FINDING URBAN TREES FOR A CHANGING WORLD

by

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submitted by Jehane Samaha in partial fulfillment of the requirements for the degree of Master of Science in Forestry.

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Abstract

The well informed selection of street tree species is crucial to improve the diversity and functionality of urban forests, with the potential to provide lasting environmental and socio-cultural benefits. This multi-method project aims to characterize the complexity of the tree species selection process: which selection criteria do street tree planting professionals value, and which tree species do professionals associate with valued characteristics? Furthermore, what barriers and knowledge gaps inhibit the improvement of tree species selection to accomplish urban forestry goals of increased diversity and function? Using an extensive online survey of the USA and Canada as well as a case study of interviews in Philadelphia, we found that:

- A tree's tolerance of urban stressors is more important than other major selection criteria.
- Though ecosystem services are rated as important, professionals often lack the information necessary to apply these concepts to tangible tree selection decisions.
- There are inherent trade-offs between many selection criteria, leading to planting choice compromises.
- Professionals disagree on the qualities and planting suitability of many tree species.
- The palette of tree species encouraged by professionals varies across climate regions.
- Of the professional fields surveyed, urban foresters encourage planting the most diverse palette of trees, and landscape architects have the most diverse palette of trees that they discourage planting. Tree recommendations from the fields of urban forestry and arboriculture are the most similar.
- A higher percentage of trees encouraged by public horticulture professionals are "rare" in the urban forest; collaborations with this professional field may have the potential to evaluate and expand the palette of street tree species.
- There are high level barriers to implementing ideal selection criteria, including issues of budget, nursery supply, site conditions, lack of inventory data, public perception, and the lack of accessible and functional information on the characteristics of tree species.

Expanding the palette of available street trees and increasing the availability and transfer of information on the characteristics of particular trees is a crucial step to increase biodiversity and the provisioning of ecosystem services in the face of urbanization and climate change.

Lay Summary

Trees planted in cities face many survival challenges, but when they thrive they make our cities healthier, less hot, and more beautiful. Historically, professionals have planted the same familiar trees over and over in cities since they are a safe bet, which results in a vulnerable, low diversity urban forest. To add new tree species to the urban forest, especially in the face of climate change, we need to understand what characteristics make the best trees and how professionals balance conflicting selection criteria. For example, if no "perfect" tree exists, are people willing to plant a messy tree that will provide several other benefits? Also, we need to understand how professionals share information with each other about trees to identify ways for people to work together better. We found that professionals prefer tough trees, professionals need clearer information on which trees provide more benefits, there is lots of disagreement on whether certain trees are good to plant, public gardens may have information to share on new/rare tree species, and a lot of obstacles get in the way of choosing trees that meet biodiversity goals and provide the most benefits.

Preface

This thesis is original and independent work by the author Jehane Alexandre Samaha. I was responsible for identifying research questions, completing interviews and survey methods, analyzing interview and survey data, and writing the thesis. I applied for and received ethics approval (H18-00615) from the UBC Behavioral Research Ethics Board, with the support of Dr. Cecil C. Konijnendijk van den Bosch as the Primary Investigator. Dr. Cecil C. Konijnendijk van den Bosch provided guidance and supervision as well as editorial advice. My committee members Dr. Jeanine Rhemtulla, Dr. Henrik Sjöman, and Douglas Justice provided insights related to their various expertise and helped with the revision process. Future publications may result from modified sections of this thesis in collaboration with members of my committee.

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I thank every participant who took my survey, shared my survey with others, or sat down with me for an interview. This project is only interesting thanks to your fascinating opinions, expert knowledge, and deep care for trees and people. I hope that you find the resulting thesis informative and useful.

I thank my parents, my partner, and my housemates who talked with me, inspired me, fed me, traveled with me, and supported me throughout the last two years. The love and support and conversations others shared with me helped me find and keep a sense of purpose as I navigated this project.

Dedication

To all the trees growing

in concrete boxes;

your exuberant budbreaks

in the face of adversity

forever inspire me

Prologue

This research project began with a strong emphasis on exploring the social and ecological relevance of public gardens to the urban forest ‘beyond the garden wall.’ After spending several years working in horticultural, research, and outreach roles at arboreta, I was curious about the contribution of public gardens to the introduction of urban plants. This initial focus broadened to the fascinating topic of urban tree species selection, as I was exposed through my urban forestry degree to the many other professional groups that influence the composition of urban forests.

I have been privileged to learn about trees through hands-on roles in the context of well-resourced public gardens. I am driven to share my access to and knowledge of plants with others, as well as to take action towards mitigating climate change and creating livable healthy cities. I see part of my choice to write this thesis as a stepping stone towards achieving this goal, and part of my choice as a detour away from nurturing the practical and active side of myself that intends to give back to the world. How many trees could I have planted in the time I have spent researching this thesis? The accumulation of the privilege and access granted by this academic degree feels useless to me unless paired with work that is beneficial to others both within and outside of research. Though I am tentatively hopeful that this thesis will have use and relevance beyond the academic sphere, I see any true contribution I can make to the world as coming from how I communicate my research beyond graduate school, and from the future work that I will do in collaboration with individuals and communities.

1. Introduction

1.1 Overview

As you walk the streets of many North American cities, you notice a shifting canopy of green overhead. Further down the block, different textures of leaves, colors of flowers, or shapes of trees surround you. A powerful tree root lifts a brick into your path, and you stub your toe. You cross a busy street into a different neighborhood and squint in the sunlight as the trees seem to disappear.

The backdrop of street trees in North America profoundly influences the daily lives of urban residents. However, some species of trees survive tough urban environments better than others, and some will provide greater benefits over the course of their lifetimes. Determining which tree species will be optimal to plant in a given site is a complicated decision process undertaken by a wide variety of people. The qualities of the site and the characteristics of the tree must be matched at the local level, while the tree's contribution to the overall diversity and function of the urban forest must also be considered on a city-wide scale. Furthermore, as climate change intensifies the urban heat island effect in cities (Luber & McGeehin, 2008), new tree species must be urgently considered for planting in urban environments to withstand and mitigate these increasing pressures.

In line with the above, the central question of this thesis is: what criteria determine how professionals select street tree species for urban environments? The purpose of this study is to answer this fundamental yet complex question in order to provide useful information to decision makers and professional urban tree planters in the USA and Canada. I also attempt to identify knowledge gaps between relevant professional groups (e.g. urban foresters, arborists, landscape architects, nurseries, and public gardens, among others) regarding the selection of urban tree species and propose areas for increased collaboration between professionals. In particular, I investigated opportunities for increased knowledge sharing between the staff of public gardens and professional groups more traditionally involved with urban tree planting. After many informal conversations, I began this project with the conjecture that one potential area for collaboration is increased partnerships between urban foresters and public gardens and arboreta located in or near urban areas. There are significant existing partnerships on which to model new collaborations for the testing of potential urban tree species and the education of the public and professionals through plant display and active outreach. My studies explore this potential and also reveal important caveats and areas of caution.

To explore these questions of how professionals utilize selection criteria to choose trees and what scope may exist for increased collaboration on the topic of urban tree selection, I designed and carried out two linked studies. First, I distributed an online survey to a range of professionals across the USA and Canada. This survey collected opinions on various tree species linked to ratings of the trees' characteristics. Then, I conducted a case-study in Philadelphia, PA, USA, and interviewed 20 professionals in order to delve into the complexities and context of tree species selection decisions. These two studies inform each other and paint a vibrant thematic picture when interpreted in tandem.

This thesis explores themes regarding street tree species selection criteria at two scales. Chapter 1, "The Search for the Perfect Tree" focuses on which tree species professionals recommend and the criteria they consider as they evaluate a tree's suitability. Chapter 2, "Tree Palettes for a Diverse, Functional, Resilient Urban Forest" examines the ecological and social context within which professionals make urban tree planting decisions, including the hetero- or homogeneity of species palettes, and what barriers limit the planting of a diverse and functional urban forest. This larger context illuminates the overarching influences on planting decisions as well as the cumulative patterns created by the sum total of many planting decisions over time.

1.2 The role of trees in the urban environment

In the face of global urbanization and climate change, the trees and associated vegetation in urban areas, or the "urban forest" is crucial for human health and well-being. Urban forests, when they are healthy, extensive, and biodiverse, convey numerous benefits to humankind. Trees planted in urban environments provide crucial ecosystem services. These services include the cooling effects of shade and evapotranspiration (Chen et al., 2016), the uptake of pollution and CO_2 (Calfapietra, Peñuelas, & Niinemets, 2015), the mitigation of stormwater (Bartens et al., 2008), mental health benefits, air quality improvement, food, and a suite of other environmental, social, aesthetic, and health benefits (Ferrini, Bosch, & Fini, 2017, and Lafontaine-Messier, Gélinas, & Olivier, 2016). These services are especially crucial in urban environments, that are often characterized by paved surfaces which lead to the urban heat island effect and to the increased surface run-off of storm water.

These ecosystem services depend on urban tree species diversity (Morgenroth et al., 2016); in other words, the same quality of services would not be provided by a homogeneous urban forest. The diversity of urban forests has long been recognized as a key component of forest health, especially in the face of devastating pests and diseases such as Dutch elm disease (*Ophiostoma ulmi*) which destroyed a large proportion of urban forests in the 20th century that were over-planted with elms (Potter et al., 2011), as well as the ongoing invasion of pests such as the emerald ash borer (*Agrilus planipennis*). Biodiversity, including the functional diversity that often follows species diversity, is increasingly being recognized as important for the reliable provision of a variety of ecosystem services to the urban environment. Higher tree diversity generally leads to greater ecosystem productivity. This is especially true under stressful abiotic conditions as niche differentiation and facilitation between species become more important, enhancing the importance of the complementarity effect of diversity (Mori, 2018). Though there is recognition of the benefits of species diversity, and though cities are capable of supporting high species diversity, many cities experience low and even declining tree diversity (Sjöman, Östberg, & Bühler, 2012).

Tree inventories are used to assess the diversity of urban forest canopies. These inventories, with various levels of accuracy and completeness, exist for only a fraction of major and minor cities in the USA and Canada (Koch et al., 2018). In the case study city of Philadelphia, a comprehensive street tree inventory is underway, while an open-source map of street trees currently exists online that any organization or individual can edit (Azavea, 2019). Tree inventories can be used to assess whether cities meet the tree diversity 30-20-10 'rule of thumb' with no more than 30% of trees from any one family, no more than 20% from any one genus and no more than 10% from any one species (Santamour, 1990). Recent unpublished work suggests that few cities meet this rule of thumb when percentages are calculated based on the number of tree stems from each species, and even fewer cities meet this mark when percentages are calculated based on the basal area of each species (Ambrose, 2018b). Diversifying the palette of trees in a city is possible by adding less-used trees as well as by restricting the percentage of trees planted from each genus every year (for example to 5% or less from any one genus). A limited palette of trees curbs the potential diversity and functionality of the urban forest (Morgenroth et al., 2016).

Trees may also cause ecosystem disservices in urban environments. These disservices include damage to infrastructure, risk to human safety, monetary costs, allergenic pollen production, mess from fruits or wildlife associated with the tree, unpleasant aesthetics, fear of crime, excessive shade or obstruction of views, and obstruction of water drains (Delshammar, Östberg, & Öxell, 2015). Disservices are infrequently included in theoretical discussions of tree species selection criteria, however the impact of disservices are important to consider when choosing which tree species to plant in urban sites.

