health, structure, and free of pests and diseases. Singapore lists detailed specifications for tree stock form and size but does not mention stock material (e.g., if balled or burlapped, bare root). Berlin complies with TL nursery plants technical delivery conditions and specifies either wire ball or container grown trees. Berlin also had detailed requirements for transportation, storage, and control of the tree upon delivery.

Diversity requirements

Two municipalities include an overall diversity target for their urban forest in their design specification. Vancouver sets a target of no more than 30% one family, 20% genus, 10% species, and 3% cultivar. Melbourne's approach was found to be more ambitious with no more than 20% family, 10% genus, and 5% species. Berlin provides a general recommendation that a higher diversity of species should be a goal to reduce sensitivity to disease and pest and foster biological diversity.

Vancouver stands out as the only municipality to delineate diversity requirements at the development project scale. This design requirement includes:

- >100 trees – maximum genus 40%, maximum species 25%
- 50-100 trees – maximum genus 50%, maximum species 30%
- 1-24 trees – maximum genus 100%, maximum species 100%

Species selection

All municipalities provide recommended species for planting however, the detail and longevity of those recommendations varies. Melbourne provides the most recommendations utilizing a tree selection matrix divided by street, park, and trial trees with the idea of updating after trees are successfully trialled. Toronto takes a similar matrix approach by providing a Vegetation Tool as part of the Green Street program which outlines 87 trees adaptable to stormwater tree trenches and Green Infrastructure tree pits on top of a 10-species list of trees tolerant of hardscape environments. Seattle has an ambitious list of 145 approved street trees divided into large, large-columnar, large-medium, medium columnar, medium, small, and small columnar.

Singapore has a list of 70 recommended trees for roadsides with an additional 26 palms. Berlin provides two street tree lists within their Working Group of German Garden Office Manager's Meeting and the Berlin Street tree list. Vancouver has the smallest list of recommended trees with only 69 trees divided by large, medium small, columnar, conifers, and broadleaf evergreen.

Size selection

Only Singapore and Vancouver were found to detail size suitability based on available spacing in the boulevard as shown in Table 6.

Table 6. Comparison of tree size selection

Vancouver	Melbourne
• Large trees suitable for 3 meters or larger boulevard width with building setbacks larger than 8 meters • Medium trees suitable for larger than 1.5 meters • Small trees for below overhead utilities or where soil environment is restrictive • Columnar in confined locations or offset from electrical • Conifers not planted on boulevards generally • Broadleaf evergreens unacceptable for street tree usage in shrub form	• Large trees for major roads with verge larger than 3 meters • Medium trees for major roads and some minor with planting verges between 1.5-3 meters • Small trees on minor roads with narrow planting verges less than 1.6 meters in width

Growing medium

Soil selection

Nearly all municipalities were found to have detailed specifications on growing medium mixes for boulevard trees with organic matter percentage detailed except for Melbourne; soil preferences differ globally as growing conditions and soil needs are dependent on climatic differences. Seattle and Singapore have similar requirements of a minimum 10% organic matter in their soil as detailed in their planting mixes while Toronto requires 2.5-5% and Vancouver 10-20%. Seattle, Toronto, and Singapore stand out from Vancouver in requiring amendments of compost in their soil mix. Berlin recommends adding compost as a soil amendment but it must not be put into deeper soil layers.

Fertilizer

Seattle and Berlin were the only municipalities found to detail fertilizer amendments with Seattle detailing an amendment minimum of 50% nitrogen fertilizer must be in slow release or controlled form based on undertaking a soil analysis. Berlin specifies, if necessary, a fertilizer must be introduced into the upper 10 cm of substrate and if utilized in Autumn, use coated fertilizer only. A general recommendation was provided to fertilize in the spring for locations particularly affected by de-icing salt.

Structural (Engineered) soils and soil cells

Vancouver, Toronto, and Melbourne were found to have detailed information on soil cells and structural soils with Toronto utilizing the most in practice. A breakdown of differences in their use can be found in Table 7 below.

Table 7. Comparison of structural soil and soil cell utilization details of use

Vancouver	Toronto	Melbourne
• Engineered soils and soil cells used for new trees only • Soil cells only used alongside new road construction where utilities will not be impacted, no native soil is available, and approved by City Engineer • For Engineered soils, use non-woven filter fabric installed as separation layer above compacted soil mix	• Structural soil used under paved areas • Soil cells used where surface area is limited under conventional concrete pavers or under interlocking concrete pavers • Does not define if for new construction or new tree installation only	• Structural soils not to be used where trees have access to good quality sufficient soil; a minimum of 15 m3 volume and depth of 1 meter is to be provided. • Structural soils are to be used along with kerb inlets or other passive drainage systems. • Soil cells are used where future excavation is unlikely and where clear soil volumes can be achieved without crossing utility services

Planting and watering methods

Warranty period

Vancouver, Seattle, and Singapore detail warranty periods requiring tree maintenance and irrigation for newly planted trees for contractors. Vancouver has the longest warranty period of two years followed by Seattle with on year, and Singapore eight months. Seattle requires a detailed watering schedule to be submitted, including irrigation zone requirements for each tree. Berlin is unique in providing a flexible period of developer maintenance, detailing a variable period lasting until the functional state of the tree is reached which can be between 3-5 years.

Subgrade prep and backfill

In specifying subgrade prep, Vancouver is unique in recommending sloping slides of the planting hole at a 45-degree angle when possible but has limited information on backfilling and amending surrounding soil. Seattle and Berlin further detail backfill requirements with Berlin requiring soil to be properly removed and if the adjacent soil surrounding tree pit cannot be rooted through, it must be improved. Seattle further specifies for bare root when backfilling, roots should be properly spread to avoid circling or girdled roots.

Staking, trunk painting, and dog urine prevention

Four of the six municipalities require staking for newly planted trees in the right-of-way with Berlin, Melbourne, and Seattle utilizing wooden stakes and Singapore requiring galvanized steel pipes. Requirements vary on method of construction and attachment with general recommendations to remove within the first few years of tree growth. Seattle further requires separate construction methods for deciduous and coniferous trees and specifies removal after 1 year and replacement of damaged stakes. Berlin is unique in specifying a coat of paint on the bark upon planting certain species to protect the trunk from cracking in extreme temperature fluctuations and requires tree brackets and slats to prevent dog urine in susceptible areas. Vancouver does not require stakes for newly planted trees.

Planting installation

When it comes to tree planting installation, four of the six municipalities have readily available specifications varying in level of detail and provided either in a planting drawing, construction specification, or both. Vancouver provides this information in both a technical drawing and in the city's Design Guidelines, specifying a 10-centimeter saucer around the perimeter of the rootball. Seattle details placing root crown two inches above surrounding curb and sidewalk and meeting a minimum 3-inch horizontal clearance to both curb and sidewalk. This differs from Berlin's requirement to plant the tree at the same height it was planted at the nursery but generally around 10 cm above ground.

Singapore is unique in requiring a tree collar protector for all trees with a PVC tube with slit along length of tube and requirement of an aeration trough for trees larger than 0.5 meters in girth if planting area is less than 3 meters wide.

Vegetation under trees

Nearly all municipalities were found to have specifications regarding vegetation under trees but take different approaches when discussing incorporation of shrubs and plants alongside trees. Melbourne has the most information on understory plantings ensuring any planting does not limit opportunities to plant trees and general avoidance of ground covers below small and medium sized trees. Melbourne notes, understory plantings can be useful as a pedestrian barrier to reduce the negative look of barrier fencing and if no tree can be planted, shrubs can be suitable alternatives. Singapore further outlines shrubs as a camouflage device where vehicular impact guard-rails are used.

Seattle is unique in outlining no permit is required for growing food crops in planting boulevards, aligning with their in-depth program to involve community members in tree planting and maintenance in the boulevard. Vancouver approaches shrubs as an important part of rainwater management while improving aesthetics, outlining any plantings should be native or well adapted, drought tolerant, diverse, and attractant of pollinators, however does not outline recommendations for planting. Berlin takes a general approach that the surface of the tree pit can be covered with greenery only if competition for watering and available space is accounted for.

PEER MUNICIPAL REVIEW SUMMARY

CATEGORY	KEY FINDINGS
Planting site	• Vancouver's current boulevard minimum is smaller compared to other municipalities. • While Vancouver has detailed soil volume requirements, there are still planting locations that are not meeting the standards • All municipalities set utility setbacks, however, Singapore takes a unique approach by requiring a utility service verge adjacent to their tree planting verge • Municipalities differ in the tree grates they prefer with Vancouver's standard a four-piece concrete surround. Berlin is unique in requiring detailed maintenance practices for annual tree pit cleaning. • Vancouver does not have specifications for tree guard use which other municipalities have. • Berlin is unique by requiring the root area to be enlarged and site conditions approved with various methods if specifications cannot be met in extreme locations. • Municipalities vary in their detail on surface treatments; while Vancouver uses crushed gravel in open tree pits, there are no standard specifications.
Tree selection	• Cities are selecting climate adaptive trees for their plantings however, their selection criteria differ. • Vancouver has the smallest list of recommended trees compared to the other municipalities. • Some municipalities have detailed tree selection tools, including for their green infrastructure plantings. Vancouver does not have a tree selection toolkit.
Growing medium	• Vancouver has no requirement for compost amendment in their soil mix which was observed in three municipalities. • Some municipalities (not including Vancouver) have a fertilizer amendment specification. • Three municipalities including Vancouver were found to have detailed information on structural soils. Melbourne further specifies a minimum soil volume of 15 m3 must be achieved to utilize structural soil.
Planting and watering methods	• Vancouver has the longest developer warranty period for newly planted trees. Some municipalities such as Seattle, require a detailed watering schedule to be submitted to the City. • Berlin is unique in requiring soil to be improved prior to planting if soil surrounding a tree pit is too heavily compacted. • Municipalities follow regional standards for their stock acquisition which will vary considerably by country. • Four municipalities (not including Vancouver), require staking for newly planted trees. • Municipalities take different approaches when planting vegetation in the boulevard under trees. Melbourne provides the most information and note they are a good pedestrian barrier and can be used when no tree can be planted.

CASE STUDIES

This section highlights several case studies where unique methods to improve sidewalk mitigation and tree health in hardscapes have been trialled, both in Vancouver, and elsewhere. The projects were specifically chosen for their feasibility in replication, observed successes, and solutions at addressing both tree health alongside mitigation of sidewalk damage. Sites in Vancouver were also selected based on recommendations from City of Vancouver staff members.

Maximizing soil volume

Rainwater tree trench – *Richards Street – Vancouver, BC*

Vancouver has been exploring long-term GRI (green rainwater infrastructure) systems as part of the Rain City Strategy as a cost-effective approach to deliver multiple benefits while utilizing trees to capture, store, and clean runoff as well as cooling streets in hardscapes. Richards Street, between Cordova and Pacific Street provided the grounds for an ambitious 8-block installation of rainwater tree trenches finished in 2021, collecting water from the bike land and street and directing toward the trenches (Figure 5). The trenches include three major design components designed to maximize soil volume and water storage capacity including:

- **Permeable pavers** – provides both a walking surface and allow for infiltration of water into the trench
- **Structural soil** – allows for additional root growth and water infiltration while still providing a compacted surface
- **Silva cells** – Engineered frames of soil growing medium for additional space for tree roots to grow, increasing ability for rainwater infiltration

Over 20 internal and external stakeholders worked in close collaboration to accommodate four significant utilities including BC Hydro, Water, Sewer, and Electrical (City of Vancouver, 2022). From the project, a few key takeaways were learned to drive future projects:

- Permeable pavers can become clogged and require regular monitoring and maintenance
- For construction of the tree trench, vertical walls should be avoided whenever possible.
- Maintaining curb base backfill can be a challenge to meet a 2:1 slope. The City is currently working to develop a series of staging diagrams for installation of structural soils which will provide several methods for meeting the required slope.

Figure 5. Looking northeast along the Richards Street bikeway. Engineered soil allows for additional soil under the bikeway.

Addressing irrigation in small tree pits

Permavoid pilot project – *Spadina Ave - Toronto, Ontario*

In 2020, the City of Toronto explored new technologies to improve the health of their street trees planted in small tree pits in commercial areas, while reducing fluctuating water levels they suspected was the cause of the higher mortality rates (Permavoid, 2020). Through the use of the Permavoid system, the City's Commercial Tree Division tested the effectiveness of the Permavoid system by establishing several tree pits along Spadina Avenue (Figure 6). The Permavoid system was installed under newly planted trees to provide passive irrigation and minimize the subgrade for healthier tree pit growing conditions through the use of a water retention system which collects and re-uses water (Figure 7). Cellular sensor devices were installed to monitor the field capacity of soils and also alerted when water should be added. No levels of over-saturation were found during the project (Permavoid, 2020). The City is currently in a process of re-examining their street tree irrigation practices for future use, building off the pilot project.

Figure 6. Permavoid installation of structural cells and aeration pipe in tree pit on Spadina Avenue (Images courtesy of Neil Courneya).

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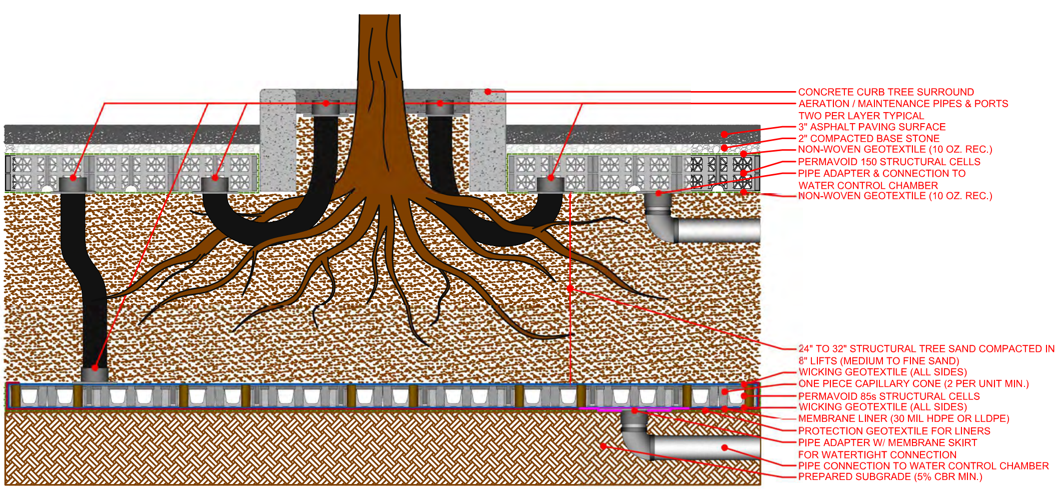


Permavoid 150 Structural Subbase &
Permavoid 85s Capillary Irrigation w/ Stormwater Retention for Trees

Figure 7. Typical detail for larger pit installation of permavoid system (Image courtesy of Neil Courneya).

Mitigating root & sidewalk conflict

Trip stop – *Battison Street – Vancouver, BC*

To prevent root damage by some of the City's only mature Douglas-fir trees in the right-of-way, TripStop was installed the sidewalk to prevent the need for root trimming by moving dynamically with the tree roots (Figure 8). The TripStop Sidewalk Join system uses a PVC profile and transverse joints embedded in concrete sidewalks to prevent tripping from misalignment than can occur along pedestrian walkways and can easily be installed adjacent to existing paving structure to allow for future expansion (Tripstop, n.d.). TripStop could be applied within proximity of a tree pit in highly impervious areas.

Figure 8. (Top) Mature Douglas-fir trees in the boulevard on Battison Street. (Bottom) sidewalk with Trip stop routes around street tree, minimizing future root conflict.

Rubber sidewalks – *17th Avenue and West 10th Ave. – Vancouver, BC*

To address existing cracked sidewalks and mitigate tree root heave while providing rapid drainage of rainwater, rubber sidewalks were installed along East 17th Avenue in Vancouver (Figure 9). Rubber sidewalks are typically made from regional and recycled materials and are an alternative to asphalt, concrete, and preformed pavers with best application along city sidewalks and new urban developments, where their flexibility allows them to move alongside root growth. While numerous vendors exist, Eco-Flex ® sidewalk blocks were installed and made from 100% recycled rubber tires (Eco-Flex, n.d.). Along West 10th Avenue between Willow and Laurel Street, two types of rubber sidewalks were recently installed adjacent to mature trees and a bikeway: (1) Romex at the Northeast corner at Willow Street and West 10th Avenue and (2) rubber playground poured in place west of Willow Street along West 10th Avenue (Figure 9). Due to recent installation, the rubber sidewalks will need to be revisited during their lifespan to determine the successes of the different materials and their relationship with tree roots.

Figure 9. (Top left) Rubber sidewalk using Eco-Flex ® along 17th Avenue. (Top right) Romex material installed at Willow Street and West 10th Avenue. (Bottom) Rubber playground sidewalk material installed adjacent to a mature tree west of Willow Street.

Rebar sidewalk – *Burnaby Street – Vancouver, BC*

In the case of 1450 Burnaby Street, an existing tree was causing sidewalk damage and the sidewalk wasn't able to be raised over the roots to meet the grade required. The solution was the use of rebar alongside concrete expansion joints, a relatively cost-effective approach which places concrete over the root directly lined with expansion joints which prevents the need for root trimming or cutting (Figure 10).

Figure 10. New rebar sidewalk installed around a maturing boulevard tree in the right-of-way along Burnaby Street. The project was completed in October 2020.

Trees and Sidewalks Operations Plan – *Seattle, WA*

The City of Seattle delineates street tree maintenance within the public as a responsibility of the adjacent property owner, except for trees designated for maintenance by the urban forestry department where a street tree map enables confirmation. For trees maintained by the City, an Operations Plan was developed to provide guidance on the installation, repair, and maintenance of sidewalks and street trees in response to growing challenges with small tree pits and limited soil volumes where an estimated 20% of street trees considered for possible removal due to improper location, structure, and health (Seattle Department of Transportation, 2015). The Plan includes work process and assessment diagrams for trees and sidewalks and includes a solutions toolkit of proactive and reactive methods to plant and retain healthy trees within hardscapes with some approved by the city and some as potential solutions. Table 8 is provided on the following page, illustrating the recommended solutions provided in the Operations Plan.

Table 8. Solutions toolkit for healthy trees alongside walkable surfaces from the SDOT Trees and Sidewalks Operations Plan.

Category	Tool	Cost	Life expectancy
Paving and surface materials	Asphalt	$ - $$$	Decades
	Expansion joints	$	Years
	Pavers	$$ - $$$	Decades
	Pervious concrete	$$$ - $$$$	Decades
	Reinforced/thicker slab	$$ - $$$	Decades
	Rockery/wall	$$ - $$$$	Decades
	Beveling	$ - $$	Years
	Porous asphalt	$ - $$$	Decades
	Shims	$	Years
	Tree guards/rails	$$ - $$$	Decades
	Decomposed granite	$ - $$	Years
	Mudjacking	$$ - $$$$	Decades
Infrastructure-based solutions	Monolithic sidewalks	$$$	Centuries
	Pavement thickness	$$$	Decades
	Tree pit sizing	$	Decades
	Bridging	$$$$	Decades
	Curb bulbs	$$$ - $$$$	Centuries
	Curb realignment	$$$ - $$$$	Centuries
	Curving or offset sidewalks	$$ - $$$	Centuries
	Easement	$ - $$$	Centuries
	Suspended pavement systems	$$$ - $$$$	Decades
	Lowered sites	$$$ - $$$$	Decades
	Soil volume	$-$$$	Centuries
Root zone based materials	Mulch	$	Year
	Root barrier	$	Decades
	Continuous trenches	$$$	Decades
	Foam underlay	$ - $$	Years
	Modified gravel layer	$	Decades
	Root paths	$ - $$	Decades
	Soil modifications	$ - $$	Decades
	Steel plates	$$ - $$$	Decades
	Structural soil	$$ - $$$	Decades
	Subsurface aeration/irrigation	$$	Years
Tree based solutions	SDOT Tree list	$	Decades
	Corrective pruning	$ - $$	Year
	Root pruning	$ - $$	Year

Rebuilding difficult soils

Soil remediation – *Evans Avenue – Vancouver, BC*

The Vancouver Board of Parks and Recreation's Urban Forestry department is currently working to remediate a site with poor soil along the industrial Evans Avenue by rebuilding the soil profiles for an existing site in a heavily paved and industrial low-canopy area, prior to planting of new trees (Figure 11). The site was selected due to no utility conflict, long boulevard length (450 meters) and 2.5-3-meter-wide boulevard for suitable planting. Adopting the 'scoop and dump' approach derived by urban soil specialist Dr. Susan Day, organic material was mixed with the existing boulevard using Varitec's organic compost mix. This project is one the first major soil amendments the City of Vancouver has trialled.

Figure 11. Evans Avenue remediation prior to planting (image source: Google Street View)

Prioritizing equitable areas

Street tree planting – *Hastings Street – Vancouver, BC*

In the Downtown Eastside, low canopy cover under 10% has contributed to the urban heat island effect where surface temperatures ranged from 42 C to 49 C in 2018. To address concerns in a neighborhood with vulnerable populations, the City set a target to double the tree density in the Downtown Eastside by 2030 through a tree planting strategy. In 2022, the City was granted a climate levy of $1 million which the Urban Forestry and City Engineering department put towards growing low canopy areas, planting approximately 30 medium-sized *Parrotia* (ironwood) trees under trolley lines within four-paneled concrete tree pit systems (Figure 12) (Turner & Kelly, 2023).

In 2022, nearby in Crab Park, fences were put up for park soil remediation, preventing access to canopy cover for populations that are especially impacted by the heat. As quoted from Fiona York, an advocate for Crab Park, "*The population here in the park is very impacted by the heat and really needs access to shaded areas*" (Pitargue, 2022). More work is needed to work alongside the community to make sure canopy cover is accessible for community members in the Downtown Eastside.

Figure 12. Newly planted Parrotia species in the four-paneled tree pit design along Hastings Street (left) and installation (right).

Community tree pit programs

Adopt-a-Street-Tree Program - *Toronto*

The City of Toronto relies heavily on the public for management of its approximately 600,000 street trees, driven by local community groups in collaboration with local BIA's through the Adopt-a-Street-Tree Program, developed in collaboration between LEAF (Local Enhancement & Appreciation of Forests) and the City of Toronto (LEAF, n.d.). A manual provides information on typical stressors of street tree growth including drought, compacted soils, physical damage, dog urine, and salt. Through the community groups, tree stewards provide summer watering and maintenance for trees in tree pits and are encouraged to plant perennials under boulevard trees with permission from the City. Specifications for perennial selection are to be 30 centimeters from the tree trunk and hardy native species (LEAF, 2017).

Sponsor a Tree Pit Program - *Berlin*

The City of Berlin has utilized a 'Sponsor a Tree Pit' program as an approach to asking the community for help to care for trees in tree pits where damage and dog urine are known – the rates of trees has been declining and every new tree planted has to replace 2.4 trees removed (Molina, 2021). Tree sponsors are tasked with cleaning pits, removing garbage and weeds, watering trees, removing overgrown suckering shoots, and acting as a liaison to other community members (Lachmund, 2022). Herbaceous plants are the only understory allowed and no planting is permitted for the first three years of a tree's establishment to minimize competition for available water and nutrients. A quote from a tree pit steward highlights the value and impact on the program (Alex H, 2020):

"the tree pit garden has become a talking point for our neighbours, and two other neighbours on our street established their own gardens after ours. Second, our children are more inclined to play on the footpath between our house and the tree pit, and enjoy taking care of the garden. They like to go down to pick flowers, and in spring they were eager to see each plant bud and grow."

HOW DOES VANCOUVER MEASURE?

Adopt a catch basin program

While Vancouver does not have a community street tree care program, the City has asked for community help in managing stormwater infrastructure. In the case of 45,000 catch basins, the Adopt a catch basin program allows community members to help manage stormwater by making sure catch basins are clear of leaves, debris, and litter and encouraging stewards to share larger concerns through the City's 311 app (Figure 13).

Figure 13. Example of one of the City's catch basins.


78% of Vancouver's
street trees are planted
in a grass boulevard

ANALYSIS

Methodology

To identify current practices in Vancouver's urban forest and streetscape design promoting good street tree health, a GIS and data analysis was undertaken both city-wide and at a more detailed scale for priority areas. A full list of the datasets analyzed is found below in Table 9.

Table 9. Datasets analyzed to evaluate current trends of Vancouver's urban forest and streetscape design

Dataset	Description
Disproportionately Impacted Populations index (2021)	Highlights where people are more likely to experience systemic oppression in consideration for seniors, Indigenous people, visible minorities, single-parent households, people with limited knowledge of English, rent-burdened households, and the median household income. Each category is ranked with an equity score from 1-10 (low to high impact) which is summarized by the equity proportional metric from 0-60 (low to high impact), utilized in the Vancouver Plan and Climate Emergency Action Plan.
Street Tree Inventory (2023)	Captures locations, species, conditions, maintenance requirements, size, and area planted for Vancouver's public trees. The inventory is updated frequently by the Urban Forestry division in Parks and captures trees along streets and within some parks.
Sidewalk Defects (2021)	Collected by the Streets Design department in 2021 highlighting addressed and existing defects for public sidewalks including the material, panels affected, sidewalk width, and type of defect including heaving, join spalling, linear cracking, and more.
Urban Forest Canopy Coverage (2021)	Displays the percentage of canopy coverage for both private and public trees city-wide in 1-hectare areas utilizing LiDAR data collected in 2021. Canopy coverage measures the area occupied by a tree's crown (upper leafy surface), commonly expressed as a percentage compared to the total city area to allow for municipal comparison and benchmark tracking. Vancouver's city-wide canopy cover was estimated at 23% in 2021.
Green Rainwater Infrastructure (2023)	Highlights the City's actively maintained assets that collect and treat rainfall to reduce demand on sewers which often include street tree plantings in the public realm. Assets include infiltration trenches, bioretention cells, rainwater tree trenches, and more.

City-wide analysis

Across the city, trends were explored to assess the impact of planting area on tree condition, genera in hardscaped areas by condition, tree health for trees in hardscaped areas, relationships between street tree health and sidewalk condition, and relationships between street tree health and road condition. Most of the focus of the analysis is on trees in particularly hardscaped areas, indicated if they are planted in a cutout.

Overall planting area conditions

First, evaluating the urban forest citywide provides an assessment of the overall conditions for trees both in hardscape areas and for trees in larger boulevards. The question was asked: What are the conditions for trees citywide and how do they compare across planting areas? Trees in grass boulevards, sidewalk cutouts, behind sidewalks, and with no sidewalk were included in this analysis and trees in parks and behind lanes were excluded for the purposes of this analysis.

Findings

Overall, most street trees are in good (45%) or excellent (42%) condition with only 2% dead pointing to an overall healthy urban forest. Most street trees are planted in grass boulevards with only 6% planted in cutouts; of the trees in cutouts, only 1% of total tree plantings have a tree grate (Figure 14).

Though trees in cutouts make up only 6% of the inventory, proportionately they have the highest percentage of dead trees of all the planting types at 4% of all the trees in cutouts which is double the average mortality rate city-wide (2%), suggesting trees in tree pits experience higher rates of mortality than trees in other planting locations (Figure 15).