The scope of this inquiry is limited to street trees. While trees planted in parks and private yards constitute larger percentages of the urban forest, the specific issue of street tree selection poses a more difficult and interesting question due to increased site stressors and high public visibility. In Philadelphia, wooded parkland areas cover only 8.4% of the city area yet contain 49.8% of the tree population, while residential areas (which include residential street trees) make up 40% of the city and contain 27.9% of the tree population (Nowak et al., 2016). Due to their smaller overall coverage, street trees may contribute fewer net regulating services than park and yard trees, yet their placement in tough environments provides services where they are needed the most. “Street and other city-owned trees do not represent the majority of the urban forest, but they are often some of the most accessible trees to urban residents, and are therefore a significant part of the forest in terms of shaping residents’ experiences and expectations” (Conway & Vander Vecht, 2015); people interact frequently with street trees, and thus the cultural services they provide gain importance. Visible and accessible nature in neighbourhoods increases sense of community belonging and contributes indirectly to improved mental health (Rugel et al., 2019). Furthermore, neighbourhoods with higher population density and lower levels of existing canopy indicate both greater need and greater opportunities for tree planting, in order to increase equity across urban areas (Nowak et al., 2016).

Street trees are commonly under the direct jurisdiction of professionals in public urban forestry organizations, one of the primary survey populations. The nomenclature of “street tree” is recognizable especially in the context of North American urban forestry. In a European context, street trees have also been described as trees for “Urban paved sites/environments” or “sites where the surface is sealed with hard (impervious) materials such as concrete, asphalt, pavement, etc.” Multiple synonyms exist for these conditions: “...‘roads and streets’...‘down-town plantings’...‘extreme urban environment’...‘the toughest of conditions’, and ‘trees for CU-structural soils’”(Sjöman & Busse Nielsen, 2010).

1.3 The role of professionals in street tree selection

There are many people who select and plant street trees, including residents, city officials, non-profits, commercial arborists, and landscape architects, among others. This thesis focuses on the decisions and knowledge of expert practitioners or professionals who self-identify as knowledgeable about urban trees. Multiple types of professionals are included in order to draw comparisons between their knowledge bases, hopefully leading to the identification of opportunities for knowledge sharing between these groups. Professionals more likely hold the power to promote or dictate tree planting choices. Residents who solely make planting decisions in their own yards or streets were not surveyed or interviewed, in order to focus on planting selection decisions that have clear city-wide impacts. Furthermore, there is already a significant body of literature examining resident planting preferences (Conway, 2016; Kirkpatrick, Davison, & Daniels, 2012; Lohr et al., 2004) while existing studies including professionals are limited in geographic scope (Conway & Vander Vecht, 2015). In a study comparing tree selection choices among landscape architects, non-profit organizations, retail nurseries and garden centers, and municipal forestry staff in Toronto, Canada, Conway & Vander Vecht (2015) found that:

> *[F]our sets of practitioners are motivated by different decision criteria when selecting the types of trees they plant or sell, with each drawing on their own knowledge and goals. The results highlight several notable findings: different decision making criteria do not always lead [to] different species planted, while similar goals may be achieved through divergent sets of species.*

It is important to understand which trees different types of professionals plant and why (what criteria they use in their decision process) in order to understand city-scale and continental-scale patterns in urban forest species composition and whether goals of diversity and ecosystem function are being met. Since this thesis surveyed a broad geographic area (across the USA and Canada), it was expected that wide variations in the tree selection criteria used by professionals would be detected and that there may be great complexity in how these criteria are linked to actual planted species.

Expert practitioners from a variety of professions, fields, and sectors make decisions about tree species selection. This study categorizes these relevant professional fields into eight categories of arboriculture, ecology/conservation, forestry, horticulture, landscape architecture, parks and recreation management, public horticulture, and urban forestry. The sectors included in this study are government, not-for-profit, academia, business/commercial, and partnerships combining two or more of these sectors. The jobs of individual professionals are highly varied, with dozens of titles and levels of seniority nested within each professional field. For example, the field of arboriculture (which deals with preserving the health of trees) includes professionals from all sectors, with jobs including arborist, researcher, urban forester, policy maker, consultant, and public works manager. Categorizing professionals by their field allows for a useful disciplinary differentiation at an intermediate level of specificity. However, defining the professional “field” of individual respondents can be complex. Urban forestry in particular is viewed as a highly interdisciplinary and even trans-disciplinary field (Konijnendijk et al., 2006), and can easily encompass the variety of affiliated professional fields listed above. Professionals in urban forestry may include city employees as well as key decision makers and experts in non-profit organizations involved in urban tree planting. A given respondent may identify with several fields. This large amount of overlap in the professions and education of this highly interdisciplinary group of respondents creates complexity in the interpretation of results. In a recently conducted survey, 55% of respondents who were involved in managing urban forests identified with professions other than “urban forester” and “arborist”; a long list of professions are “allied” with or linked to these primary identities, including engineer, landscape architect, planner, public administration, horticulturalist, outdoor recreation professional, botanist, land developer, ecologist, environmental interpreter, environmental scientist, forester, geospatial analyst, grants manager, landscape designer, non-profit manager, and public relations professional (O'Herrin et al., 2019, unpublished data).

Past studies on urban tree species selection have not surveyed the opinions of public garden practitioners. This study compared all eight identified professional fields against each other, but especially highlighted comparisons between the field of public horticulture and the other seven fields which are more typically associated with urban forestry. Public gardens, or the field of public horticulture, are rarely mentioned as significant decision-making participants in the urban forest, though public gardens typically are understood to be one component of the urban forest (Ferrini et al., 2017). Trees in public gardens are inventoried separately from trees managed by the city. The largest professional organization for public horticulture in North America is the American Public Gardens Association (APGA). Public gardens include botanical gardens, arboreta, and similar institutions. A public gardens is defined as:

> *an institution that maintains collections of plants for the purposes of public education and enjoyment, in addition to research, conservation, and higher learning. It must be open to the public and the garden's resources and accommodations must be made to all visitors. Public gardens are staffed by professionals trained in their given areas of expertise and maintain active plant records systems.*
>
> (American Public Gardens Association, 2019)

As institutions with a mission to display plant species for the public, public gardens are often highly curated and diverse, including exotic and native specimens. For this study, professionals from public gardens who self-identify as having insight on urban tree species were specifically targeted, as some employees of public gardens may not deal with trees at all. Historically public gardens have made major contributions to urban tree species selection across the globe, serving a crucial role in the introduction and testing of new trees with urban forestry potential (Campana, 1999). This influence is linked to the colonial history of public gardens. Public gardens utilized global networks to harness transnational resources, exchanging seeds, plants, and colonial landscape aesthetics. For example, the Sydney Botanic Gardens campaigned from 1890 to 1920 to plant tree line boulevards across New South Wales, Australia, and distributed nursery stock to municipalities; "as colonial institutions, botanic gardens became one of the centres that moved notions of street form and function into the colonies" (Frawley, 2009). The top-down imposition of street tree plantings in this case benefited white settlers to the exclusion of indigenous people.

In modern day public gardens, many plant exploration, evaluation, and education programs exist with some connection to urban biodiversity. A recent report from Botanic Gardens Conservation International (BGCI) summarizes these contributions from public gardens in the overlapping arenas of "contributing to urban forestry and resilient landscapes," "supporting and advancing urban agriculture," and "supporting urban biodiversity" (Cavender, Smith, & Marfleet, 2019). The report provides case studies from several categories of ongoing activities, including:

> *1. Plant evaluation, selection, and breeding*
> *2. Inventories and mapping*
> *3. Urban planning and development*
> *4. Community planting and stewardship*
> *5. Tree ordinances and protection policies*
> *6. Research*
> *7. Training and consulting*
> *8. Plant sales*
>
> *(Cavender et al., 2019)*

Another recent paper also deals with the strengths of botanical gardens that can be harnessed to improve the health of trees, people, and cities, identifying improvements to "tree selection, diversity, and age structure" as a priority (Cavender & Donnelly, 2019).

One major issue with limiting the study scope to street trees is that while urban forestry professionals (and other allied professionals) deal directly with street trees, the majority of public garden professionals do not. Planting sites in public gardens are unlikely to be paved, and thus to participate in the study, some public garden professionals likely had to imagine street tree selection criteria in a theoretical sense. However, public gardens may have access to living specimens of potential new street trees: “Despite presenting occasional problems with replication, botanical gardens and arboreta have highly diverse landscapes with the potential to yield hugely valuable information on currently under-utilized species. Therefore, the use of established tree collections should be facilitated where possible” (Sjöman, Hirons, & Bassuk, 2015). No previous studies on street tree selection have focused on this population of professionals. Public garden professionals potentially are an underutilized resource with respect to species selection in urban forests. Thus, despite introducing some difficulty in the study design, the participation of public garden professionals remains valuable.

Though the lines may blur between the professional fields of arboriculture, ecology/conservation, forestry, horticulture, landscape architecture, parks and recreation management, public horticulture, and urban forestry, these groups are distinct enough in culture, history, and methodological emphases that we may reasonably expect differences among the groups in regards to what tree characteristics they prefer and what selection criteria they emphasize.

1.4 Summary of past studies on street tree selection criteria

The literature is limited concerning tree selection decisions in urban environments, and many papers illuminate this topic indirectly. A series of surveys probe disparities between the trees that Ohio urban foresters desire and the trees that nurseries had in stock (D Amato, Sydnor, & Struve, 2002, Sydnor, Subburayalu, & Bumgardner, 2010). A street tree planning article explicitly laid out primary criteria (tree size, form, environmental suitability, and maintenance requirements) and secondary criteria (aesthetics and environmental services) for tree selection in Israeli cities (Amir & Misgav, 1990). A case study in Tehran, Iran ranked the importance of tree selection parameters and graded species for arid landscapes using thorough modeling techniques (Asgarzadeh et al., 2014). A survey of residents in southern California, USA explored links between tree attribute preferences (such as shade) and local environmental factors (Avolio et al., 2015). An article from Chicago, USA explains the benefits and majesty of large trees (Barro et al., 1997). Two studies from Ontario, Canada examine the tree planting choices of practitioners (Conway & Vander Vecht, 2015) and residents (Conway, 2016), finding that practitioners' tree selection is variably influenced by native status, the diversity of neighboring trees, pest issues, and nursery availability, while resident planting choices were primarily motivated by aesthetic preferences and concerns regarding maintenance. Although Conway & Vander Vecht (2015) explore divergent tree species selection criteria among a variety of types of practitioners in Toronto, Canada, this study does not include public garden practitioners. Another study from Ontario surveyed the opinions of urban foresters on planting trees from other climates in anticipation of climate change, or assisted migration, finding that this strategy is viewed favorably but rarely implemented due to high risk and uncertainty (Fontaine & Larson, 2016). A psychological study provided a review of many tree selection criteria and experimentally tested the perceptual preferences of humans regarding tree shape, dimensions, and crown density (Gerstenberg & Hofmann, 2016). An Australian survey grouped residential tree opinions into multiple groups based on their responses regarding the aesthetics, functions, social roles, environmental roles, and health impacts of urban trees (Kirkpatrick et al., 2012). A study contrasting tree planting and natural regeneration highlighted the importance of large long-lived tree species and the tree cover and species composition goals of North American urban areas (Nowak, 2012). A review of urban afforestation emphasized native biodiversity, invasion threats of exotics, ecosystem services, and the financial costs of maintenance in non-street tree sites (Oldfield, Warren, Felson, & Bradford, 2013). A Scandinavian study reviewed the information on street tree stress tolerance available to practitioners, especially regarding trees that are not traditionally planted and viewed as riskier (Sjöman & Busse Nielsen, 2010). A series of articles explored potential new street tree species that exist in natural environments that are analogous to street tree sites in Northern Central Europe, especially in regards to drought stress tolerance (Sjöman, Nielsen, & Oprea, 2012; Sjöman, Oprea, & Nielsen, 2012; Sjöman, 2015). A paper on urban tree species selection in Philadelphia, USA discussed climate change adaptation, stress tolerance, and the mitigation of pests and diseases, finding there may be little impact of climate change on future tree species selection in Philadelphia (Yang, 2009).