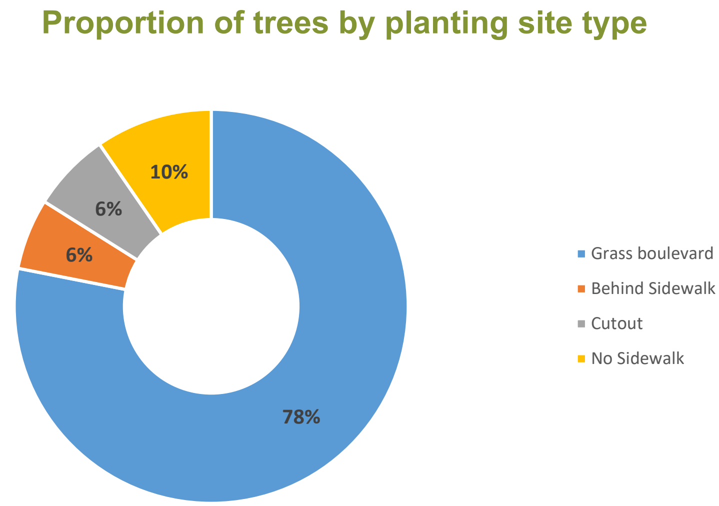


Figure 14. Proportion of trees by planting area

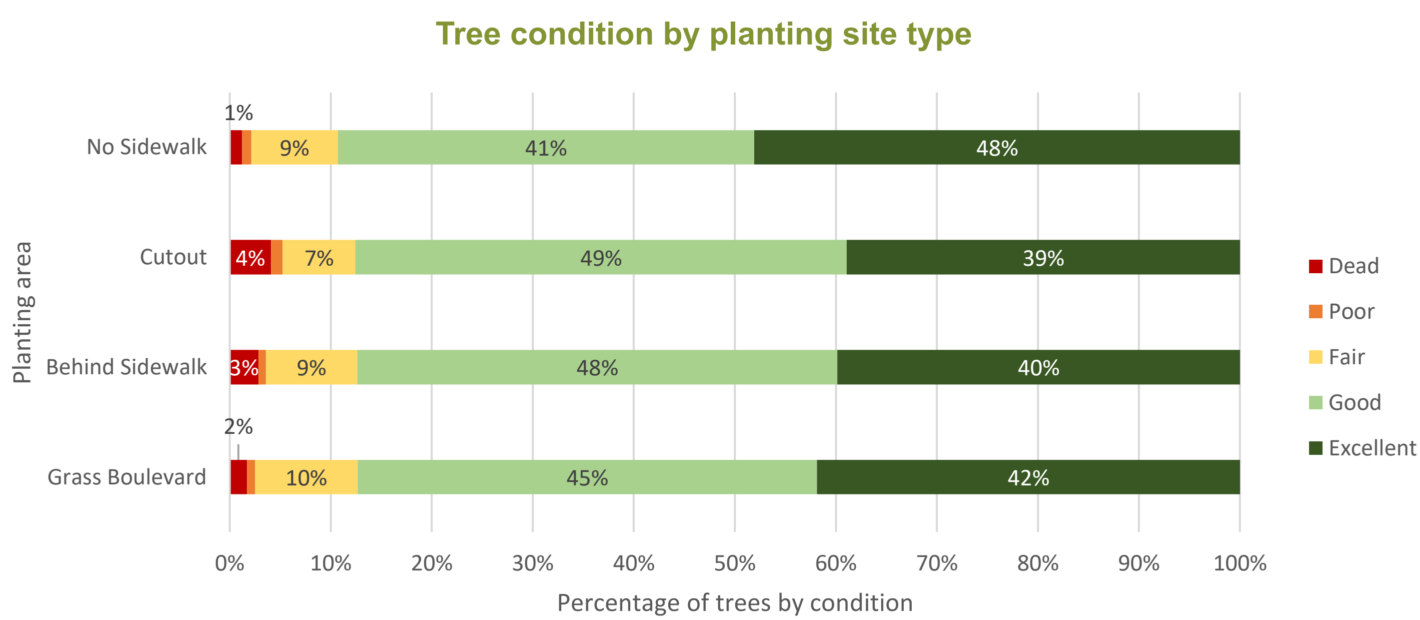


Figure 15. Condition of street trees by planting area

Genera analysis

A brief analysis on tree genera identified in the City's tree inventory was conducted to see if there were any major trends associated with condition of trees in cutouts and if trees were fairing particularly well or were experiencing poor health.

Findings

Maple trees are overwhelmingly the most common genera planted in tree cutouts (40%). Though maple trees are also the most planted tree citywide on streets, the proportion is almost half of the proportion represented by tree cutouts at 26%. While over 90% of maple are in good/excellent condition in cutouts, maple trees also experienced the highest proportion of trees in poor or dead condition in cutouts with *Acer rubrum* contributing the most. Linden is the second most planted tree in cutouts (10%) however more than 20% are in dead, poor, or fair condition suggesting linden experience more challenges in cutouts than maple. Interestingly, Ironwood experiences the highest rate of trees in excellent condition, suggesting they are more suitable for cutouts. More details on genus tree conditions for trees in cutouts for the top ten most planted genera can be found in Figure 16.

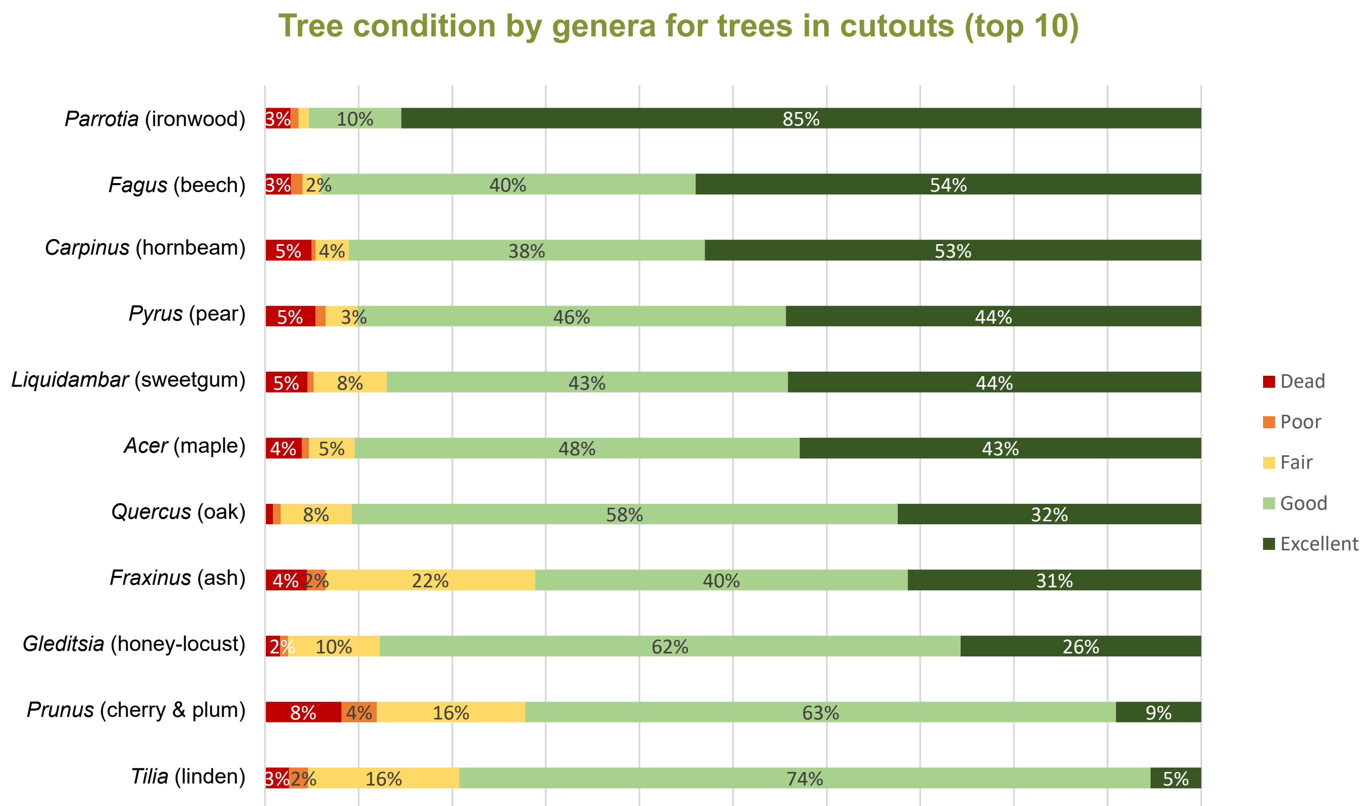


Figure 16. Proportion of genera condition for street trees in cutouts (top ten genera planted shown only)

Trees and sidewalks

Relationships were explored between current sidewalk conditions identified in the Sidewalk Defects database and the street tree inventory. Two questions were asked: (1) are there any relationships between sidewalk conditions and street trees and (2) are smaller boulevard widths associated with more sidewalk defects?

A four-meter buffer analysis was conducted to locate associated street tree with sidewalk defect. Four meters was selected as roots from trees are located beyond the tree's crown with the limitation that this assessment cannot correlate all defects caught in this analysis are actually associated with trees. The analysis looked at primary defects only and excluded 247 duplicate values where two trees were associated with the same sidewalk defect. The sidewalk defects are also only a snapshot in time (captured in 2021) and they do not reflect new defects and addressed defects since undertaking the field study. 700 defects had a street tree associated with multiple sidewalk defects and these were included in the analysis. A limitation to the study is only sidewalk heaves are confirmed to be attributed to a street tree. All other sidewalk defects associated by proximity are estimations only and in some cases, defects will not be caused by trees.

Findings

Under half of the city's sidewalk defects (43% or 16,911 defects) are associated with a street tree. Sidewalk defects most associated with trees include faulting (32%), linear cracking (17%), and heaving (17%). When assessing defect type by tree age, younger trees were most associated with faulting (24%) and linear cracking (21%) while older trees were most associated with faulting (37%) and heaving (25%) (Figure 17). Overall, trees were most associated with a defect in the early part of their life (64%) (<40 cm DBH) however, trees associated with sidewalk heaving which can create tripping hazards, were most associated with semi-mature trees (34%). Of trees associated with defect, exposed concrete is the most common to be damaged (52%) followed by concrete (47%). To assess sidewalk defects and planting typology, trees planted in cutouts had the largest rate of dead trees associated with these sidewalk defects resulting in 3% of all trees in cutouts experiencing mortality (Figure 18).

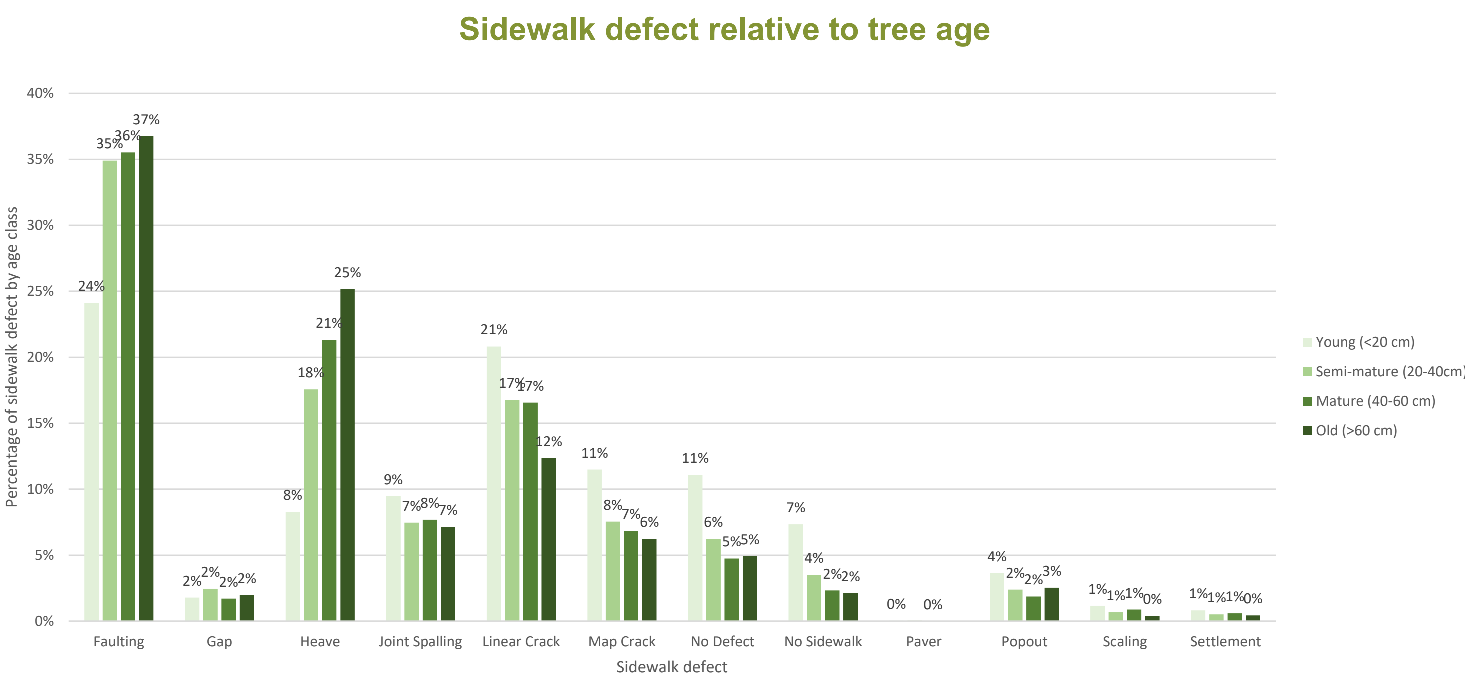


Figure 17. Sidewalk defect relative to tree age using diameter at breast height or 'DBH' in centimeters.