1.5 Stressors affecting street trees

Cities are globalized novel environments highly affected by human choices (Kowarik, 2011). Street tree sites suffer the toughest stressors of the human-constructed urban environment. The tree species that we choose to plant in these landscapes are expected to provide a great deal of services under difficult conditions. The provisioning of ecosystem services relies fundamentally on the good health and successful growth of urban trees—for example, trees with full mature canopies intercept more pollution and rainfall and provide more shade (Brack, 2002). The environmental factors that we hope to mitigate by planting trees double as a suite of stressors, inhibiting tree growth in urban environments. Certain environmental stressors are particularly associated with urban sites, including compacted soils, limited rooting volumes, drought, heat, air pollution such as ozone, soil pollution including high salinity, certain pests and diseases, and the stress of injury due to human activities. Many of these stressors co-occur and interact, often synergistically intensifying each other (Cotrozzi et al., 2017).

Street sites are stressful for trees, almost by definition, with a suite of interrelated stressors resulting from impervious surfaces, poor soil engineering, and heavy traffic. In the root zone, these stressors include reduced water supply, reduced gas exchange, and reduced nutrient availability (Gillner et al., 2017). Many engineering solutions have been tested to mitigate these stressors, such as structural soils, permeable pavements, and larger tree pits (e.g. Bühler et al., 2017, Haege & Leake, 2014, Layman et al., 2016). However, these solutions are often expensive, and street trees on average must still be able to cope with these stressors. Above ground stressors may include low air humidity, ozone pollution, radiative heat, and mechanical stressors (such as injury from vehicles and other human activities).

Urban stressors interact with one another, often intensifying each other (Figure 1). Impervious surfaces transform solar energy into heat, creating warm microclimates and contributing to the urban heat island effect (Arnfield, 2003). These warmer urban environments increase susceptibility of street trees to pests (Meineke, 2016). Trees in paved environments experience both warmer soil and air and thus accelerated bud burst (Chen et al., 2016). Infrared radiation reflected by pavements can raise the leaf temperature of a tree, affecting stomatal conductance and transpiration (Kjelgren & Montague, 1998). High vapor pressure deficit (VPD) and heat loads exacerbate the problem of drought (Gillner et al., 2017). Ozone pollution and drought also synergistically stress trees (Cotrozzi et al., 2017).

Above-ground issues of heat, air pollution, and low humidity are further compounded by below-ground stressors. Soil compaction decreases soil aeration, increases surface run-off, decreases water infiltration through the soil, and weakens root systems, which increases susceptibility to drought (Bartens et al., 2009) and to wind-throw (Rahardjo et al., 2016). Soil compaction also lowers the rate of photosynthesis, changes the balances of growth hormones, and decreases absorption of major mineral nutrients (Kozlowski, 1999). Root development is further inhibited by the accumulation of high CO_2 levels beneath pavements (Viswanathan et al., 2011). Urban soils are often characterized by poor soil structure and low organic matter, which limits tree growth (Layman et al., 2016). However multi-scale models find imperviousness alone is not a significant driver of tree height variation—instead this growth limitation may be driven by other environmental variables (such as elevated concentrations of heavy metals, high levels of soluble salt, and increased acidity) that are correlated with imperviousness along the urban-rural gradient (Plowright et al., 2017).

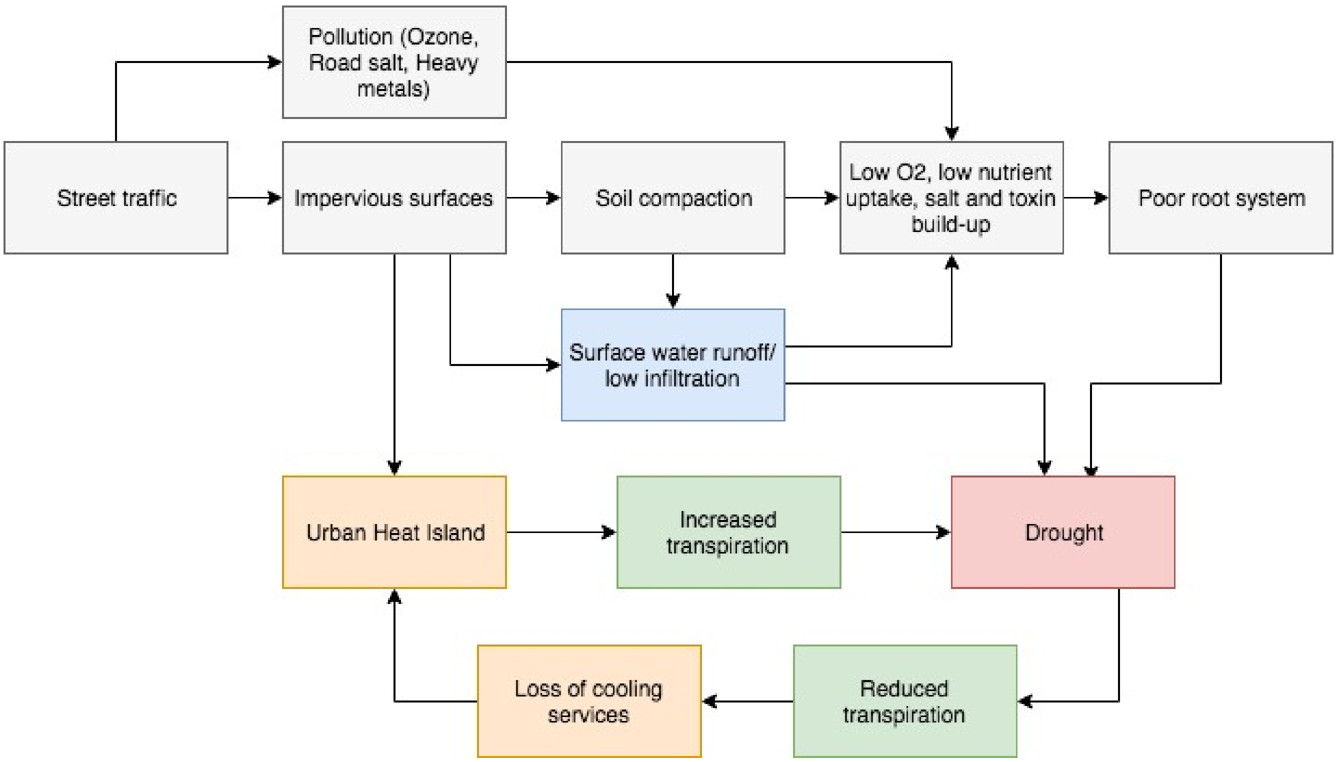

Figure 1: A summary diagram of interactions between selected urban stressors and resulting stress.

The sum total of these correlated and interacting environmental variables poses a major challenge to urban trees. When a plant is already stressed, for example due to low rooting volume, it may have fewer resources stored (i.e. water, carbohydrates, nutrients) to avoid damage during times of intensified stress, such as a period of drought. Furthermore, the cumulative stress load on an urban tree is especially large when considering that tolerance to one stressor may inhibit or decrease tolerance to another stressor.

In order to select appropriate trees for stressful sites, we must understand the physiological basis for tolerance to urban stressors. Overall, the various interrelated stressors of an urban environment can limit a tree's access to necessary conditions and resources and can negatively shift the balance of physiological processes. These necessary conditions and resources for healthy tree growth include: water, sunlight, macronutrients, micronutrients, air (including O_2 and CO_2) both above ground and in the soil, appropriate soil volume, appropriate temperature ranges, and appropriate pH ranges. The fundamental physiological processes that depend on these resources yet may be disrupted by stressors include: photosynthesis, water absorption, nutrient absorption, and growth hormone synthesis (especially abscisic acid and ethylene), among others (Kozlowski, 1999). Plants have numerous mechanisms to overcome these physiological dysfunctions. These mechanisms fall under the categories of stress avoidance and stress tolerance, with trees often employing a combination of these strategies (Levitt, 1980). While it is sometimes difficult to parse the responses of a plant to a single stressor, drought, heat, and compaction are common stressors at paved urban planting sites.

Drought stress

Conditions of drought may be exacerbated in paved planting sites by heat and by soil compaction. Trees use water to maintain turgor in cells, supply the photosynthetic process with hydrogen and oxygen, translocate nutrients in solution from the soil to tree tissues, and perform transpiration. Transpiration cools the tree and facilitates the upward flow of water and nutrients through the trunk to the leaves. Warmer temperatures, light, and dry air speeds the rate of transpiration—stomata may close to moderate accelerated rates of water loss. Air may be more drying at street tree sites due to tunnel effects, which produce higher wind spells (Gillner, Bräuning, & Roloff, 2014). Lack of soil moisture may interrupt transpiration by reducing the water potential of the soil to the point that the tree may no longer take up water. Loss of moisture in the xylem results in cavitation of the xylem, which may serve as a further obstacle to water flow and perpetuate drought conditions within the tree tissues until new conduits are established.

Heat stress

In cities, the urban heat island effect may increase future temperatures by 1°C to 6°C on top of projected warming due to climate change (Luber & McGeehin, 2008). Heat waves (three or more days with maximum temperatures reaching 32.2°C or more) are predicted to be more frequent and severe with climate change (Zhao et al., 2018).

Heat increases the rate of a tree's metabolic activity and therefore increases the demand for resources such as water and nutrients. When heat is combined with drought and compaction, these resources may be in short supply. Additionally, when stomata are closed due to drought, latent heat dissipation through transpiration may be restricted, resulting in leaf temperatures up to 15°C above air temperature (Leigh et al., 2012). Up to 40°C, photosynthesis may be reversibly inhibited due to impaired Rubisco activase activity; at higher temperatures, the inhibition of photosynthesis may be irreversible and plant tissues may be damaged by time-dependent propagation of cellular lesions (Hüve et al., 2010). Additionally, heat softens the lipid bilayers that form important membranes within plant cells. Heat stress, especially combined with drought, may limit leaf size, development of bud clusters, radial growth, and carbohydrate storage. These limitations extend their effects to following growing seasons, hindering earlywood formation and bud break as well as encouraging the allocation of carbon to reproduction rather than growth (Gillner et al., 2014).

Compaction stress

The activities and infrastructure requirements of humans and machinery contribute to compaction in urban environments. Soil compaction includes a loss of total pore space and aeration pore space and, in minor cases, an increase in capillary pore space (small water filled pores). Textural components (such as sand, silt, and clay particles) are resorted and soil aggregates are destroyed. In extreme cases, all pore space and structure is eliminated, no space remains for water, and the soil bonds internally as particles contact each other (Coder, 2000). Therefore, compacted soil results in deficits of water, oxygen, and growth space for the root system. Since compaction contributes to drought stress, the tolerance mechanisms for this stress component overlap with the discussion of drought above. On the other hand, stressors such as anaerobic conditions and high bulk density/soil strength require a different suite of tolerance responses.

1.6 Is species identity linked to service provisioning and tree survival?

The functional traits of a tree transcend species boundaries, with many species sharing traits that improve stress tolerance or services provided. Since we expect street trees to survive stressful environments while providing ecosystem services, it is important to understand the variation in these traits among different tree species. In some cases, the stress tolerance and service-providing characteristics of a tree may differ at the genus or family level rather than at the species level. Tree selection and management decisions require parsing the distinctions that exist between tree species.

1.6.1 Species identity and ecosystem services/disservices

Many phenotypic characteristics that differ between tree species are directly linked to the ecosystem services (or disservices) those trees provide. These variable characteristics include, among others: mature size, flowers, fruit, pollen production, seed dispersal, suckering, branch structure, brittle wood, and rooting depth.

Mature tree size is a gateway characteristic to multiple regulating ecosystem services. Larger, older trees support lower rates of photosynthesis and growth (Steppe, Niinemets, & Teskey, 2011), have larger root systems, and larger pools of non-structural carbohydrates (Niinemets, 2010). Trees with larger diameter at breast height (DBH) and greater leaf area index (LAI) accomplish greater carbon storage, pollution filtration, and rainwater interception. In Philadelphia, only 9.5% of trees are large (DBH >18 inches), yet these trees form 51.5% of the total leaf area in the city (Nowak et al., 2016). A tree's mature size determines the regulating services it may provide. The variation in mature tree size among species is also important to consider in urban environments due to potential conflicts between larger trees and infrastructure. An ongoing study in two European cities (Rimini, Italy and Kraków, Poland) preliminarily found that several ecosystem services (CO_2 assimilation, cooling via transpiration, and particulate matter (PM10) adsorption) when calculated per unit leaf area varied significantly across the studied species (Fini, 2019). Furthermore, the study found that anisohydric species (which keep their stomata open in drought) continued to assimilate carbon and cool microclimates via evapotranspiration even during periods of heat and drought, resulting in a greater overall provisioning of these services. Of the species studied, *Populus nigra* and *Quercus robur* assimilated the most CO_2 per unit leaf area, and *Aesculus*, *Acer negundo*, and *Quercus ilex* adsorbed more PM10 per unit leaf area than *Lingustrum japonicum*, *Populus nigra*, or *Platanus* x *acerifolia* (Fini, 2019). These findings are highly significant because it indicates that the services species provide are not linked indefinitely to LAI, and with appropriate physiological data, tree species may be ranked based on their ability to provide ecosystem services per unit leaf area.

Traits such as flowers and leaf color vary dramatically and visibly among species, and provide cultural ecosystem services such as aesthetic appreciation and tourism ("Ecosystem Services," 2019). Trees with edible fruit contribute provisioning ecosystem services, though fruit when left unharvested may create a messy disservice. Wildlife provisioning services vary widely between tree species. In the southeastern United States, native tree species provide habitat for moth, butterfly, sawfly, horntail, and wood wasp larvae with cascading benefits up the trophic pyramid, while no larvae were found on non-native tree species such as *Zelkova serrata, Pyrus calleryana*, and *Acer palmatum* (Clem & Held, 2015). Pollen production supports the health of bees and other pollinating insects but also causes human allergies. The timespan of pollen production varies between trees. For example, *Betula* and *Populus* emit pollen for approximately 12 days while *Quercus* emits pollen for approximately 40 days. Trees from the genera *Acer, Salix,* and *Platanus* cause strong allergenic reactions in many people (Ribeiro et al., 2009). Vigorous seed dispersal and suckering indicate invasiveness that may be harmful to ecosystems (Reichard & Hamilton, 1997). Wide branch crotches, low wind drag caused by small and open canopies, and elastic wood increase public safety and decrease maintenance by lowering the risk of tree limb breakage (James et al., 2014). Fast growing trees (such as *Populus* sp. and *Eucalyptus* sp.), large trees at their mature size, and trees with shallow rooting depths lift sidewalks creating trip hazards, although this sidewalk damage is more related to limited rooting volume and tree age than to variable characteristics among species (Randrup, McPherson, & Costello, 2001). Understanding the phenotypic characteristics of individual species is often key to selecting trees that will provide the greatest services while avoiding disservices.

1.6.2 Species identity and survival

The strategies trees employ to maintain growth in stressful conditions can vary by taxonomic group, genetic provenance, and ontogenetic stage. Street trees have a mean life expectancy of 19 to 28 years, though shorter life spans are frequently cited (Roman & Scatena, 2011). The age and size of a tree affects its vulnerability to single and combined stressors. Trees are especially vulnerable to stress during the first several years of growth after planting, and may not reach reported levels of stress acclimation until fully established (Bassuk et al., 2009). The early survival of a planted tree does not primarily differ based on species identity; factors such as nursery practices, planting conditions, maintenance during establishment, and ownership are more important factors (Roman et al., 2015).

Trees are not static entities; many of their characteristics shift over their life cycles. The challenge for urban foresters is to select species that will survive and thrive as established trees under the stressful conditions of urban sites.

In many cases, the strategies mature trees employ to cope with stressors of drought, heat, and compaction vary at the species level, resulting in the increased suitability of some species over others for planting in urban environments. Trees have evolved a range of strategies to survive and maintain growth under adverse conditions, including strategies to avoid stress and to physiologically tolerate stress. Different tree species exhibit variable tolerance levels to various stressors, and functional trade-offs prevent perfect tolerance to multiple simultaneous stressors (Niinemets & Valladares, 2006). Much of the variation in stress tolerance between species and populations is due to the adaptation of tree populations to specific natural habitats and climate conditions. Thus, the exploration of sites with conditions that are analogously stressful to urban sites may yield useful species or provenances for the selection of future urban trees.

Species tolerance to drought

Responses to drought, and therefore tolerance to drought, varies by species and also by cultivar (Sjöman et al., 2015). Some species wilt (lose turgor) more easily than others, and this behaviour may be quantified by measuring the leaf water potential at turgor loss; trees that lose turgor at lower water potentials are more drought tolerant (Sjöman et al., 2015). Stomatal behaviour varies from species to species, constituting different water management strategies. Isohydric species rely more heavily on stomatal closure to maintain leaf water potential, avoiding drought stress by reducing transpiration. This strategy also results in a slowing of photosynthesis, which may weaken or kill a tree during a long period of drought. Meanwhile, anisohydric species rely more heavily on osmotic adjustment (producing osmolytes to decrease plant water potential and maintain water uptake) to combat drought stress, keeping their stomata open for longer periods resulting in more variable leaf water potential. This riskier strategy may be beneficial under moderate drought, allowing processes such as photosynthesis to continue, yet is dangerous under intense drought (Sade, Gebremedhin, & Moshelion, 2012). Isohydric tree species include *Acer pseudoplatanus* and *Picea abies*, while anisohydric species include *Fagus sylvatica* and *Larix decidua* (Pröll et al., 2016). It is unclear which stomatal strategy leads to more drought-tolerant street trees, as street trees may experience both short intense episodes of drought as well as prolonged periods of drought.

Wood properties have also been shown to influence a tree's response to drought. Trees with greater trunk volume and thus high capacitance may draw on stored water to survive drought events (Mcculloh et al., 2013). Ring-porous versus diffuse-porous species respond differently to drought (Bush et al., 2008). Diffuse porous species avoid xylem cavitation by closing their stomata more frequently. The isolated vessels of ring-porous species provide fewer opportunities for air-seeding, thus they can more sustainably keep their stomata open and tolerate some level of xylem cavitation (Ogasa et al., 2014).

Species with shallow rooting systems have decreased drought tolerance (Pröll et al., 2016). Though typical rooting depth for a species is relatively easy to determine in natural environments, the small volume typically available for root growth in paved sites renders moot many of these species-specific differences.

Species tolerance to heat

Plants respond to the stressor of excess heat by dissipating heat (avoidance) and/or by acclimating to heat (tolerance). Leaf temperature may be reduced by increased transpiration, higher reflectance of leaves, smaller leaf size, and increased leaf thickness (Leigh et al., 2012). Thus, trees with these traits may be more able to avoid heat stress in urban environments.

Trees may acclimate to higher temperatures by increasing the saturation of their membrane lipids. This controls the passage of calcium ions across the plasma membrane and reduces the expression of heat shock genes (Saidi et al., 2010). Heat and drought may also lead to oxidative stress, thus antioxidant systems are important, yet once trees are heat or drought stressed, their "leaves do not regain their ability to acclimate antioxidant defences according to stress levels" (Rennenberg et al., 2006). Isoprene synthesis may increase tolerance of oxidative stress as well as the stability of membranes. Isoprene emission is species-specific, and trees that emit isoprene during heat events, such as oaks, may be overall more heat tolerant than trees that do not, such as maples (Lerdau, 2007). However, though trees that emit more isoprene may be more heat tolerant, these emissions may contribute to ozone production in the presence of urban concentrations of nitrogen oxides from vehicle emissions. High temperatures (above 32°C) are associated with increased production of ground-level ozone (Luber & McGeehin, 2008), which causes additional stress for tree species that do not emit isoprene.

Trees that are more tolerant of high light levels (i.e. early successional species) may be less sensitive to changes in temperature: Rennenberg et al. (2006) found that "heat causes higher intrinsic stress in beech than in birch and may point to an increased requirement for oxidative stress compensation." Selecting early successional species may therefore be a good strategy to increase the heat tolerance of the urban forest. However, early successional species may not grow as large and may have shorter lifespans, conflicting with other urban forestry management goals.

Species tolerance to soil compaction

The anaerobic conditions of (dry) compacted soils are perhaps counter-intuitively similar to the anaerobic conditions of water-logged soils. Though water-logged soils suffer from too much rather than too little water, the mechanisms trees use to tolerate low oxygen levels under these conditions are similar. Trees are more tolerant of low O_2 levels when they have lower respiration rates, for example during dormancy or at low temperatures. In general, however, trees avoid low oxygen rather than acclimate to low oxygen. Trees have various strategies to supply oxygen to their tissues when this becomes impossible via their roots. Some species have lenticels, which facilitate transfer of oxygen through the bark and to roots. Adventitious roots may form from hypertrophied lenticels, with aerenchyma to promote oxygen transport (Yamamoto, Sakata, & Terazawa, 1995), though this root formation is less likely under the dry conditions of compaction. Trees from the genus *Taxodium* develop above-ground root structures called "knees" (pneumatophores) which facilitate oxygen access. Many other trees will develop roots close to or above the ground surface in order to escape compaction (Fountain, 2012), though this is an undesirable characteristic at paved sites as this damages sidewalks and causes tripping hazards.

Soil bulk densities above 1.45 g cm^{-3} may halt the growth of tree roots, though coarser soils maintain pore space at higher bulk densities. In urban settings, bulk densities from 1.3 to 1.6 g cm^{-3} are common (Bartens et al., 2008). High soil strength affects the conditions and space available at the meristematic site, impeding the growing tip. This shortens and thickens roots, in some cases leading to the development of shallow branching lateral roots (Kozlowski, 1999). Different species are more able than others to initiate roots in compacted soil; for example, *Larix sibirica* and *Quercus robur* are reported to grow at bulk densities exceeding 1.8 g cm^{-3} (Kozlowski, 1999) and the invasive *Ailanthus altissima* grows long coarse lateral roots even through compacted soils (Pan & Bassuk, 1986).

Choosing street trees adapted to analogous conditions

Since many stressors interact to limit the growth of a street tree, it is insufficient to base planting decisions on laboratory tests of a species' tolerance to a single stressor. Instead, sites in nature that are analogously stressful may be used as fertile sources of well-adapted, poly-tolerant species.

Several site types are frequently cited as appropriate sources of genetic stock for urban trees: bottomlands, dry montane sites, and disturbed or early successional sites.

Bottomland sites are often wet or flooded, and thus experience low oxygen conditions. Trees from bottomlands often "perform well in drier conditions and constitute a large proportion of the most common and successful street tree species" (Bartens et al., 2008). Trees that are tolerant of waterlogged soils may not only tolerate the low oxygen conditions at urban sites, but may also be more able to grow during time periods of lower soil strength when soils are saturated (Day, Seiler, & Persaud, 2000). Bottomland species that are commonly planted in urban environments include: *Taxodium distichum*, *Acer saccharinum, A. rubrum, A. negundo, Gleditsia triacanthos, Ulmus americana*, *Quercus nigra*, *Q. phellos*, *Liquidambar styraciflua*, and *Platanus* x *acerifolia*. Other bottomland species that are tolerant to some flooding include: *Fraxinus pennsylvanica*, *F. profunda*, *F. americana*, *Betula nigra*, *Nyssa sylvatica*, *Populus deltoides, P. heterophylla*, *Cornus drummondii*, *Planera aquatica*, *Carya ovata*, *Quercus palustris*, and *Q. bicolor* (Allen et al., 2001). Bottomland hardwood forests are especially prevalent in the southeastern United States (Figure 2).