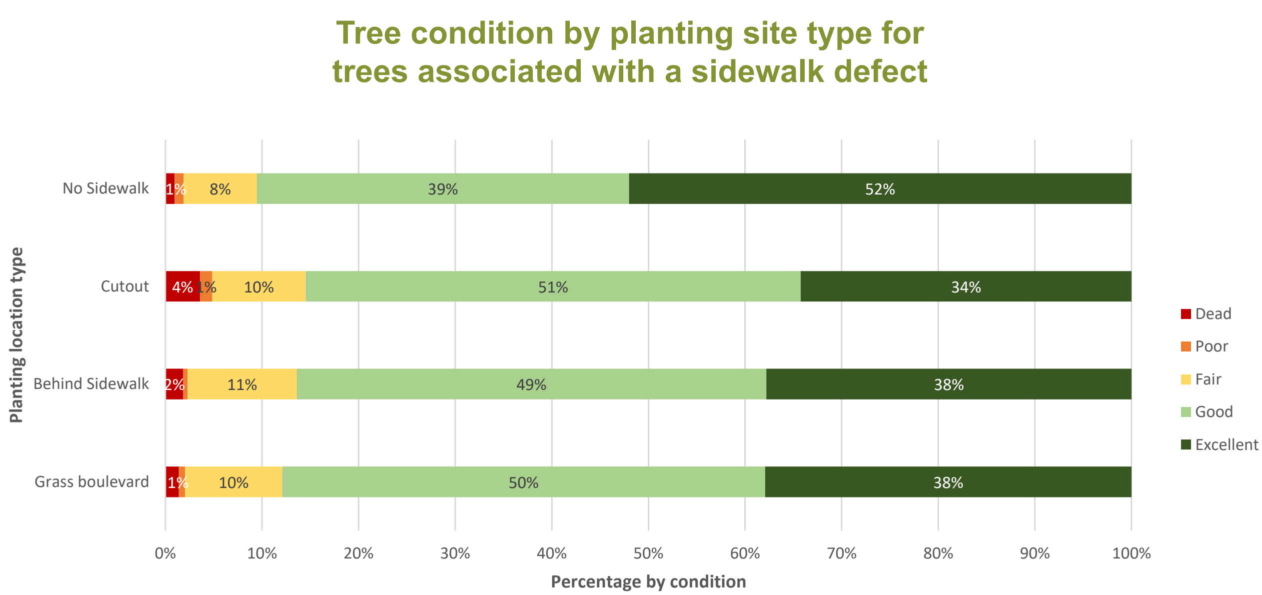
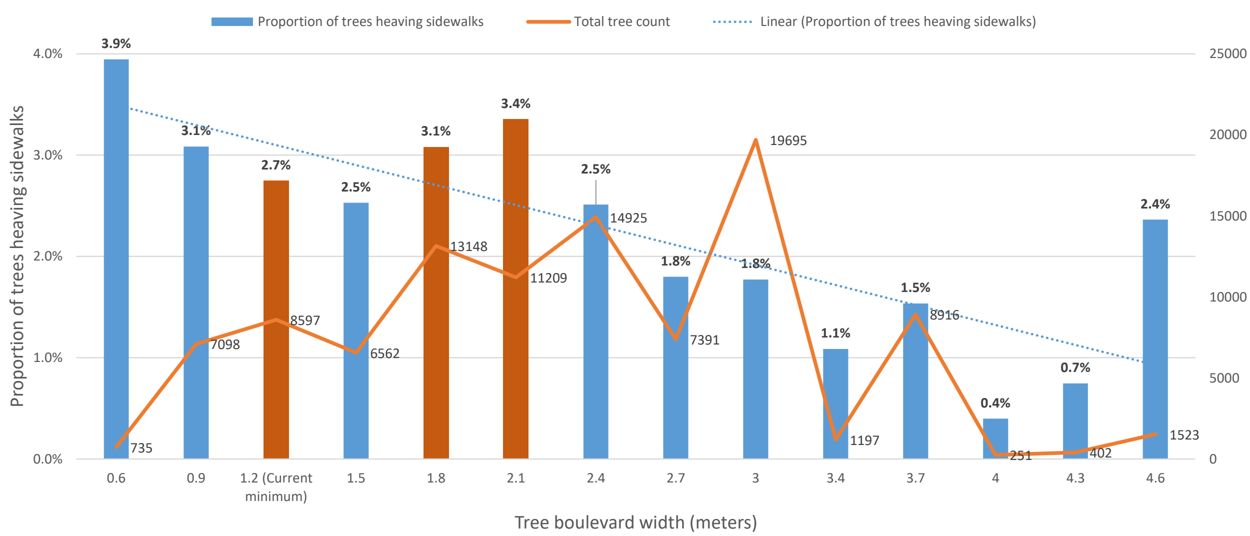


Figure 18. Proportion of tree condition by planting typology for trees associated with a sidewalk defect within a four-meter buffer. Trees in alleys and parks were excluded from the analysis.

Sidewalk heaving was looked at in more detail to see if there is a correlation between boulevard width and heave associated with a tree. Smaller boulevard widths were found to correlate to more trees heaving sidewalks. Street trees in boulevards between 1.8 - 2.1 meters were found to be more associated with sidewalk heaves than the current boulevard minimum (1.2 meters) as seen in the **orange bars** in Figure 19.

To explore the relationship further, the proportion of young trees (under 20 centimeters DBH) was assessed as younger trees are generally associated with less sidewalk heaving as their root zone is smaller (Figure 19). More than 50% of trees are young in the current 1.2 meter minimum boulevard width compared to only 38% for 1.8 meter and 29% for 2.1 meter boulevards (**orange bars** in Figure 19) suggesting the lower heaving rate in the current minimum boulevard may be due to the proportion of young trees.

Proportion of trees associated with a heaved sidewalk by boulevard width



Proportion of young trees by boulevard width

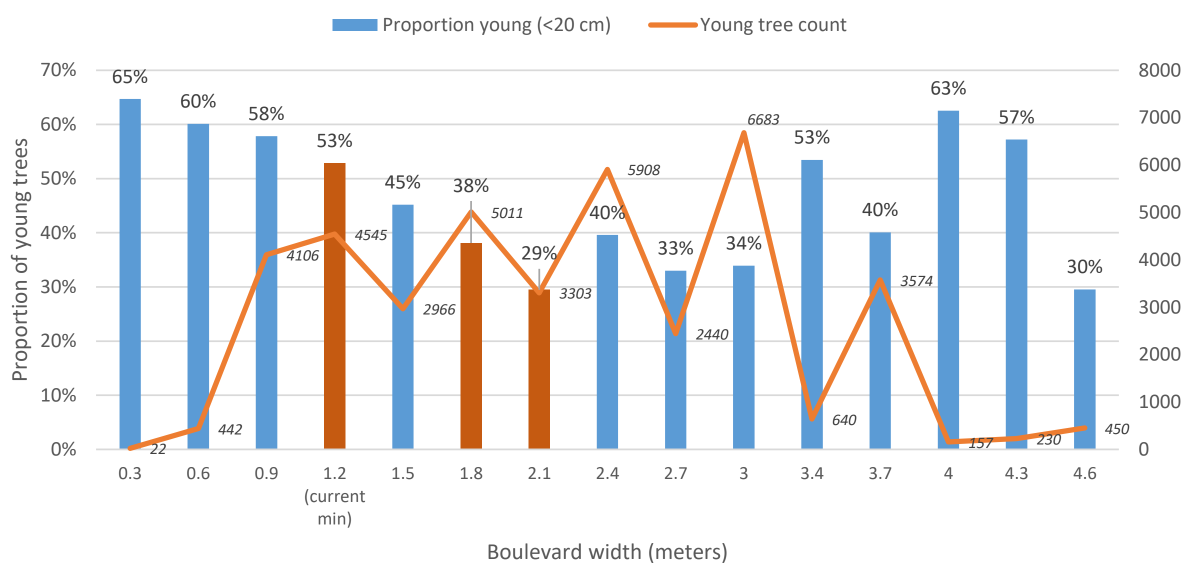


*Figure 19. (Top) Proportion of trees associated with a heaved sidewalk by boulevard width compared to total tree count (orange line) and (bottom) proportion of young trees by boulevard width compared to total count of young trees (orange line). **Orange bars** show the key relationship between the current boulevard standard and 1.8 and 2.1 meter boulevards.*

Tree age by planting type

To identify trends with tree age and planting type, an analysis was conducted looking at the age composition of street trees throughout the city and by planting type. Tree ages were classified based on Richard's Rule on tree age diversity which classifies age classes by diameter at breast height (DBH) which is measured at 1.3 meters around the tree trunk (Figure 20).

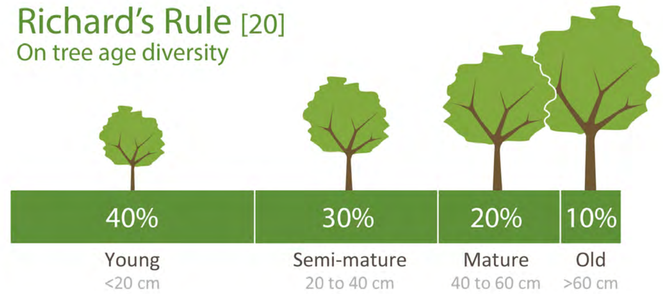


Figure 20. Richards Rule on tree age diversity; graphic from Vancouver's Urban Forest Strategy (2018).

Findings

As seen in Figure 21 below, street trees in cutouts have the lowest proportion of mature or old trees (10%) which is roughly one third of the proportion found in grass boulevards (32%). This suggests trees are living shorter lives in hardscaped areas.

When looking at tree cutouts city-wide, downtown has the highest proportion of tree cutouts across neighborhoods in the city, however it has one of the lowest neighborhood canopy cover at just 13% identified in the 2018 Urban Forest Strategy (Figure 22). Findings suggest while trees are in relatively good condition in highly urban areas, they are not living long enough to contribute to a large canopy cover.

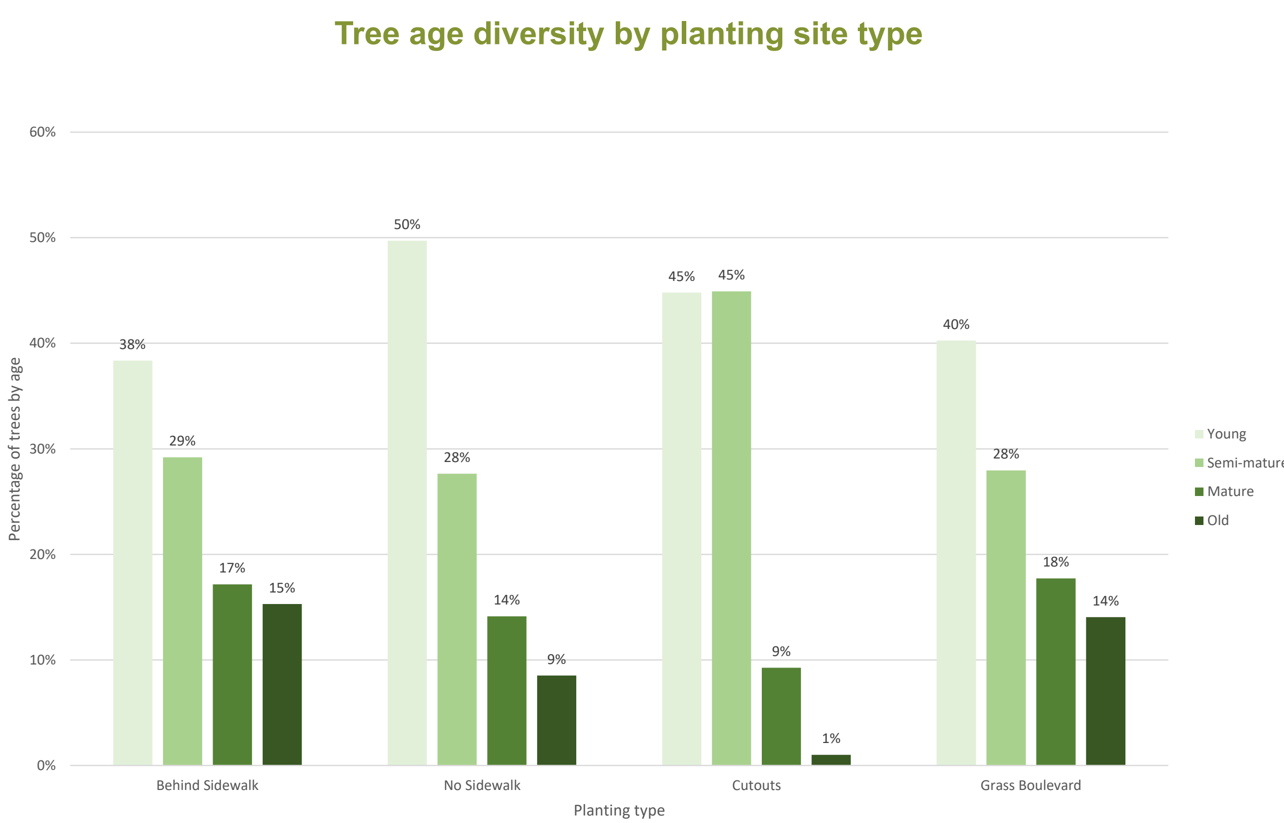


Figure 21. Tree age by planting type city-wide based on Richard's rule utilizing tree diameter at breast height (DBH). Note: excludes trees in back alleys and in parks.