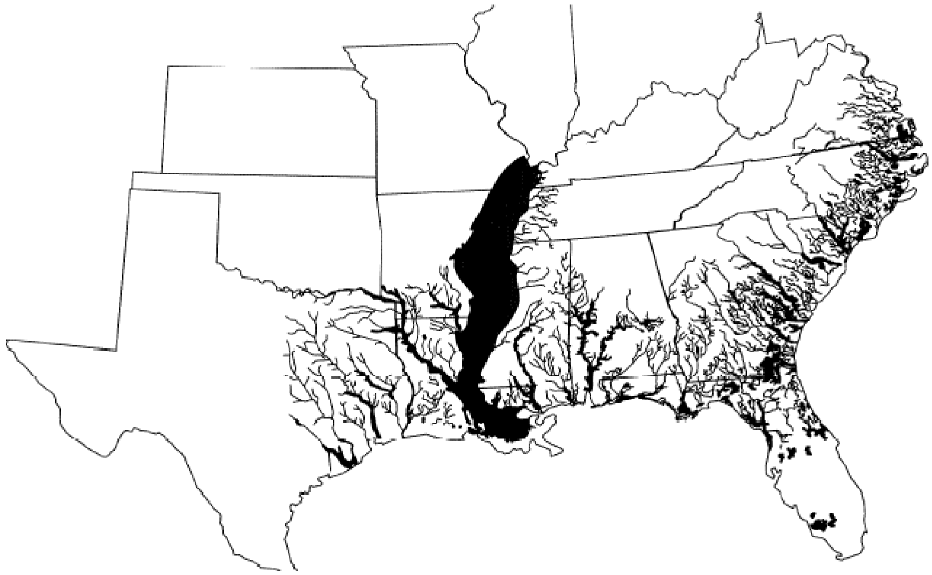

Figure 2: The distribution of bottomland hardwood forests along rivers and stream in the southeastern USA (Allen et al., 2001)

Dry montane sites are emerging as potentially excellent analogs for the street tree environment. The majority of trees planted in eastern North American and northern European cities derive from rich moist forest habitats (Sjöman et al., 2015), and these trees often fare poorly under drought conditions. Habitat studies of periodically dry steppe environments in Central Europe revealed many drought tolerant species that could be added to the palette of street tree options, including *Fraxinus excelsior*, *Quercus dalechampii*, *Q. frainetto, Q. robur*, and *Q. pubescens* among others (Sjöman, Nielsen, et al., 2012). This study additionally noted the increased stress tolerance of trees that occur in the canopy layer in nature, which weather a more exposed and stressful set of conditions. Species from drier environments may also genetically favor a high root to crown ratio, increasing drought tolerance and aiding recovery from drought (Ware, 1994). Additionally, plants from dry ecotypes may have lower transpiration rates, shorter hydraulic pathways, and greater water use efficiency (Denny, 2007). The long-term adaptation of species to conditions of drought may overall increase the tolerance of those species to harsh urban conditions.

Disturbed, early successional sites such as compacted clear cuts and barren fields after the removal of mineral resources are very adverse sites for plant life. Disturbed sites may have poor soil structure, high winds, and very high light conditions. The tree species that are first to colonize disturbed, open sites are very tough and may be successful as urban trees (Ware, 1994) and may have increased heat tolerance (Rennenberg et al., 2006). These “pioneer” trees include species of *Rhus*, *Crataegus*, *Ulmus*, *Salix*, *Populus*, *Betula*, *Gleditsia*, *Alnus*, and others.

Though this review has primarily focused on species-level differences in stress tolerance, sub-species variation in tolerance levels may also be important to consider when selecting street trees. Ecotypic variation may occur within a species due to distinct ecological conditions acting on different populations; for example, rainfall may differ widely across a species' range. Bassuk et al. (2009) note, for example, that western seed sources of *Cercis canadensis* are thought to be more drought tolerant than eastern seed sources. Though the geographic source of the genetic material (provenance) for a tree species is important to understand, this knowledge is difficult to encounter. Much of this information is obscured by the complications of supply and demand within the nursery industry, which places heavy emphasis on the marketing of clonal cultivars; the provenance of nursery stock is often unknown. “Local, natural tree populations are generally recognized as good sources of trees for urban use locally. But commercial distribution often sends trees far from their place of natural origin” (Ware, 1994). Since populations differentiate regarding tolerance based on habitat and climate, matching the habitat and ecology of the seed source to the stressors of the urban environment is important (Mijnsbrugge, Bischoff, & Smith, 2010). Therefore, a lack of emphasis and information on provenance inhibits the ability of urban foresters to select nursery stock that is appropriate for their region and their planting needs.

1.7 Literature review synopsis

Past research has discussed in great depth the benefits of trees in urban spaces and amply demonstrated the stressors acting on urban trees and the tolerance levels they must achieve in order to survive. As cited above, biodiverse urban forests provide important ecosystem services including cooling, pollution filtration, stormwater mitigation, health benefits, wildlife habitat, food provisioning, and aesthetic enjoyment (among others). These services depend heavily on the healthy establishment and growth of urban trees, which is especially difficult under stressful urban conditions. Paved urban sites bring together a suite of interrelated stressors that often inhibit and injure street trees. Heat, compaction, and drought are major issues, and exacerbate other stressors such as pollution, pests, and wounds due to human activity. Due to these stressors, street trees in particular provide fewer ecosystem services than trees in wooded areas (Nowak et al., 2016), yet trees are especially needed in tough urban environments to mitigate the very same stressors which limit them. Therefore street tree species selection poses a difficult and interesting question.

Various tree species have unique combinations of characteristics that lead to variation in the services and disservices they provide as well as variation in their tolerance of stressors. These differences between species (in services provided and stress tolerance) are primarily apparent after the establishment phase (Bassuk et al., 2009, Roman et al., 2015). Although synergistic urban stressors create a need for poly-tolerant urban trees, functional trade-offs prevent tolerance to the full array of simultaneous stressors (Niinemets & Valladares, 2006). Thus, the stress tolerance of any tree should be evaluated based on realistic conditions of multiple stressors, and analogously stressful sites in nature (such as bottomlands, dry montane sites, and disturbed sites) are useful provenances for the identification of useful urban trees.

The literature on the stress that urban trees encounter and the services they provide serves as a strong foundation for this thesis, which synthesizes the physiological differences in performance across tree species with the complex process of tree selection for planting in street tree sites. Many professional fields are involved with the selection and planting of urban trees, including arboriculture, ecology/conservation, forestry, horticulture, landscape architecture, public horticulture, parks recreation and public works, and urban forestry. This study is unique in its exhaustive treatment of a wide range of potential tree selection criteria, linked to the practical decisions of professionals across the USA and Canada.

2. Methodology

2.1 Overview

I used mixed qualitative and quantitative methods to investigate what selection criteria determine professionals' tree planting choices and what knowledge gaps surrounding this topic exist between professional groups. I used a survey tool with both closed and open-ended questions, followed by semi-structured interviews, in a sequential mixed methods design (Creswell, 2014). Since data from both the survey and interviews were utilized in every chapter of this thesis, this combined methodology is presented in advance of the chapters rather than imbedded in the later text. The overall design occurred at two scales: I administered the survey across the USA and Canada with an emphasis on temperate regions, although responses from other climate regions were accepted. I then focused specifically on the context of Philadelphia, USA, as a case study. The methodological emphasis for the case-study was semi-structured interviews, however I also distributed the survey to interviewees in advance of the interview. This combination of broad, large-scale data with in-depth local data illuminates interesting themes with a higher degree of validity.

2.2 Online survey methodology

In order to gather data across a broad geographic scale from multiple professional groups, I distributed an online survey across the USA and Canada. The survey was open from June 23, 2018 to November 5, 2018, or 136 days. Since the sample frame consisted of experts, targeted strategies were used to inform potential participants of the survey. I e-mailed the survey to the Canadian Urban Forest Network listserv administered by Tree Canada. A representative of the Society of Municipal Arborists (SMA) included the link in an e-newsletter to SMA members. The link was also posted on LinkedIn, including on the official page of the International Society of Arboriculture, as well as on the Facebook group pages “Women in Horticulture” and “Emergent: A Group for Growing Professionals” (where it was re-posted by many individuals). Responses were also solicited in person via a student conference presentation and poster at the American Public Gardens Association annual conference in Anaheim, California, USA (June 2018), at the 2018 Annual Conference and Trade Show of the International Society of Arboriculture in Columbus, Ohio, USA (August 2018), and at the International Urban Forestry Congress in Vancouver, British Columbia, Canada (October 2018). Small fliers with the survey link were distributed at these conferences, and the survey link was e-mailed to conference attendees who provided their contact information and permission. I emailed the link to approximately 165 individuals that connected with me through conference networks. Many participants forwarded the link and initial contact text to other potential participants, without providing the study team with any information on the other potential participants. Before closing the survey, it was determined that the geographic spread of received responses did not contain representation from several southern provinces (western Ontario, New Brunswick, and southern Manitoba, Canada) and several states (Montana, Idaho, Wyoming, Nevada, Utah, North Dakota, South Dakota, Arkansas, Mississippi, Alabama, South Carolina, Tennessee, West Virginia, and Maine, USA). The largest three to four population centers in each of these areas were identified, and publicly available contact information was obtained on the internet for relevant professionals. Additionally, all USA state urban forestry coordinators with contact information available online were e-mailed at this time. Approximately 480 contacts were obtained through this method and were e-mailed the survey link. Because of the primarily digital nature of the survey distribution and the way in which the distribution snowballed, it is impossible to accurately estimate the total reach of all distribution methods. The survey was viewed 1196 times with a total of 981 complete or partially complete responses from the USA and Canada.

I designed the survey to collect information both on the species that professionals select as well as the criteria they use when making those decisions. The largest section of the survey involved identifying a single strongly encouraged tree and a single strongly discouraged tree, and answering the same set of 43 selection criteria questions for each of those two trees. Although it was expected that professionals would not volunteer the same tree species, their answers nevertheless could be lumped to cumulatively describe the characteristics of encouraged vs. discouraged trees. In order to understand which criteria to include as potential dependent variables in the survey design, I conducted an informal review of important papers in the tree selection literature. Current tree species selection and preference literature provides overlapping discussions and lists of selection criteria. I combed studies on tree species selection and planting to find key words and ideas related to species selection criteria; whenever reasoning was given for planting or excluding particular trees, or general value statements were made, these references became "codes" which were sorted into categories termed "nodes." I coded papers using NVivo software. The coding was designed to prioritize the tree selection criteria that professionals use, however the more extensive literature on the tree preferences of the public/residents is also presented in several relevant nodes—for example when discussing aesthetic preferences, it can reasonably be assumed that preferences held by the general population may be similar to or at least affect the preferences of professionals. This coding process resulted in the initial identification of 47 "nodes," which were pared down to 43 final criteria. These criteria were then transformed into semantic differential survey items (Appendix 1), to allow respondents to describe how the tree species they encourage and discourage fulfill each of these criteria.

The major items included in the survey are summarized in Table 1 and the full survey questionnaire is included in Appendix 1.

Table 1: Summary of major online survey items.

Response/dependent variables:	
Item	**Description**
13 tree species ratings	Respondents rated 13 given tree species on a 7-point Likert scale from “strongly discourage planting” to “strongly encourage planting.” The tree list was developed with committee member Henrik Sjöman, with trees we believed to be from the following usage groups: “Promising but rare”: *Acer miyabei, Ostrya virginiana.* “Promising but limited use”: *Quercus bicolor, Gymnocladus dioicus, Tilia tomentosa, Amelanchier canadensis*. “Common but not overused”: *Zelkova serrata, Ginkgo biloba*. “Overused”: *Acer saccharum, Gleditsia triacanthos, Acer platanoides*. “Aesthetically pleasing but low stress tolerance”: *Magnolia salicifolia, Prunus sargentii*.
4 short selection criteria	Respondents ranked 4 broad criteria by importance: **services** provided by the tree species, **disservices** caused by the tree species, the tree species' **tolerance of urban stressors**, and the **ecological origins** of the tree species.
Encouraged and discouraged trees	Respondents identified (open-response) one tree that they strongly **encouraged** planting in their city, and commented on why they encourage that tree. Respondents identified (open-response) one tree that they strongly **discouraged** planting in their city, and commented on why they discourage that tree.
43 selection criteria	Respondents rated 43 characteristics for their identified “encouraged” and “discouraged” trees on 7-point semantic differential scales.
Explanatory/independent variables:	
Item	**Description**
Location and climate	Country (USA or Canada), state/province, city, ZIP/postal code. This information was used to determine climate regions/zones of respondents.
Profession	Respondents self-identified their Sector, Field, and Job. For each of these 3 items, I sorted the ‘other’ responses into existing or new categories. Some similar categories were merged for final analysis.

Knowledge, confidence, and influence	Respondents self-reported their own knowledge and confidence levels regarding urban trees and tree species selection. Also, they self-reported how frequently they influence tree planting decisions.
Demographics	Respondents provided demographic information including: Certified arborist (yes/no); Gender; Age (birth year); Education level; Political inclination (from liberal to conservative); Race; Employment. I collected demographic information, as these factors may strongly influence the species selection criteria of professionals. For example, younger professionals may have been exposed to more training regarding climate change, and may be sensitive to climate change adaptation criteria when selecting trees.

Survey data were analyzed using R statistical programming (R Core Team, 2019). The data were first cleaned to standardize the spelling of respondents' countries, zip/postal codes, encouraged tree species, and discouraged tree species. In many cases, trees were mentioned ambiguously, or at the genus level (e.g. "Oak") and these mentions were reformatted (e.g. "*Quercus* sp."). Though "*Quercus* sp." is less informative than "*Quercus phellos*," henceforth both "*Quercus* sp." and "*Quercus phellos*" will be counted and referred to as "trees" or "tree species." To preserve the greatest degree of information, mentions of species such as "*Quercus phellos*" were not lumped into the generic category of "*Quercus* sp." which was reserved for trees with no provided species information. Thus, lists of encouraged and discouraged trees were analyzed with entries at both the genus and species levels.

The "Other" responses for several demographics were standardized, including job, job sector, job field, race, and employment. Using the "Other" responses, new categories were created for many of these variables. For simplified analysis, I created new categorizations for some demographics and merged similar groups. This was especially important for the job field responses. It was particularly complicated to sort respondents who reported multiple job fields; in some cases their responses to the job and job sector questions were used to choose a single field.

Table 2: The number of survey respondents from each professional field, including the sum total of respondents from all fields. These totals exclude respondents from outside the USA and Canada and responses that did not reach this early section of the survey. Final field categories sometimes include other merged categories, listed here.

Professional field	Number of respondents	Categories that were merged into professional field for simplified analysis
Arboriculture	197	"utility arboriculture"
Ecology/conservation	50	n/a
Forestry	78	n/a
Horticulture	31	“nursery,” “landscape construction”
Landscape Architecture	94	“architecture,” “landscape design”
Other	66	“permaculture,” “multiple,” “pest management,” “civil engineering,” “planning,” “economics,” “social sciences,” “sciences”
Parks, rec, and public works	48	"parks and recreation management,” "public works management,” "municipal administration,” "public property management"
Public horticulture	119	“community horticulture”
Urban forestry	296	"community forestry,” “tree board”
All Fields	979	n/a

Cleaned survey data were linked with geographic data using GIS methods *(ArcGIS Release 10.6*, n.d.). For each ZIP Code (USA) or postal code (Canada) provided by respondents, the centroid of the polygon was calculated from publicly available geospatial data (US Census Bureau, 2016; CanMap Postal Code Suite, v2016.3, 2016). These centroids were overlaid with Köppen-Geiger Climate Zones (Kottek et al., 2006) to determine the climate region for respondents from both the USA and Canada.

To understand which selection criteria were strongly associated with encouraged vs. discouraged trees, descriptive and summary statistics were computed to characterize the variation between encouraged and discouraged trees for each of the 43 criteria. The mean scores of each of the 43 variables were compared between encouraged vs. discouraged trees using a Welch Two Sample t-test (Appendix 5). I chose a conservative p-value significance cutoff of $p \leq 0.001$ to ensure the most stringent results. A Mann-Whitney test for non-parametric data was also calculated and gave similar results as the Welch Two Sample t-test. As a rough metric of the "importance" of each of the 43 criteria, I calculated the absolute value of the mean discouraged tree rating for each criteria minus the mean encouraged tree rating for each criteria (Appendix 5). This produces an index where larger values signify a greater difference between the qualities of encouraged and discouraged trees, indicating that those criteria are potentially more important when making selection decisions.

To understand what variables explain the trees professionals choose and how they rate those trees along certain criteria, I then used Kruskall-Wallis tests to examine correlations between pairings of response variables and explanatory variables. I examined correlations between the response variables of: the rankings of each of the 13 given species (individually), each of the 43 criteria ratings (individually) for both encouraged and discouraged trees, each of the four main selection criteria (individually) and the open response selections of encouraged and discouraged trees, against the explanatory variables of: professional field, Köppen climate zone, country, the frequency of planting influence, self-reported knowledge, self-reported confidence giving tree advice, whether respondents were certified arborists, years of experience, gender, age, education, political inclination, race, and employment. Additionally, I duplicated my use of the three self-reported knowledge variables (the frequency of planting influence, self-reported knowledge, and self-reported confidence giving tree advice), using them as response variables and examining potential correlations with the remaining explanatory variables above. These pairings of response and explanatory variables (that exhibited significant correlations) are reported in Appendix 3. For the Kruskall-Wallis tests, I chose a conservative p-value significance cutoff of $p \leq 0.01$ to ensure stringent results. Likert and semantic differential data were grouped by significant explanatory variables and plotted using the Likert package (Bryer & Speerschneider, 2016).

Various ecological measures of diversity were appropriated to compare the “palette diversity” between professional fields and between climate regions. The vegan R package was used to calculate these metrics (Oksanen et al., 2019). As a first look at the tree palettes that survey results revealed, I used the concept of species richness, or a simple count of the number of unique species volunteered by each group. However, the number of responses from each field (n) or region varied widely (i.e. there were far more responses from the field of urban forestry than horticulture), and a simple count of unique species encouraged or discouraged by each group did not account for sample size variations. Thus, Menhinick's index for richness was also computed, which does take into account sample size by dividing the number of unique species recorded (S) by the square root of the total number of individuals in the sample (n):

$$D_{mn} = S / \sqrt{N}$$

The rarefaction curves for the professional fields and climate regions were also calculated using the vegan R package (Oksanen et al., 2019). These curves show the increase in number of unique tree species as the number of respondents increases for each field or region.

Moving beyond the simpler species richness metrics, the Shannon-Wiener Index (H'), which is a commonly used diversity index in ecology, was calculated using the vegan R package (Oksanen et al., 2019). This index takes into account not only the number of species (richness), but also the evenness in abundances of individuals from each species. The Shannon-Wiener Index ranges from 0 to 5 (typical values 1.5 to 3.5) with higher values indicating greater diversity. This index may be converted into a more intuitive true diversity number (by calculating eH').

The above metrics of richness and diversity give some insight on the Alpha-diversity of the species palette available to different professional fields and climate regions, however they do not illuminate the similarities and dissimilarities between these palettes. To examine how much overlap exists between the species recommendations from the different professional fields and climate regions, the concept of Beta-diversity was used. By computing Beta-diversity indices it is was possible to compare each pairing of fields to show how much overlap exists in the identity and frequency of species recommended by each field. The Bray-Curtis dissimilarity was used to compute the distance between each pairing of fields and between each pairing of climate regions. Small values indicate low dissimilarity (or high similarity), while values approaching 1 indicate high dissimilarity (or low similarity). To visually express the distance between the full set of palettes (broken down by professional field and broken down by climate region) and show the trees that are associated with various palettes, I created Non-Metric Multidimensional Scaling (NMDS) plots using the vegan R package metaMDS function, incorporating the Bray-Curtis dissimilarity index and k=2 dimensions (Oksanen et al., 2019).

2.3 Philadelphia case study methodology

For the case-study in Philadelphia, semi-structured interviews were conducted (Schensul et al., 1999) with 20 expert practitioners to understand the full complexity of how tree planting choices are made in Philadelphia. Respondents included urban foresters, arborists, researchers, landscape architects, and public garden professionals (Appendix 2). The interview schedule is included in Appendix 4. Professionals were asked the same questions for the bulk of the interview, while also being asked different questions specific to their professions for a small portion of the interview. Interviews were transcribed and inductively coded (Saldana, 2013) using NVivo software (Bazeley & Jackson, 2013).

Philadelphia was identified as an excellent case for this study for several reasons. As the "garden capital of the USA" with 30 public gardens within a 30-mile radius ("About Greater Philadelphia Gardens," n.d.), opportunities exist to investigate links between public gardens and urban forestry. Historically, Philadelphia has been a hub of plant introductions to North America (Schlereth, 2007). Its climate is neither extremely hot nor cold, so findings may be applicable to other temperate North American cities. There are public organizations and public-private partnerships involved in urban tree planting. I lived a year in Philadelphia prior to this study, working at a public garden and attending conferences, and harnessed a network of contacts to connect me with interviewees there. To construct my sample groups, an initial targeted group of experts were approached with the interview request. In the initial round, interviewees were asked to identify other potential participants, and snowball sampling was utilized until a reasonable level of saturation occurred (Small, 2009).

To analyze the interview data, interviews were transcribed and the resulting text was coded in NVivo (Bazeley & Jackson, 2013) to understand the characteristics of urban trees that practitioners value and prioritize, to characterize any gaps in knowledge on tree selection, and to explore reasons for any gaps in knowledge between these professional groups. Though an inductive coding process was prioritized, the coding was in part deductive, as the 43 criteria utilized in the survey were specifically searched for, while remaining open to other emergent themes and codes.

Going into the process of interviews and coding, I held several biases and assumptions. After working in the field of public gardens and commencing graduate study in urban forestry, my lens was narrowed to the dynamics between these two fields. This positionality may have differential effects on how I relate to professionals in each of my study groups, and how they relate to me. I also believe this positionality strongly affects my lens, as I find it easy to draw hypotheses based on my own anecdotal personal and professional experiences. For example, I hypothesized that urban forestry professionals may highly value characteristics of trees that reduce tree maintenance and increase tree survival. Meanwhile, public garden professionals may place greater emphasis on aesthetic characteristics or on the climate adaptation characteristics of a tree. However, I expected that any difference in how these groups prioritize tree characteristics would be dwarfed by a much greater difference in the palette of tree species that each group is familiar with. I hypothesized that public garden professionals would identify a greater diversity of tree species that exemplify certain characteristics, while urban forestry professionals would link a more limited palette of trees to the same characteristics. I had to see these hypotheses mostly in the context of potential bias, and scrutinize my questions and behaviours as a researcher for evidence of bias effects. I entered this research project with an awareness of these biases/ hypotheses, and kept myself open to unforeseen connections and new understandings that reflect more accurately the complexity of species selection knowledge.

3. The Search for the Perfect Tree

3.1 Overview

As noted by many in my interviews, there is no singular perfect tree, and thus it is a false mission to ask professionals to choose one. However, given a tough urban planting site and often poor funding for maintenance (among other challenges), professionals must optimize their daily tree planting choices. The criteria they work from are often in reality conflicting and therefore represent a set of trade-offs of varying magnitudes. Since the palette of street trees is limited, we must continue to search for trees that pass important tests of toughness and meet as many other criteria as possible. Professionals encourage and discourage a wide range of trees, and have conflicting evaluations of many of these species. For some important criteria, such as the ability of a tree species to provide ecosystem services, insufficient information is available to professionals. Additionally, the information available on new potentially good urban trees is limited. As professionals from a variety of disciplines strive towards the common goal of planting optimal trees, greater coordination and increased common understanding is needed. Public gardens and other collaborations may have a role in searching for and evaluating potential urban trees.