Distribution of street trees in cutouts

Includes trees in cutouts in the sidewalk AND trees in cutouts with a metal or concrete grate over the pit

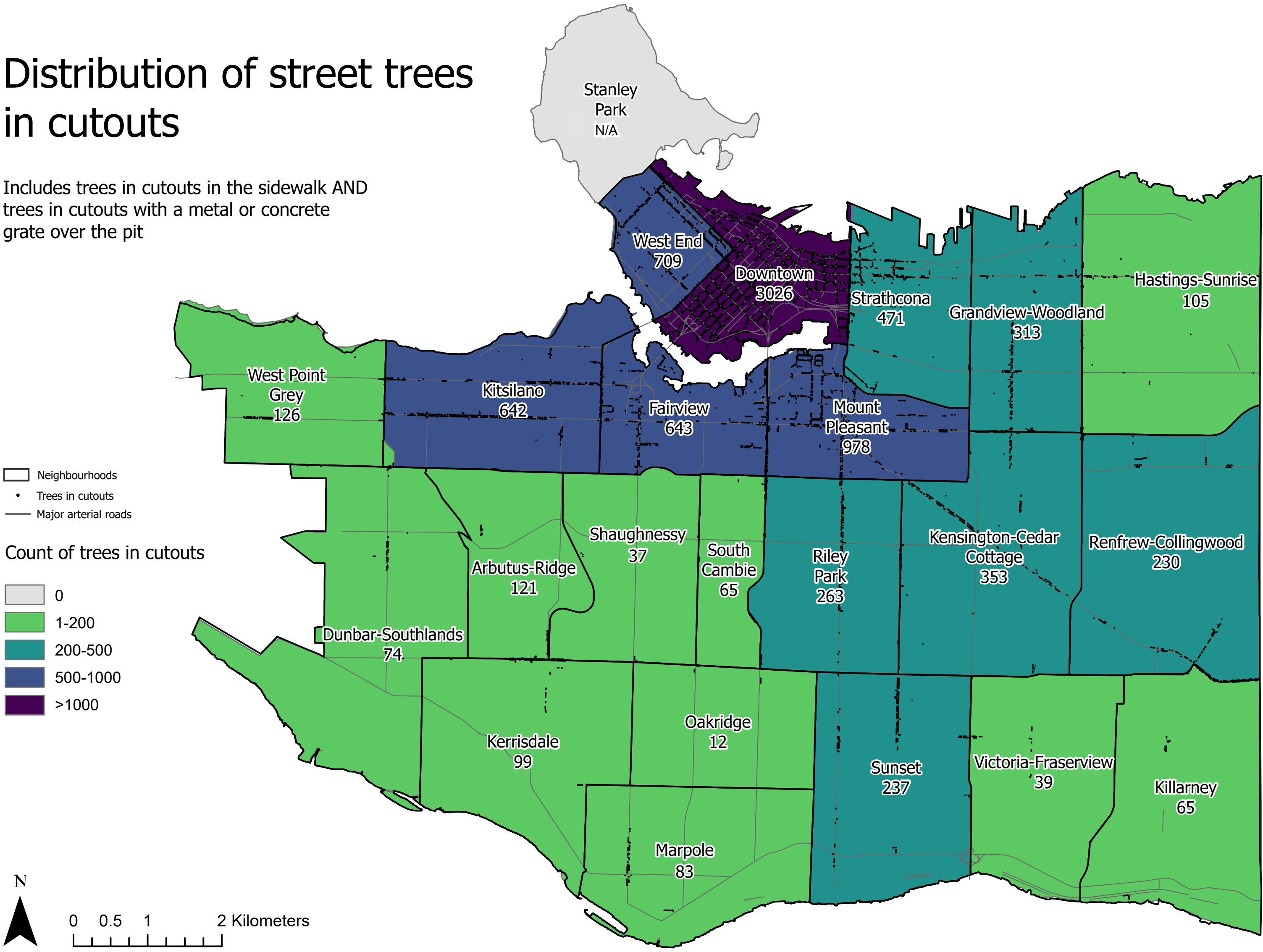


Figure 22. Citywide distribution of street trees located in cutouts.

Boulevard width and tree condition

Are there any trends between tree condition and the width of the city's grass boulevards? To explore the effect of boulevard width on tree condition, conditions of mature trees larger than 20 centimeters DBH were examined. Young trees were excluded as the impact of boulevard width is more significantly felt in the limitations of larger root systems.

Findings

When looking at the relationship of mature trees (larger than 20 cm DBH) compared to boulevard width, smaller boulevards are generally associated with higher rates of trees in poor or dead condition (Figure 23). Of the overall trees in dead and poor condition, trees in boulevards between 1.8 and 3 meters contributed to a large number proportion (67%). However, boulevards between 1.8 and 3 meters are also represent a large proportion of grass boulevard widths (63%), suggesting rates are relational to proportion of boulevard width.

Trees in dead or poor condition by boulevard width

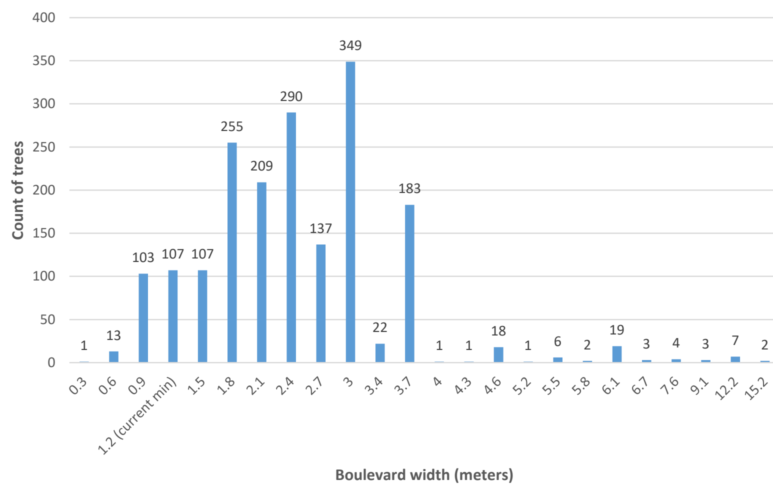


Figure 23. Count of trees in dead or poor condition by boulevard width.

To explore the proportion of tree conditions relative to boulevard width further, trends were looked at for mature trees across conditions. As shown in Figure 24, no clear trends are observed across classes suggesting no clear relationship between tree condition and boulevard width alone. While most street trees are found in smaller boulevards and are associated with more declining trees, boulevard width alone is not a determining factor of a tree's condition.

Proportion of mature tree condition by boulevard width

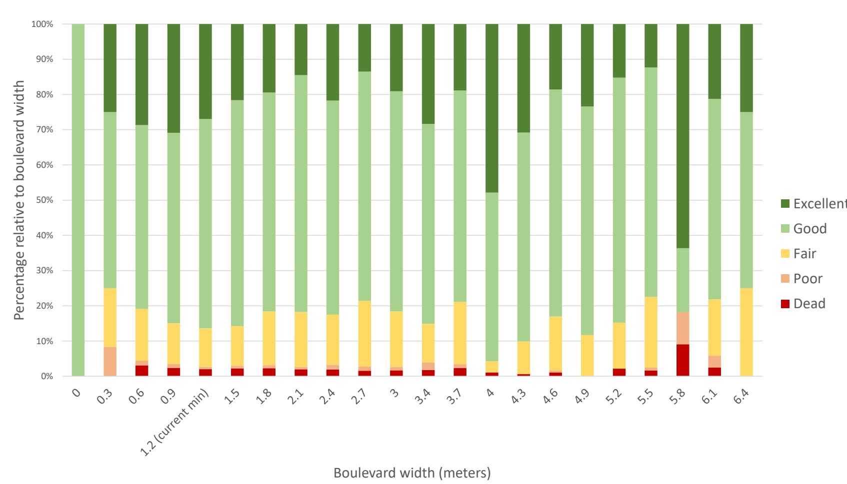


Figure 24. Tree condition by grass boulevard width excluding trees under 20 centimeters diameter at breast height (DBH).

Tree condition associated with green rainwater infrastructure

To assess the condition of trees in green rainwater infrastructure systems (GI), a buffer analysis of five meters was conducted to correlate street trees with associated GI system with the limitation that this is a generalized analysis only and no field visits were conducted for confirmation.

Findings

592 street trees were found to be associated with a GI asset and the majority (95%) were found to be in excellent or good condition (Figure 26). This is relatively higher than the City-wide average of 88% of trees in excellent or good condition (excluding trees in parks and alleys). Street trees associated with GI were most associated with permeable concrete pavers (133), bioretention bulges (83), and bioswales (77). Of all the trees associated with GI, trees associated with bioswales had the highest mortality rates (5% dead) which suggests further analysis to be conducted on the health of trees within Vancouver's bioswales (Figure 25).

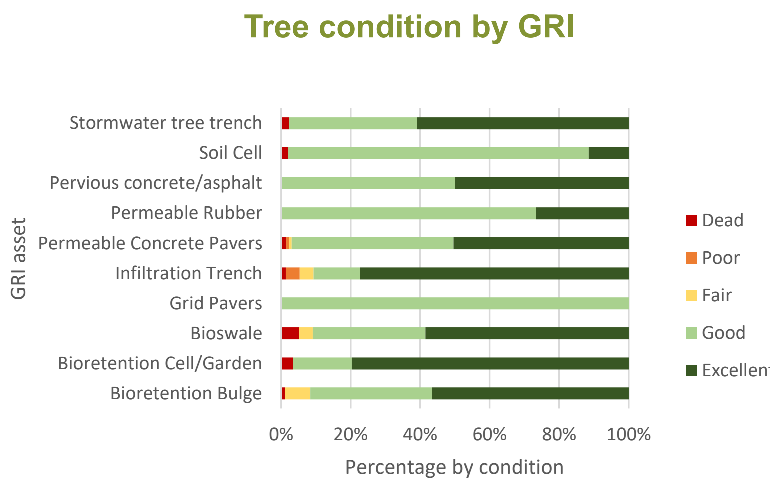


Figure 25. Trees associated with green rainwater infrastructure (GI) by tree condition.

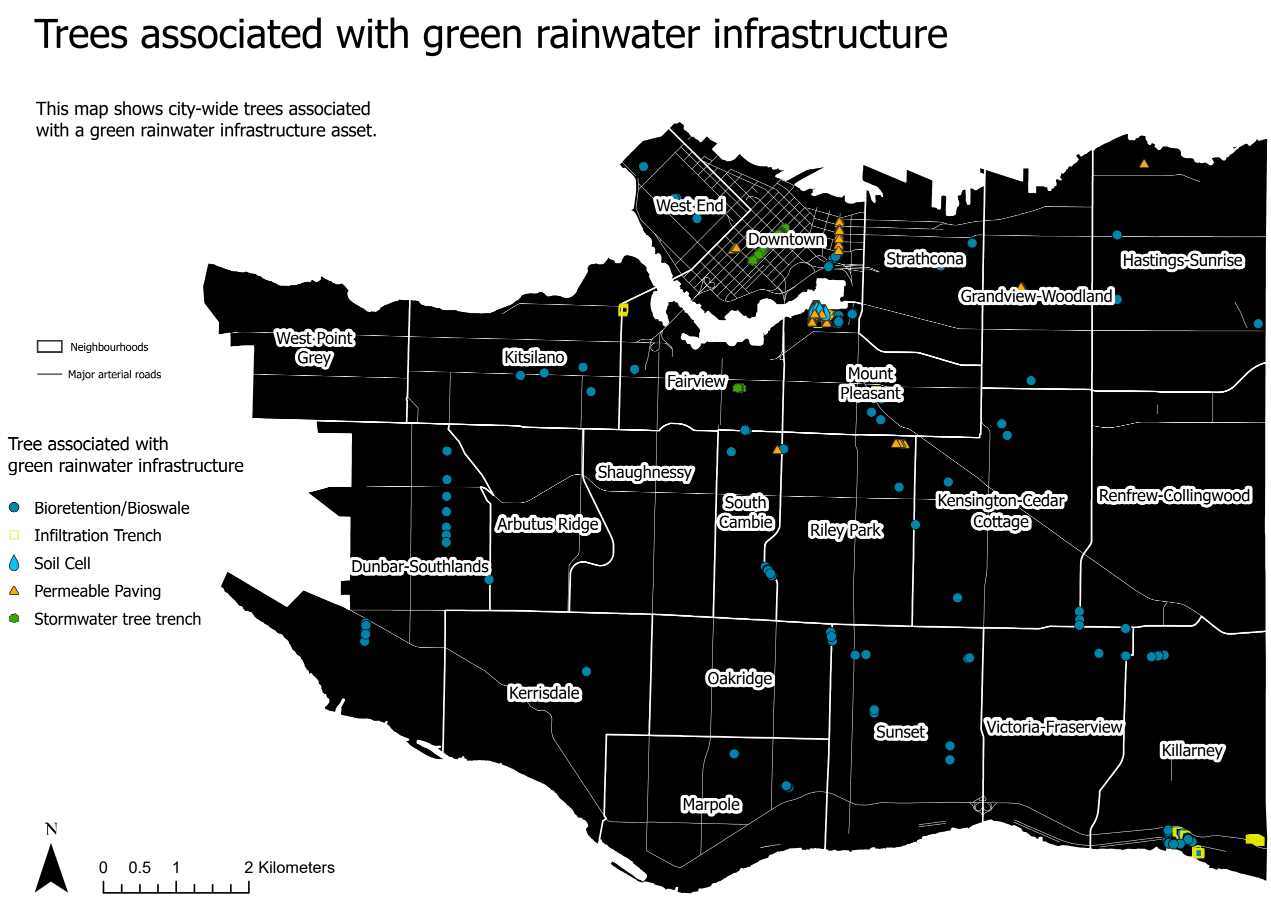


Figure 26. Trees associated with green rainwater infrastructure in Vancouver

Priority areas

Vancouver's Urban Forest Strategy (UFS) set a strategy in 2018 to increase tree planting in neighborhoods with low canopy cover and guiding principle five aims to distribute ecosystem services equitably. To support the UFS, priority areas were identified using the Disproportionately Impacted Populations index overlaid with areas of low canopy cover identified through the 2021 LiDAR analysis experiencing canopy cover just below the city-wide average of 23% (Figure 27).