As this first chapter focuses on tree selection criteria and knowledge of specific tree species, it will lean more heavily on data from my survey, with support from interview data. First I will present results regarding the selection criteria that various professionals prioritize, the knowledge and uncertainties that different groups of professionals bring to planting decisions, and the trees that respondents encourage, discourage, and disagree upon. I will then discuss these results in the context of the history and future of urban tree introductions, trade-offs between selection criteria, and the larger goals that professionals hope to achieve in the urban forest by selecting the best possible trees.

3.2 Results

3.2.1 Urban Tree Selection Criteria

Rankings of the 4 short selection criteria

When balancing tough trade-offs and choosing a tree for a street site, what selection criteria should be emphasized? To answer this question in the broadest sense, survey respondents ranked which of four generalized criteria (urban stress tolerance, ecological origins, services provided, and disservices caused) are most important to them when choosing a tree species for a street tree site in their city. On average, respondents rated the tree species' tolerance of urban stressors as most important, the services provided by the tree species as second most important, with ecological origins of the tree species and disservices caused by the tree species tied for last (Figure 3).

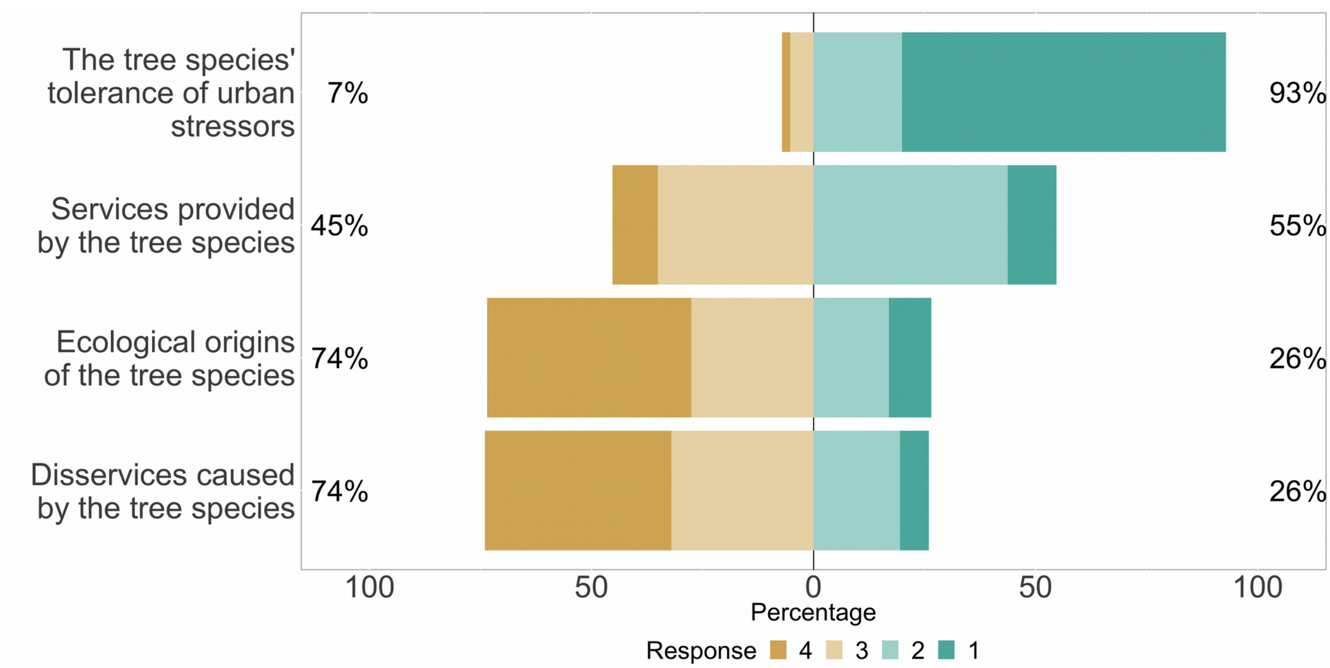

Figure 3: Rankings of the most important short/generalized criteria for street tree selection. The most important criterion is ranked as #1, the second most important as #2, and so on. (n=755)

Asking respondents to rank these four "short" criteria was an attempt to combine the 43 criteria into large but still meaningful groupings in order to understand larger patterns. Though these four choices are simplified, they paint a strong picture of the types of criteria that professionals believe are most important when choosing trees to plant.

Though disservices are ranked as less important than services or stress tolerance by survey respondents, in the interviews disservices anecdotally take on greater significance, and are frequently mentioned as reasons to cease planting a particular tree species. For example, interviewees frequently cited (with regret) the messiness of otherwise excellent trees as a reason to avoid planting them on the streetscape:

> *I'm not a huge fan of Styphnolobium, I mean it does really great, and I hate to be one of those people who say it's a messy tree (laughs), but when it, have you ever been around when the fruits, when the seeds come down? It's really pretty much of a mess.*
> *Anthony Aiello, Director of Horticulture and Curator, Morris Arboretum*
>
> *Yeah. But we often have to make the choice of using like the fruitless variety because, depends on the site, but you know that can become an issue, and that's like the people again, and expectations, and messy trees, and it's like, you know, I would want to plant only straight species everywhere, but it's like sometimes we don't have that ability.*
> *Chloe Cerwinka, Landscape Planner, The University of Pennsylvania*
>
> *The stuff that's going on with like food forests and Philly Orchard Project and all that, I think that's pretty cool (tentative tone), that's tough though on the streetscape because a lot of that fruit makes a really nasty mess over pavement. It's really cool doing it on vacant lots and lawns and stuff, that's a neat idea.*
> *Associate Director of Grounds Operations, Temple University*

Interviewees discussed disservices in 108 instances, nearly as many times as services were discussed (Table 3). In the survey, respondents rated several criteria related to disservices; unattractive aesthetics, unattractive smell, pollen production, debris production, strong rooting system, infrastructure damage, limb breakage, and invasiveness are arguably all within the realm of disservices. In the interviews, references were coded for many of these disservices: pollen production (3 references), debris production/cleanliness (35), infrastructure damage (30), breakage hazards (27), and invasive potential (28).

Table 3: Number of references coded from interview transcripts regarding 4 short selection criteria, with sub-nodes that were included in this count and sample codes.

4 short selection criteria	References coded	Sub-nodes	Sample codes
Tree species' tolerance of urban stressors	236	Cold tolerance; heat tolerance; pests and disease; physical damage; salt tolerance; soil; water relations	"Compaction, air pollution, just like car doors, people you know not really caring, locking their bikes to the trees." "They do really well. They're a tough tree." "usually in the city I go with salt tolerant, I think that's a big one, especially if there's no means for irrigation to flush out salts."
Services provided by the tree species	121	Climate adaptation; environmental benefits; health benefits; resilience; shade; social; water catchment; wildlife	"...if we can get these other trees to do well, I'd much rather plant those that are gonna support habitat and wildlife." "we talked about air pollution mitigation, and cooling on buildings, not to mention carbon sequestration, all of these impacts, but also there's this quality-of-life thing"
Ecological origins of the tree species	33	Native/original environment/provenance; native species	"American elms were widely planted… a flood-plain species, tolerant of over-drainage" "predicting if a tree, based on how it performs in its native habitat, might be turn out to be more weedy" "So some of the newer trees that are being asked for now, there's a big movement for native trees, there's a lot more native genus and species that are being grown and kind of used as urban street trees. Some of them are very appropriate and easily used, and others are not as tolerant and durable to be used in the sidewalk."
Disservices caused by the tree species	108	Cleanliness; pollen/allergies; infrastructure damage; safety/breakage	"People freak out when they go onto the sidewalks and the little fruits..." "They've got that like the hair on them, they make people sneeze." "red maples pull up the sidewalks, too. We had them for quite a while in some places, but boy, very shallow roots." "you know you don't want Callery Pears that are gonna break up and kill somebody so you want strong wooded trees."

Ratings of the 43 selection criteria

Survey respondents rated the tree they encourage and the tree they discourage on a 7-point semantic differential scale for each of 43 criteria (Figure 4). The ratings of respondents' encouraged trees and discouraged trees were significantly different at the $p<0.001$ level for all but 4 of the 43 criteria (Appendix 5). The criteria that differed most clearly between discouraged trees and encouraged trees are (in order of importance): risk of limb breakage, life expectancy, invasive potential, pruning requirements, pest and disease resistance, appropriateness of provenance, winter aesthetic attractiveness, provisioning of habitat, frequency of infrastructure damage, and debris production (Appendix 5). The 4 criteria for which there was no significant difference between the encouraged and discouraged trees are: ease of establishment, shade tolerance, pollen production, and nursery availability (Appendix 5).

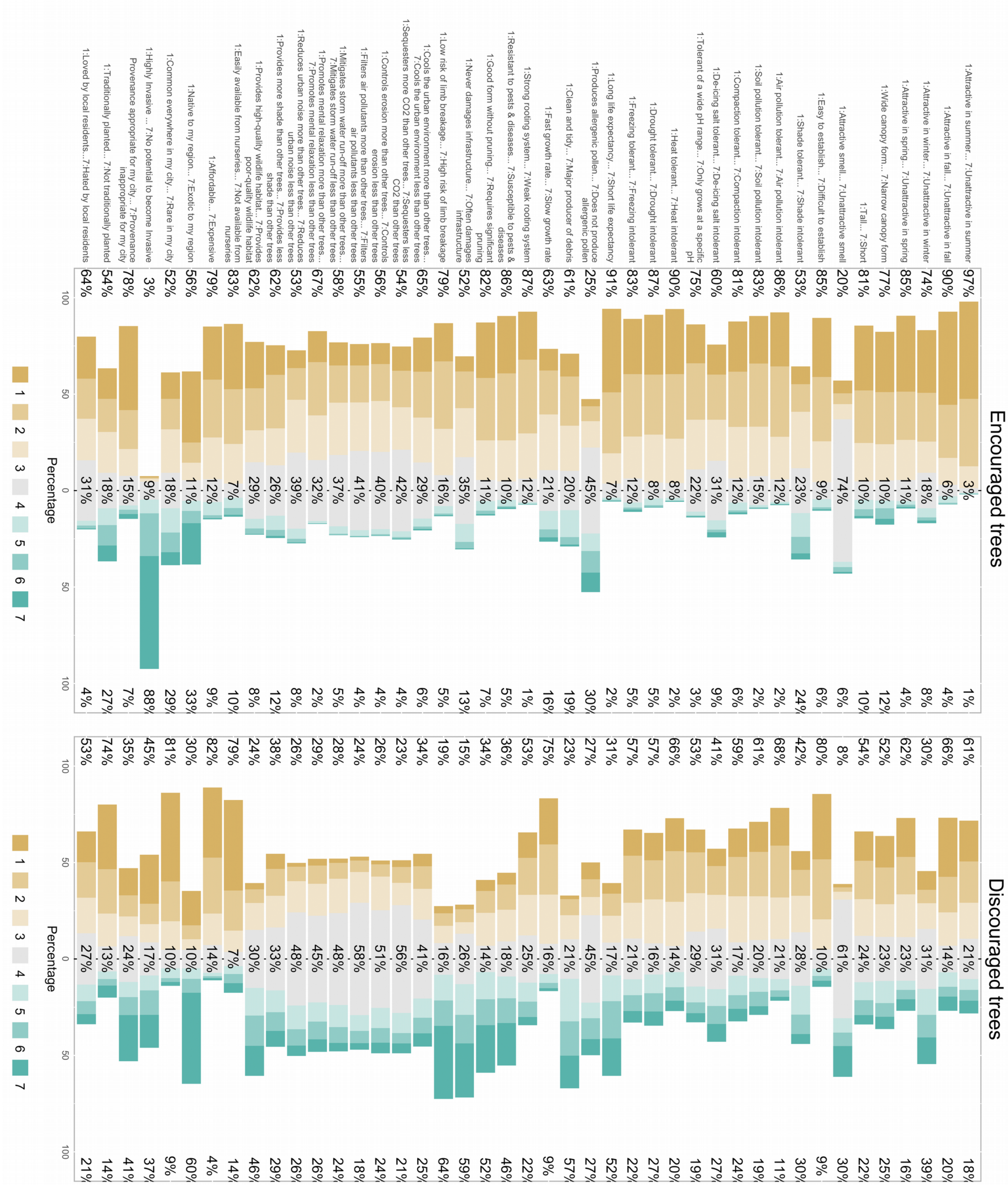

Figure 4: Semantic differential ratings on seven point scales of 43 street tree selection criteria for encouraged and discouraged trees.