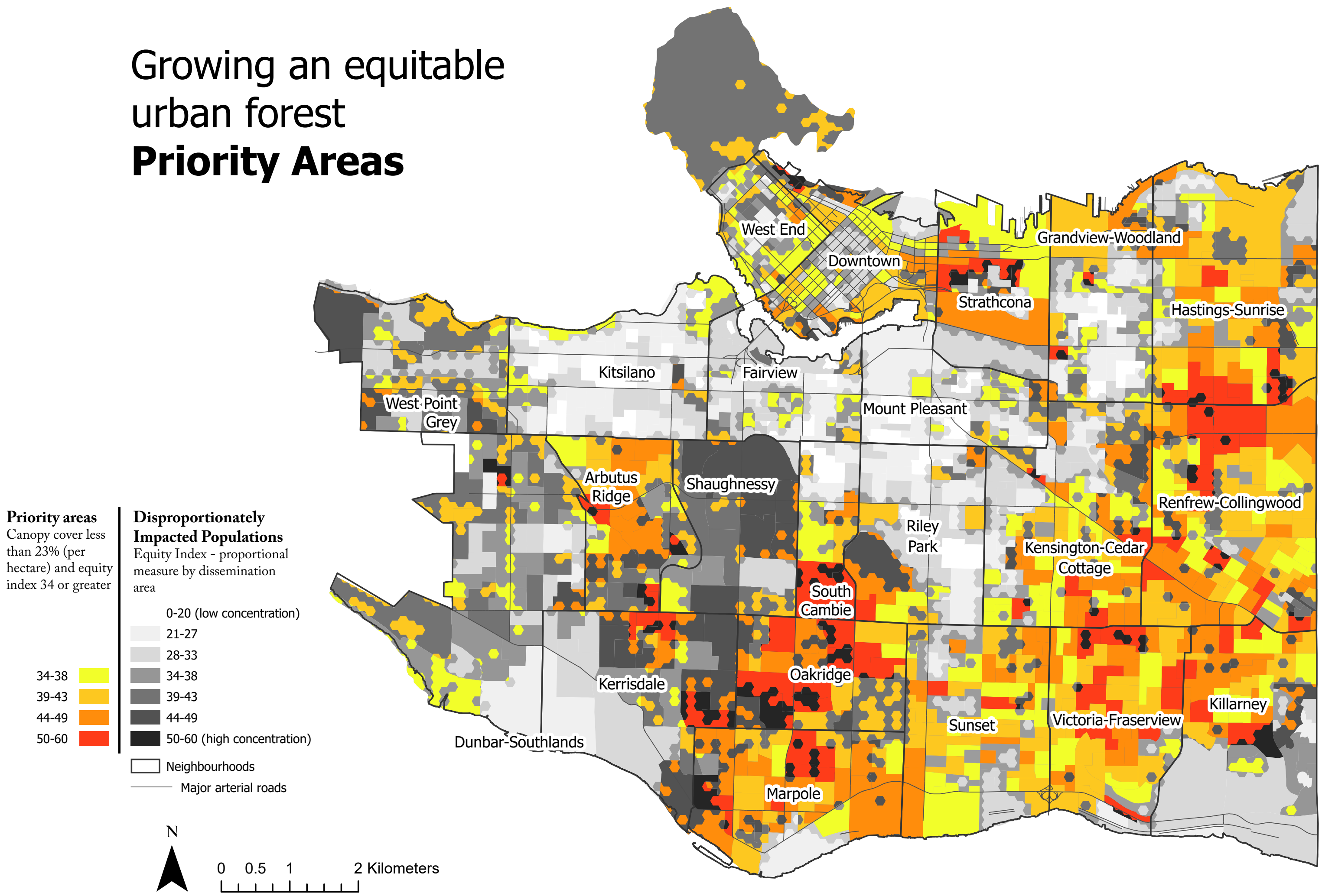


Figure 27. Urban Forest equity map using the City's Disproportionately Impacted Populations (DIP) index and the 2021 canopy cover data which includes both public and private tree canopy cover.

Potential street tree retrofitting locations

Sidewalk heaving is one of the more significant types of sidewalk damage attributed to street trees and often results in the use of asphalt as a temporary measure to fill the lifted sidewalk panel. This can also result in asphalt sealing tree pits where tree grates or surrounds are damaged, or concrete panels are lifted.

While findings suggest faults and linear cracking are other significant types of sidewalk damage that can be attributed to trees, sidewalk heaving is the focus of this analysis due to the more significant safety impact to pedestrians and direct association with a street tree. 522 locations were identified within the priority areas for existing trees that could potentially benefit from a tree pit or boulevard retrofit alongside addressing sidewalk heave (Figure 28). Sidewalk heave included both trees where the defect has and has not been addressed as despite addressing sidewalk heave, temporary measures can result in additional damage within a few years as the roots continue to grow. Two major categories distinguish the locations:

- **Trees in cutouts** – Locations where trees are in cutouts associated with either a primary or secondary sidewalk heave. Cutout locations could be assessed for expansion of tree pit cutout size, removal of damaged grates/cement surrounds, improvement of surface treatment, and/or exploring a sidewalk solution to work around existing roots if the heave is significant.
- **Trees in grass boulevards** – Locations where trees are in a grass boulevard less than 2 meters wide (6 feet) and associated with either a primary or secondary sidewalk heave. 2 meters was selected as a cutoff as the proportion of sidewalk heaving decreased in boulevards larger than 2 meters (Figure 19) and the peer municipal review found Vancouver to have a smaller minimum boulevard width than other municipalities. Boulevard locations could be assessed as candidates for curb bumpouts in residential locations, sidewalk material upgrades and rerouting, boulevard width expansion, and/or exploring sidewalk solutions to work around existing roots if the heave is significant.

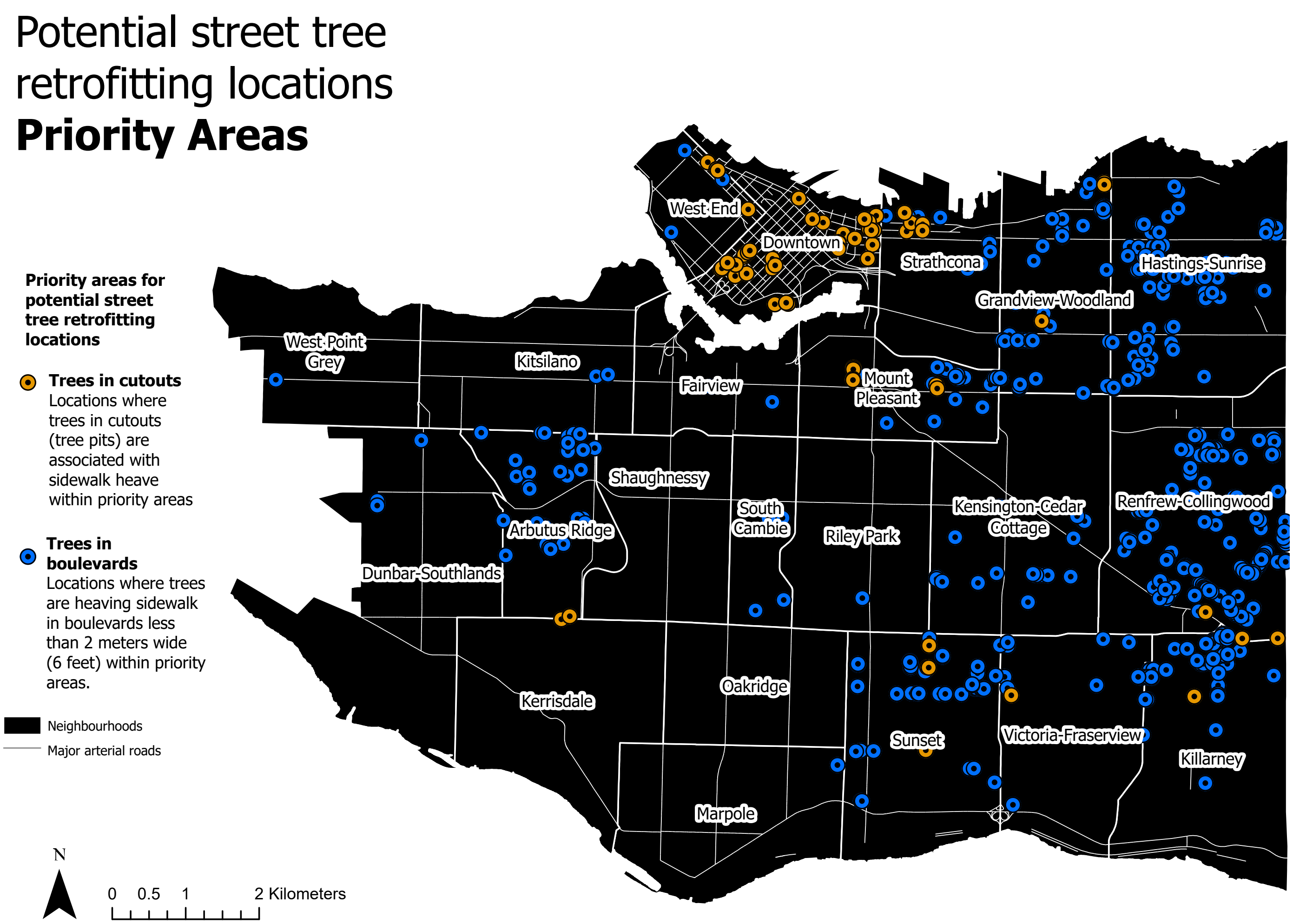


Figure 28. Map of potential retrofitting candidates for equitable priority areas.

DATA ANALYSIS SUMMARY

CATEGORY	KEY FINDINGS
Overall planting area conditions	• Vancouver's street trees are healthy overall with most street trees in good or excellent condition • Most street trees are planted in grass boulevards. Trees planted in cutouts make up a small proportion of the planting sites. • Street trees in cutouts experienced higher rates of mortality than other planting locations.
Genera analysis	• Maple (Acer) is the most common genera planted in tree cutouts • Linden (Tilia) trees experience more health challenges in cutouts than maple • Ironwood (Parrotia) trees are performing well relative to other trees in cutouts
Tree health and sidewalk conditions	• Faulting, linear cracking, and heaving are the most associated sidewalk defects from street trees • Smaller boulevards widths are associated with more trees heaving sidewalks. • Sidewalk heaving is most associated with trees in the middle stage of their life (semi-mature) • Trees planted in cutouts associated with sidewalk defects had higher rates of dead trees than other planting locations.
Tree age by planting type	• Street trees in cutouts have the lowest proportion of mature or old trees (10%) compared to other planting locations • Downtown has the highest proportion of trees in cutouts but one of the lowest neighborhood canopy cover percentages
Boulevard width and tree condition	• Most grass boulevard widths are 3 meters or less • Trees in boulevards between 1.8 and 3 meters have the highest counts of trees in dead and poor condition • Boulevard width alone is not a determining factor of a tree's condition
Tree condition associated with green rainwater infrastructure	• Trees associated with GI are healthier than city-wide trees on average • Trees were most associated with permeable concrete pavers, bioretention bulges, and bioswales • Trees in bioswales experience higher mortality rates compared to other GI assets

RECOMMENDATIONS

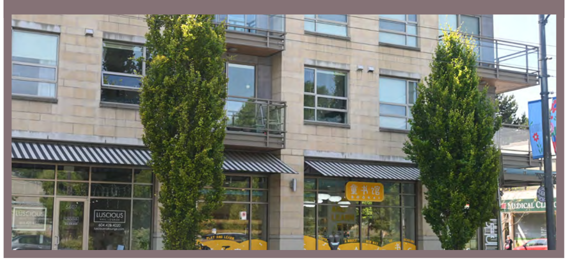
Recommendations

The goals and associated recommendations below provide a framework to proactively improve the likelihood of street tree survival into maturity and limit the adverse impact of the sidewalk in urban hardscape rights-of-way. The recommendations are informed by the findings from the literature review, meetings with key City staff, comparisons with other municipalities, case studies, and the results from the data analysis. The goals and associated recommendations provide guidance on Vancouver's Design Standards, Construction Specifications, Standard Detail Drawings, and overall recommendations for future management. The goals and recommendations are associated with two categories:

1. **Improving the health of existing trees and limiting impacts to sidewalk conditions**
2. **Setting up future trees and sidewalks for success**

Figure 29 below summarizes the six key goals.

IMPROVING THE HEALTH OF EXISTING TREES AND LIMITING IMPACTS TO SIDEWALK CONDITIONS



GOALS

1. Shift from a reactive to proactive approach to managing sidewalk damage from trees
2. Manage an equitable urban forest that provides tree canopy in areas most vulnerable
3. Improve the health of existing street trees in hardscapes

SETTING UP FUTURE TREES AND SIDEWALKS FOR SUCCESS

GOALS

4. Minimize sidewalk damage and maximize healthy trees by situating trees in appropriate soil volumes and soil conditions.
5. Increase the likelihood of tree survival into maturity in hardscapes
6. Streamline interdepartmental coordination for planting site design

Figure 29. Overview of seven associated goals to improve street trees and sidewalk conflict in hardscapes

Improving the health of existing trees and limiting impacts to sidewalk conditions

Recommended actions	Department	Notes
Goal 1: Shift from a reactive to proactive approach to managing sidewalk damage from trees		
1A. Develop a management and tracking system for trees in cutouts (tree pits) as part of the street tree inventory database. Add an attribute in the tree inventory for 'tree pit repair needed', which triggers a notification to Street Operations with an associated comments field.	Engineering Services - Street Operations & Streets Design, Operations & Engineering (Urban Forestry)	
1B. Continue to work to establish procedure to update sidewalk condition assets. Add an attribute to confirm connection to an existing street tree and associate with tree ID # attribute.	Engineering Services - Streets Design & Operations & Engineering (Urban Forestry)	Discussion needed between Urban Forestry & Streets Design on how to operationalize and if tree ID's can be linked.
1C. Where trees are heaving sidewalks, assess opportunities to retrofit tree pits and grass boulevards as sidewalks require repair adjacent to trees. Continue developing a decision matrix or a checklist for approval by an engineer and arborist to determine the best recommendation for mitigating sidewalk damage and maximizing tree health. Retrofitting options are case specific but could include: • Removing metal tree grate and/or concrete tree surround if damaged and tree has outgrown and lifting • Increasing the size of the tree cutout opening alongside an anti-compaction surface treatment • Replacing the surface treatment and/or decompacting soils using air spading if soil is surface sealed • Rerouting or raising an existing sidewalk or installing a different material (e.g., rubber sidewalk) • Install a curb bulge to increase soil volume Track progress in the sidewalk condition asset database and in the inventory database through a shared attribute in both datasets.	Engineering Services and Operations & Engineering (Urban Forestry), IT, Engineering Services - Streets Design	• The City of Seattle has an Initial Street Tree and Sidewalk Assessment Checklist for sidewalk repair when located within the dripline of a tree. An arborist and engineer determine the next steps for the tree and sidewalk. • Shared attribute could be part of ongoing VanTree replacement; discussion between Urban Forestry and IT needed.
1D. Consider trialling a longer-term pilot project 'Adopt a tree pit' program to enlist the help of the community to water trees, remove trash, plant vegetation, and report concerns with sidewalk and pit damage through 311.	Engineering Services and Operations & Engineering (Operations/Urban Forestry)	See Vancouver's 'Adopt-A-Catch-Basin' program.
Goal 2: Manage an equitable urban forest that provides tree canopy in areas most vulnerable		
2A. Work alongside disproportionally impacted communities such as the Downtown Eastside to target future GRI initiatives that respond to the needs of the community. Target areas of low canopy cover and where current infrastructure/utilities are not meeting today's standards or are damaged.	Planning, urban design, and sustainability, Engineering Services, Operations & Engineering (Operations/Urban Forestry)	Report from the Vancouver Board of Park's and Recreation to Park Board Chair and Commissioners (2020) innovative solution recommends integration of trees into GI assets to offset stormwater peak flows.

Recommended actions	Department	Notes
2B. Target tree pit retrofit and sidewalk repair efforts in areas with low tree canopy, particularly in areas with disproportionately impacted populations.	Engineering Services and Operations & Engineering (Operations/Urban Forestry)	Report from the Vancouver Board of Park's and Recreation to Park Board Chair and Commissioners (2020) innovative solution recommends installing new planting cutouts in predominantly paved areas of the city.
Goal 3: Improve the health of existing street trees in hardscapes		
3A. Where trees have outgrown grates and/or surrounds, develop a decision matrix to determine what covering surfaces could replace to increase surface permeability while limiting compaction. Decision matrix could also be included in the Engineering Design Manual for new plantings. Recommended covering surfaces by intensity of pedestrian use from low to high could include: • Mulch (approved mix of wood chips or organic mulch) (Low) • Drought tolerant, native perennial ground cover or shrubs • Rock mulch with stabilizer as an aggregate binder, lightly compacted and dampened with water • Crushed gravel or pebbles; can be bonded with epoxy resin and underplanted with ground cover or shrubs (10 mm) • Flexible porous surface treatment (High)	Engineering Services and Operations & Engineering (Operations/Urban Forestry)	Engineering Design Manual – Add subsection in section 9.3 - Urban Forest
3B. Update the Standard Drawing and Construction Specifications on the trees four-piece surround to include a panel removal plan for the concrete surround based on a tree's trunk diameter.	Engineering Services	• G10.2 - Trees four-piece tree surround (2018) • Construction Specifications – add subsection 'Four-piece surround maintenance' to Section 32 93 01 Planting of Trees, Shrubs and Ground Cover
3C. Add specification for maintenance required if using permeable pavers/pavement in a tree pit for regular cleaning to prevent clogged pores.	Engineering Services - Green Infrastructure & Streets Design	Engineering Design Manual – Add subsection in section 9.3 Urban Forest

Setting up future trees and sidewalks for success

Recommended actions	Department	Associated standard/comment
Goal 4: Minimize sidewalk damage and maximize healthy trees by situating trees in appropriate soil volumes and soil conditions		
4A. Adopt a new standard boulevard width on grass and paved boulevards from 1.2 to 2 meters and require for future developments as part of the Engineering Specifications. • Add language to the Design Standards: "*the preferred width for boulevards with street tree(s) is 2 meters. Proposed boulevards with less than 2 meters where street trees are required must be reviewed and approved by the City Engineer.*"	Engineering Services - Streets Design	• G10.2 - Trees four-piece tree surround (2018) • Engineering Design Manual – add subsection to 9.3 Urban Forest.
4B. Continue to assess the approval of Engineered soil around utilities to maximize connected soil volume in tight spaces between trees. If approved, add to the City's Construction and Design Standards and develop a standard drawing.	Engineering Services - Streets Design & Green Infrastructure	• Engineering Design Manual – add subsection to 9.3 Urban Forest. • Construction specifications – add subsection • Standard Drawings – create new drawing
4C. Adopt a standard drawing for soil profile rebuilding from Dr. Susan Day et al.'s Soil Profile Rebuilding Specification, based on the successes of the Evans Planting soil remediation project. Add a section in the Engineering Design Manual on Growing Medium, recommending the rebuilding of a soil profile where certain factors can be met (e.g., no challenges with underground utilities).	Engineering Services - Streets Design & Operations and Engineering (Urban Forestry)	Drawing standards Engineering Design Manual – 9.5.1 Growing Medium
4D. Explore partnerships with the University of British Columbia's Bachelor of Urban Forestry and Masters in Urban Forest Leadership for research-based projects focused on street tree health and/or boulevard soil remediation.	Operations & Engineering (Urban Forestry)	
4E. Secure a vendor and storage for wholesale biochar and trial as a tree pit amendment to explore potentially adding as a standard in the future. Trial areas could target future high-density tree pit installation sites where existing soils have poor health or fertility in low canopy areas.	Operations & Engineering (Urban Forestry)	
4F. As a priority over trailing biochar application, consider the addition of an organic compost soil amendment standard as part of the existing growing medium standards. Compost should be installed at an application of four inches over the compacted subsoil and tested to ensure weed seeds aren't present (Day, 2012).	Operations & Engineering (Urban Forestry) and Engineering Services - Streets Design	Engineering Design Manual – 9.5.1 Growing Medium

Recommended actions	Department	Associated standard/comment
Goal 5: Increase the likelihood of tree survival into maturity in hardscapes		
5A. Update the City's recommended species list to increase the suitability of species for a changing climate and add 'Drought tolerance' to the criteria list for general tree selection. Explore adding tree species planted in northern California and Oregon. • Add a list of recommended trees for tree cutouts (tree pits) which include trees without significant basal flare and with deeper root systems that will decrease the likelihood of damaging sidewalks. Trees must be drought-tolerant in these conditions. Consider accompanying list with a tree selection tool database.	Engineering Services and Operations & Engineering (Operations/ Urban Forestry)	• Engineering Design Manual - 9.3.4.1 PREFERRED STREET TREE SPECIES LIST • Urban Forest Strategy Action 14 – Update tree selection guidelines to reflect the city's goals for climate adaptation, rainwater management, food production, biodiversity, and reconciliation. • Climate Change Adaptation Strategy action: Ensure species and location selection criteria in the landscape guidelines reflect future climate projections.
5B. Change language around medium and small trees to be suitable for a two-meter boulevard width or larger (currently 1.5 minimum).	Engineering Services - Streets Design	Engineering Design Manual - 9.3.4.1 PREFERRED STREET TREE SPECIES LIST
5C. Adopt standard drawing for Engineered soil in the right-of-way and staging diagrams for meeting appropriate slopes during installation.	Engineering Services - Green Infrastructure	Standard Drawings
5D. Review the feasibility for continued use of soil cells. Continue to explore partnerships for trials (e.g., Permavoid, Silva Cell).	Engineering Services - Streets Design	Standard Drawings
5E. Require contractors to submit a watering maintenance plan and monitor surface compaction to ensure proper irrigation is provided during the two-year warranty period. Provide template plan for contractors with general amount to water, number of waterings, months to water, and when to water during extreme droughts + heat events. If topsoil shrinks and becomes compacted during the warranty period, require adding additional topsoil alongside watering to mitigate surface compaction.	Engineering Services and Operations & Engineering (Operations/ Urban Forestry)	Construction specifications - Section 32 93 01 Planting of Trees, Shrubs and Ground Covers (1.0.7)
5F. Consider removing the requirement for metal tree grates in Downtown special planning areas and shift to the concrete four-panel surround or open tree pit with surface treatment.	Engineering Services - Streets Design	Construction specifications - Section 32 93 01 Planting of Trees, Shrubs and Ground Covers (2.14.1)
5G. Require that appropriate soil volume must be achieved before planting a new street tree. Specify language "*soil volumes must be achieved using various method(s)*" to include various method(s) that must be undertaken (e.g., increasing boulevard width, installing soil cell, installing Engineered soils, etc.). Add language: "*Where achieving soil volume isn't possible, proposed volumes must be reviewed and approved by the City Engineer*."	Engineering Services - Streets Design	Engineering Design Manual - 9.3.3.2 SPACING AND SOIL VOLUME REQUIREMENTS

Recommended actions	Department	Associated standard/comment
Goal 6: Streamline interdepartmental coordination for planting site design		
6A. Work between departments to track use of Engineered soils using GIS from existing databases and future installation. Link through shared attribute in the tree inventory.	Engineering Services - Streets Design, Operations & Engineering (Urban Forestry)	
6B. Work between Streets Design and Urban Forestry to include a shelf base requirement in the standard tree pit drawing for the sub-base on the curb side, sidewalks, and along bike paths.	Engineering Services - Streets Design & Operations & Engineering (Urban Forestry)	G10.2 - Trees four-piece tree surround (2018)
6C. Consider the addition of an interdepartmental liaison for urban trees that works between department groups, holds interdepartmental meetings, tracks data management across departments, and drafts new standard drawings as needed. For short-term coordination, meet to delineate key responsibilities for existing staff in the interim and identify 2-3 core gaps to prioritize.	Engineering Services - Streets Design & Green Infrastructure and Operations & Engineering (Urban Forestry)	Report from the Vancouver Board of Park's and Recreation to Park Board Chair and Commissioners (2020) innovative solution for identification of cross-departmental synergies and collaboration

CONCLUSION

Planting trees in our cities is one of the best things we can do to offset our carbon footprint. A tree's health, canopy size, and ability to reach full maturity will maximize the benefits of the urban forest at regulating and cooling particularly impervious areas in dense urban hardscapes. Maintaining walkable and safe streetscapes is critical. Instead of viewing trees and hardscaped surfaces in direct conflict, there are solutions and actions to help minimize both risk and damage to sidewalks as well as improving the likelihood of a tree's ability to live a healthy life and coexist in the city. Alongside the 27 recommended actions, strategies that depave hardscaped areas and shifting from less grey to more green rainwater infrastructure are critical steps that can be taken alongside tree planting to shift the status quo.

Work must be done beyond planting to meet canopy cover targets to ensure trees are situated for successes in the challenging conditions they must survive in to live to mature age. By shifting management from a reactive to a proactive approach in sidewalk and tree conflicts, mitigation strategies can be implemented in advance to provide existing trees with healthier growing conditions to limit adverse impacts to sidewalks, and combat additional challenges they must take on in the face of a changing climate. For newly planted trees, the City of Vancouver has the opportunity to work internally and alongside developers to implement unique and innovate design approaches for new street boulevards to situate young trees for success while minimizing future costs and maintenance of sidewalks.

Vancouver's urban forest is a critical green asset, integral to the livelihood of the people and animals who call Vancouver home. The goals and recommendations provided are just the start to guide future discussions towards a long-lasting streetscape of healthier trees and safer sidewalks.

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APPENDIX - PEER CITY REVIEW TABLES

DOCUMENTS REVIEWED

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Documents reviewed	• Engineering Design Manual (2019) • Engineering Construction Specifications (2019) • Standard drawings	• Standard Specifications for Road, Bridge, and Municipal Construction (2023) • Street Tree Manual (2013) • Standard Plans for Municipal Construction (2023) • Trees and Sidewalks Operations Plan (2015)	• Green Streets Technical Guidelines (2017) • General Soil Cell Specification 32 88 88 • Complete Streets Guidelines (2017) • Design Criteria for GI in the Right-of-way (2021) • TS530	• Urban Forestry Diversity Guidelines (2011) • Design and Construction Standards (2022) • Design standard drawings	• Greenery Provision and Tree Conservation for Developments (2023) • Greenery Provision for Roadside (2011)	• Berlin Standards for the planting and the subsequent care of street trees (2022)

CANOPY COVER TARGETS

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Current canopy cover	• 23% (2020)	• 28.1% down from 28.6%	• 28.4%	• 22% (22,800 trees as of 2011)	• 29.3% (Treepedia MIT)	• Unknown; over 430,000 trees in street network with average of 80 trees per kilometer of street
Canopy cover target	• 30% by 2050	• 30% by 2037	• 40% by 2050	• 40% by 2040	• No set canopy cover target but one million tree program by 2030	• None

TREE PLACEMENT & SOIL VOLUME REQUIREMENTS

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Placement and spacing standards	• High density species to close canopy at 20 years and age 30 in low density areas • Plant only if street curbed • For spacing, 9-11m (large), 8-10m (medium), 7-10m (small/columnar)	• For spacing, 35-40' (large), 30-35 (medium-large), 25-30' (small/medium), 20-25 (small)	• Coordinate spacing with site furnishings for new construction • For retrofitting, spacing determined by context • 8 meters on centre, up to 10 m as needed	• Space trees to maximize canopy cover • Plant fewer large trees than many small • For spacing, large = 10-12 meters and small/medium = 6-10 meters	• Placement dependent on street type and development requirements	• If very cramped site conditions with no suitable measures to improve conditions, no trees should be planted
Minimum boulevard width	• 1.2 meters	• 5 feet (~1.5 meters)	• 1.5 meters	• 1.2; preferred 1.5 meters* • (Small trees: 1-1.3; medium 1.3-2.5, and large >2.5 meters)	• For new developments: 2-3 meter minimum 'green buffer'. • For planting verges along roadside, 1.2 meter minimum	• 3 meters • * Extent of crown + 1.5 meters on all sides as the root area should ideally be kept free from root penetration
Soil volume	• Large; 30m3/20m3 shared • Medium: 20m3/15m3 shared • Small: 10m3/5m3 shared • Columnar: 20m3/15m3 shared	• Not found	• 20-30m3/tree • Min. 30 m3 for continuous soil trenches per tree	• small (less than 9.5m2 planting area • medium 9.5-18.5 m2 • large more than 18.5m2 • 1-meter depth minimum	• 2-meter depth	• 1-1.5 minimum depth tree pit • 36 m3 for large trees • 24 m3 for medium • 12 m3 for small
Setbacks and clearances	• Utility setbacks range from 1.5 - 2 meters • Detailed awning setbacks (120-180 cm) • General clearances 1.5 - 6 meters	• General setbacks range • No awning setbacks	• Designers are recommended to approach utility owners during prelim. Design stage for allowable offsets between trees and utilities.	• Detailed utility setbacks • Street intersection setbacks (10-20 meters)	• Utility setbacks range from 1.5-3 meters • For roadside tree planting verges, no underground services are allowed to be laid	• 2.5 m setback for supply and disposal lines, however, if suitable protective measures are taken, distance can be reduced.

TREE SELECTION

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Species selection	• Compatibility with local growing conditions • Adequate space to reach natural form at maturity • Branch failure or wind-throw resistance • Pest resistance, freedom from significant nuisance problems • Low maintenance • Diversity (30, 20, 10, 3%)	• Only plant small and columnar trees if space limited	• City prefers large native trees in general	• Drought, heat, pollution, and wind tolerance • Longevity • Low pathogen and pest susceptibility • Allergen potential • Shade cast • Maintenance required (e.g., tree litter) • If no tree can be planted, consider lawns, ground covers, or shrubs.	• Not found	• Only plant if planting professionally carried out, good species for site, suitable soil, low degree of sealing, low degree of compaction, sufficient soil volume, tolerable to heat, dryness, radiation and wind load, sufficient light, no or very low pollutant inputs, professionally carried out care and maintenance, and sufficient protection. • Larger list of specific criteria applicable to selection of tree species.
Diversity	• >100 trees - No more than 40% max any one genus and 25% max any one species • 50-100 trees - No more than 50% max any one genus and 30% max any one species; • 25-49 trees - Can have 100% of the same genus but no more than 50% any one species • 1-24 trees - Can have 100% of the same genus and species	• Not found	• Not found	• 5% species, 10 percent genus, and 20 percent family	• Not found	• Goal to aim for higher diversity
Species lists	• List of 9 large trees, 14 medium trees, 20 small trees, 9 columnar trees, 9 conifers, and 8 broadleaf evergreen	• Approved Street Tree List (31-large, 8 large-columnar, 19 large-medium, 10 medium columnar, 38 medium, 5 small columnar, 34 small)	• 10 species listed as tolerant for hardscape environments; 87 trees in a Green Streets Vegetation Tool	• Tree selection matrix spreadsheet divided by street, park, and trial trees	• 28 large sized trees, 32 medium trees, and 10 small sized tree species in list; 26 palms	• Street tree list of the Urban Trees Working Group of the German Garden Office Managers' Meeting and the Berlin Street tree list

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Size selection	• Large - 3m+ with building setbacks >8 meters • Medium for >1.5m • Small for restricted conditions	• Not found	• Not found	• Not found	• Large trees = major roads blvd greater than 3.0 m • Medium at major roads and some minor with blvds between 1.5-3m • Small = minor roads with blvd. less than 1.6 m	• Not found
Understory guidelines	• Plantings should be native or adapted, drought tolerant, and diverse, pollinator friendly	• Specs on shrubs and ground covers • Permit not required for growing food crops	• Not found	• Plantings should not limit tree planting • Avoid ground covers below small to medium sized trees • Use areas with substandard tree soil volumes for plantings • Can reduce hostile appearance of barrier fencing	• Vehicular impact guard-rails are to be camouflaged with shrubs	• Surface of tree pit can be covered with greenery provided competition between plants for space and watering is taken into account

GROWING MEDIUM

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Growing medium	• New trees = Street Shrub Mix • 10-20% organic matter in mix	• Detailed planting soil mix • Organic matter must consist of fine compost.	• Boulevard mix: topsoil, coarse sand and compost • 2.5-5% organic matter	• Not found	• Approved soil mixture with pH 5.5-7 • Organic matter 10% minimum • Ratio of 3:2:1 loamy soil, compost and washed sand	• Soil must have good root penetration, adequate air, water and nutrients, none or only slightly compacted, none or only slight sealing, pH value below 7, no pollution, and no occurrence of harmful organisms • If currently not met, it needs to be replaced with soil dependent on location and tree species.

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Amendments	• Not found	• Amended and reused soil must be amended with compost to provide 10% organic matter for planting areas.	• Compost detailed • Soil reports may require additional amendments	• Not found	• Not found	• Only to be added with decomposition degree of 5 • Overgrown topsoil compost, and other organic substances must not be put into deeper layers.
Fertilizers	• Not found	• Minimum 50% nitrogen fertilizer must in slow release or controlled, specs on approval and based on soil analysis	• Not found	• Not found	• Not found	• If necessary, a complete/ multicomponent fertilizer must be introduced into the upper 10 cm of substrate • In autumn, use coated fertilizer • In spring, fertilization is recommended particularly for locations affected by de-icing salt
Soil cells	• Currently no detailed standard • Cells only for new road construction when utilities will not be impacted, no native soil is available, and Engineer approved	• Not found	• Used where surface area limited • Offer up to 92% porous space • Used under conventional concrete or interlocking pavers • Detailed specs on soil cells	• Used where future excavation is unlikely and where large clear soil volumes without crossing services allow installation	• Not found	• Not found
Structural/ Engineered soil	• Standards for Green Rainwater Infrastructure only • Only use for new trees	• Not found	• Structural soil used under paved areas to allow for roots to grow. • No standard detail	• Structural soil specs • Not used when trees have sufficient access to good quality sufficient site soils • Min. 15 m3 to depth of 1m should be provided with volume of topsoil included. • Use alongside passive drainage systems	• Not found	• Not found

PLANTING PRACTICES

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Warranty period	• 2 years, contractor responsible for summer watering and maintenance	• 1 year contractor period • Watering schedule submitted including irrigation zone requirements	• Not found	• Not found	• 8-week maintenance period and then passed to Singapore's National Parks Board (NParks)	• Within 3 days of planting, the contractor and client conduct inspection prior to acceptance. • Period of development maintenance variable and lasts until functional state is reached. (Experience shows 3-5 years.)
Drainage control	• Root collar planted higher in relationship to surrounding soil by 7.5-10cm where drainage correction impossible	• Not found	• Not found	• Not found	• Not found	• Root ball must be moist when planted.
Plant material	• Preference to materials grown in PNW US • Balled and burlap or in wire basket • Single leader with lowest branch at least 2m high • 6 cm caliper if deciduous, 2.5 m height if coniferous • Specs for root ball diameters based on DBH deciduous/coniferous	• Bare root, balled and burlapped, or in containers • Planting between Oct 1 and April 30 • Containers may require vertical cuts, circling roots must be loosened	• Not found	• Trees are to be good form, health, structure and free of pests and disease • Tree quality conform to Australian Standard for Tree Stock for Landscape Use	• Total height at least 2.5 m with clear trunk height of 1.5m, girth of at least 0.1m • Upright and in good form, balanced crown full foliage, terminal shoots, no included bark, no cutting back of leader, lateral branches not overlapping, no pruning wounds, no girdling roots	• TL nursery plants technical delivery conditions of the FLL • can be either wire ball or container. • Additional requirements provided. Requirements for transportation and storage, and control upon delivery.

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Subgrade prep	• Excavation to subgrade only as necessary • If material is disturbed, recompact to prevent settling of root ball. • Hole should be with sloping sides at 45 degree angle where possible.	• Before placing topsoil or amendment, subgrade must be thoroughly scarified 4 inches min • Subgrade must be cleaned of all debris and inspected	• Not found	• Not found	• Planting hole should measure 1m x 1m x 1m	• Excavated largely by hand. • Search slits dug beforehand to check area for lines. • Excavated soil removed and properly disposed if cannot be used. • Bottom and wall of pit must be loosened and bottom at least 10 cm deep. • If soil adjacent to pit cannot be rooted through, it must be improved.
Planting practice	• When backfill placed up to 2/3 of rootball, cut ties • 10 cm raised saucer around perimeter of rootball, planted in exact centre	• Detailed requirements for rootball placement • Carefully placed and compacted in lifts not exceeding 6” • 2/3 excavated native soil mixed with 1/3 compost • Place and compact without voids • For bareroot, backfill must ensure roots are properly spreading to avoid circling.	• Not found	• Not found	• Backfilled with Approved Soil Mixture and closed turfed grass • Aeration trough required for trees with girth <0.5m if planting verge is less than 3m wide	• Gradually fill with soil substrate • Bale must be moved carefully and filled soil carefully stepped on. • Trees are to be equipped with superate casting rings or with rims made of mineral materials
Staking/ collar protection	• Not found	• Deciduous trees staked with 8 foot long, 2” diameter wood stakes • Conifers have different requirements. • Remove after 1 year + replace damaged	• Not found	• Provide temporary staking to protect from vandalism with two timber stakes for all trees	• Staked with two galvanized steel pipes and PVC tubed nylon strings to fasten • Tree collar protector to be provided for all trees with PVC tube with slit cut along length of tube.	• Anchored for 2-3 years with 3-piece frame of posts with frames of semi-circular slats with connection of coconut rope or webbing. • Tree brackets and slats to prevent dog urine required.

PLANTING SITE DESIGN

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Tree grates	• Specific vendors and specs for special planning areas, concrete grate specs. • Four-piece surround standard • Min. 300 mm from curb	• Tree grates must be supported by angle iron frame • Top of grate flush with top of adjacent sidewalk	• Tree opening with grates should be min. 6 m2 • Standard details provide many designs but prefer open, raised, or tree fence options to in-ground or grated tree openings. • Where constrained space with narrow sidewalks, flush tree grates may be preferred - maintenance and growth must factor into design. • Grates should be easily lift-able and removable.	• For bioretention tree pits, use removable concentric rings. • Grates are steel and fibre-reinforced polymer	• Not found	• Tree grates require unpaved area of at least 4m3 in as square a shape as possible • Tree grate cleaned manually at least 4X a year.
Tree guards	• Not found	• Not found	• Not found	• Protection varies and key in areas vulnerable to vehicles/ vandalism • Do not use unnecessarily • Remove when trees have outgrown.	• Not found	• If collision damage feared, a tree guard post to height of at least 70 cm must be installed. • Protection from dog urine provided by slats at foot of tree buck with 4 semi-circular slats with thickness of around 8 cm attached with gaps at 2 cm.

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
General pit requirements	• Typical tree pit recommended three cubic metres of soil	• Not specified	• Min 1.5 m2 tree opening • Install soil cells where more volume needed • Open tree planters used where widths more generous + most cost effective • Precast planter w. perforated pipe outlet suitable for all types • Details for stormwater tree pits can be used in conjunction with soil cells • Three preferred systems: raised open pit with concrete/stone/metal surround, at grade open pit with metal fence, and at grade covered pit using grate. • Additional soil volume can be added to existing City trees through "connector" trenches or soil bridges which can connect to private property. See TS 5.10 Growing Medium	• Recommends curb extensions and blisters and structural soil tree pits to increase soil root volume • Use of porous or permeable pavement over structural soil to increase opportunities for gaseous exchange of water and oxygen and reduce conflicts between tree growth and pedestrian access, • Use of tree pit curb inlets to enable passive irrigation • General minimum is 1.5 x 1.5, preferred min for large is 2 x 2, and preferred overall is 2.5 x 2.5. • Bioretention tree pits use tree guard and tree pit frame to filter litter, oil, and pollutants prior to entering waterways. • Containerized trees not recommended	• Specs include a service verge adjacent to tree planting verge (in boulevard) • Excavate 1m deep roadwide verge	• If specs cannot be implemented, root area must be enlarged through suitable measures and site conditions improved. • Measures include creating deeper tree pits (up to 2.5 m), extending root space under traffic areas such as parking lanes, foot paths, and squares, and encouraging aeration by creating root ditches with an open-pored mineral mix. • Connected planting pits in the form of planting trenches have proven useful for rows of trees. • Tree pit remains open, permanently air and water permeable surface and designed in a way that rainwater can be used but ensured tree grate does not become permanently waterlogged.

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Surface treatment	• No standards for surface treatments	• Flexible porous surface treatment • Topdressing required as shown in drawings. Min depth of 2” • Specs for paver blocks	• Not found	• 50 mm compacted granitic gravel on short term basis • Permeable pebble mix preferred for high use areas • Stabilized tree pit finish is permeable pebble-epoxy paving. • For 2-3 years, granitic gravel surface is used and can transition into epoxy mix. • For structural soil around tree pit, permeable paving used	• Use turfed cow grass in unsealed aeration tree pit with loose paved PC slab	• Covered with gravel (5-10 cm) or similar suitable material. • Maintenance for granite chippings require surface to be loosened and vegetation removed • Chippings must be 10 cm high min and if ground sags, refilled with granite. • Mulch to be covered 10 cm high with bark mulch evenly.
Root barriers	• Vertical root barriers required around four concrete panels • Install where tree is within 2m of sidewalk or other hardscape feature	• Vertical root barrier AND horizontal root barriers required to cover a 4x4’ area 1 foot below root ball • Vertical root barriers must be installed between proposed trees and concrete sidewalk or curb • Horizontal must be installed as part of tree pit prep	• Not found	• Not found	• Not found	• Not found

MULCHING & WATERING

	VANCOUVER	SEATTLE	TORONTO	MELBOURNE	SINGAPORE	BERLIN
Mulching	• Inside berms of saucer to depth of 7-9 cm • Keep away from tree trunk	• Must consist of arborist wood chip or rock mulch as topdressing required for tree pits in ROW areas with high pedestrian volume. • 2-3 inches of mulch provided. • Rock mulch uses stabilizer as an aggregate binder that is lightly compacted and dampened with water.	• Not found	• All planted areas must be adequately mulched and depends on planting type	• Mulching for all trees within two days • Weeds to be removed and mulch forked lightly not heaped into high mound more than 100 mm thick. • No mulch within contact of root collar. • Mulch should be organic compost and approved material such as wood chips, oil palm husks, oil palm kernels, organic compost, or approved mix. Mulch with pH 5.5-7	• When mulching with organic substances, risk that root formation near surface will be promoted.
Watering	• Immediately and adequately water after planting	• Water must be applied after installation. • If settling occurs, Contractor must add enough soil to cover roots but must not rework soil.	• Not found	• Strategies employed: Water Sensitive Urban Design initiatives, porous and permeable pavements, bioretention basins and swales, tree selection focused on drought and wind tolerant trees, supplementary irrigation systems; rainwater collection in tree pits has been trialled and boosts short term tree growth; over time, pits can become silted and roots outgrow (they must include litter and silt traps, maintenance systems); rainwater soaker pits encouraged, passive irrigation, or rain gardens can be used.	• Regular watering required for at least 8 weeks for proper site establishment	• Water immediately after planting; around 100-200 liters of water per tree depending on weather, soil conditions, and tree species. • In the first year, water 15X and from 2-4 year, 12X from March to September. Additional waterings should be carried out during extreme heat and drought.