Several of the 43 selection criteria ratings varied significantly across professional fields at the $p<0.01$ level (Table 4).

Table 4: Criteria rated significantly differently across professional fields (p<0.01) for the trees that respondents discouraged or encouraged.

Criteria describing discouraged trees that varied significantly by professional field	p-value
Air filtration	0.004
Cooling	0.006
Habitat provisioning	0.000
Pruning requirements	0.005
Shade provision	0.001
Criteria describing encouraged trees that varied significantly by professional field	**p-value**
CO_2 sequestration	0.010
Drought tolerance	0.008
Habitat provisioning	0.002
Rarity	0.003
Salt tolerance	0.003

For many of these criteria there was no strong visual difference between how the fields rated that criterion, although for some a pattern was discernible when viewing the plotted data. Respondents from the field of parks, recreation, and public works discouraged planting a greater percentage of trees that they rated as having a good form without pruning. Respondents from the field of arboriculture discouraged planting a greater percentage of the trees that they rated as providing more shade than other trees. The field of ecology/conservation, followed closely by the field of horticulture, discouraged planting a greater percentage of trees that they rated as providing poor quality habitat. The field of ecology/conservation also encouraged planting a greater percentage of trees that they rated as providing high quality wildlife habitat. The field of public horticulture rates the trees they encourage as more rare in their city, whereas the fields of parks, recreation, and public works, landscape architecture, and forestry rate the trees they encourage as more common in their cities.

3.2.2 Encouraged and Discouraged Street Tree Species

Survey and interview data revealed extensive lists of tree species that are currently encouraged and discouraged by professionals. In the interviews, 65 total trees were discussed by 20 respondents. In the survey, respondents mentioned 204 total trees, with 144 encouraged trees from 746 respondents and 121 discouraged trees from 741 respondents. Interestingly, there was significant overlap between these lists; 61 trees were encouraged by some and simultaneously discouraged by others (Figure 5).

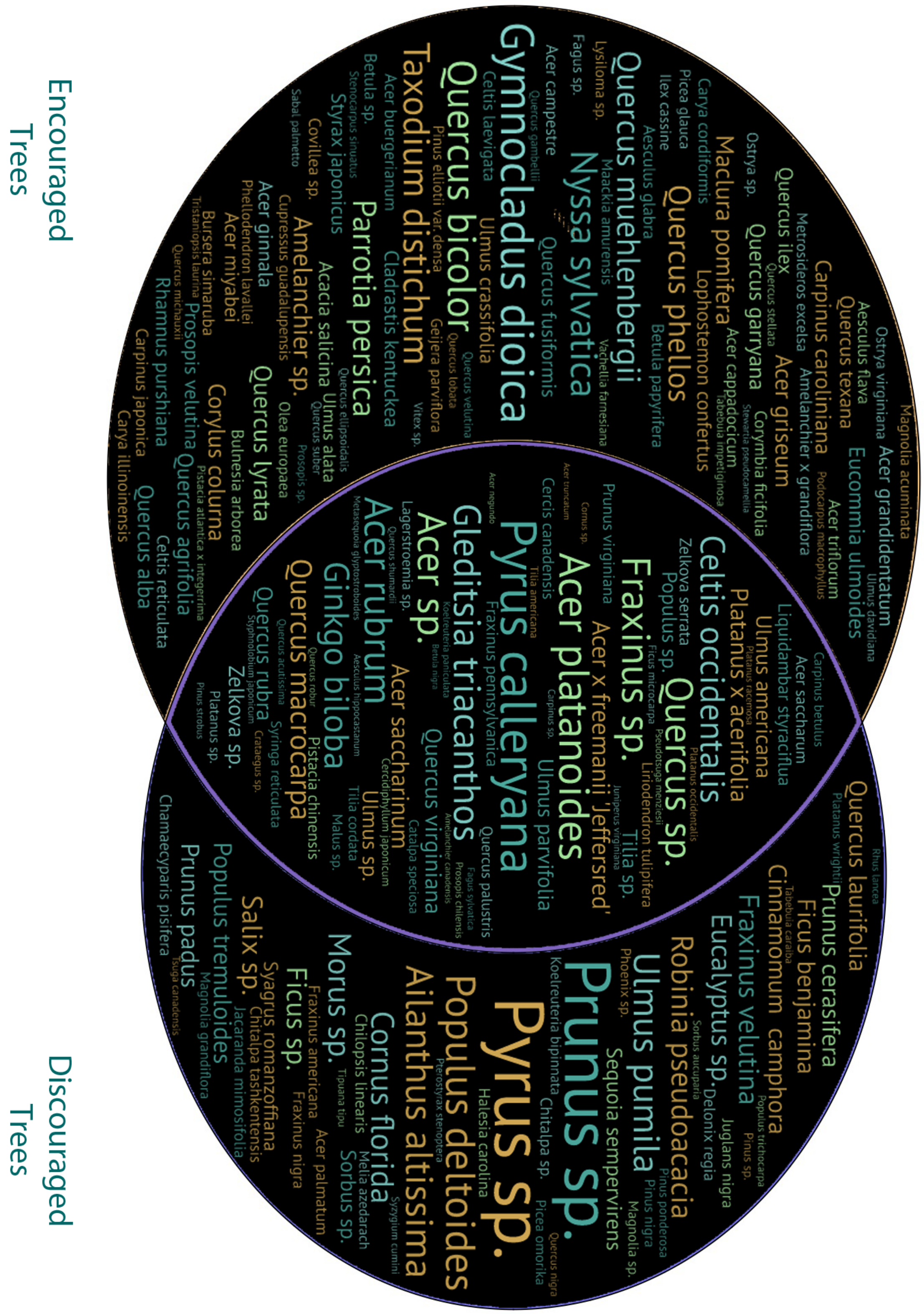

Figure 5: Venn diagram of tree taxa encouraged and discouraged by survey respondents.

Encouraged Trees

In the survey, 144 trees were encouraged for planting by 746 respondents. Across all fields, the top 15 most frequently encouraged trees were (with frequency of mentions): *Gymnocladus dioica* (59), *Quercus* sp. (46), *Gleditsia triacanthos* (37), *Quercus bicolor* (33), *Celtis occidentalis* (31), *Ginkgo biloba* (31), *Quercus macrocarpa* (31), *Nyssa sylvatica* (26), *Taxodium distichum* (24), *Ulmus* sp. (16), *Platanus* x *acerifolia* (15), *Quercus muehlenbergii* (15), *Quercus rubra* (15), *Quercus virginiana* (15), *Parrotia persica* (14).

It should be noted that several respondents did not enter a species name in response to which tree they encourage, entering instead a thematic note. These notes were excluded from species counts and further analyses. Eight respondents noted that they encourage diversity in planting, for example one respondent wrote, "We don't recommend one - we recommend diversity. Plant something different." The other thematic responses encourage native trees (two responses), fruit trees (two responses) and ornamental trees (one response).

Different professional fields recommended different groups or “palettes” of trees, and the “palette” of trees varied across geographic regions; these results will be presented and discussed in depth in the second chapter. As a brief snapshot, the top trees encouraged by each professional field (excluding the “Other” group for which there was no strong pattern) are presented below (Table 5). The lists are sometimes truncated so as not to misrepresent the popularity of a tree recommended by only one respondent, or when trees were “tied” for last place with several others.

Table 5: The top encouraged trees from each professional field.

Professional field (n= # of respondents)	Top 5 Encouraged Trees (with count of mentions)	Professional field (n= # of respondents)	Top 5 Encouraged Trees (with count of mentions)
Arboriculture (n=164)	1. *Gymnocladus dioica* (20) 2. *Gleditsia triacanthos* (14) 3. *Quercus bicolor* (10) 4. *Quercus macrocarpa* (10) 5. *Quercus* sp. (9)	Landscape Architecture (n=68)	1. *Quercus macrocarpa* (6) 2. *Quercus virginiana* (6) 3. *Gleditsia triacanthos* (5) 4. *Quercus* sp. (5) 5. *Ginkgo biloba* (4)
Ecology/ conservation (n=36)	1. *Quercus bicolor* (4) 2. *Celtis occidentalis* (3) 3. *Quercus palustris* (3) 4. *Taxodium distichum* (3)	Public horticulture (n=87)	1. *Gymnocladus dioica* (9) 2. *Ginkgo biloba* (8) 3. *Quercus* sp. (7) 4. *Taxodium distichum* (5)
Forestry (n=64)	1. *Celtis occidentalis* (5) 2. *Gymnocladus dioica* (5) 3. *Taxodium distichum* (4) 4. *Quercus macrocarpa* (3) 5. *Quercus* sp. (3)	Parks, rec, and public works (n=35)	1. *Ulmus* sp. (4) 2. *Acer* sp. (3) 3. *Amelanchier* sp. (2) 4. *Celtis occidentalis* (2) 5. *Quercus bicolor* (2)
Horticulture (n=16)	1. *Ginkgo biloba* (4) 2. *Gymnocladus dioica* (2)	Urban forestry (n=240)	1. *Gymnocladus dioica* (18) 2. *Quercus* sp. (16) 3. *Nyssa sylvatica* (12) 4. *Celtis occidentalis* (11) 5. *Quercus bicolor* (11)

Discouraged Trees

In the survey, 121 trees were discouraged for planting by 741 respondents. Across all fields, the top 15 most frequently discouraged trees were (with frequency of mentions): *Pyrus calleryana* (146), *Acer platanoides* (76), *Fraxinus* sp. (56), *Acer* sp. (53), *Acer rubrum* (46), *Acer* x *freemanii* 'Jeffersred' (25), *Acer saccharinum* (20), *Pyrus* sp. (17), *Prunus* sp. (13), *Platanus* x *acerifolia* (12), *Populus* sp. (12), *Fraxinus pennsylvanica* (11), *Gleditsia triacanthos* (11), *Populus deltoides* (11), and *Prunus virginiana* (10). Some thematic responses were excluded from further analysis, for example four respondents discouraged planting any non-native trees. Additionally, many respondents wrote in several unrelated species or entire families, for example “Most of the rosacea family” or “Any hardwoods or evergreens" and these responses were excluded from species counts. When breaking down the results for discouraged trees by professional field, there was extreme similarity among the trees that each field most frequently discouraged. The trees most frequently discouraged by each field were almost universally from the genera *Pyrus*, *Acer*, and *Fraxinus*.

Disagreement

Surveyed professionals disagreed on the use potential for many trees. Open response survey results identified 61 trees as encouraged by some and discouraged by others (Figure 5). This large amount of overlap indicates that approximately half of those tree taxa encouraged by some respondents were disputed by other respondents. Table 6 contains a sampling of 20 of these trees that exhibit higher levels of disagreement (trees that are both encouraged and discouraged more than once, with a ratio of number of times encouraged to the total number of mentions falling between 20% to 80%).

Table 6: The number of times that 20 disagreed-upon trees were encouraged by some survey respondents and discouraged by others.

Tree	Encouraged (# of times)	Discouraged (# of times)
Acer saccharinum	7	20
Acer saccharum	8	3
Cercidiphyllum japonicum	3	3
Crataegus sp.	3	2
Gleditsia triacanthos	37	11
Lagerstroemia sp.	3	6
Liquidambar styraciflua	5	8
Liriodendron tulipifera	7	3
Malus sp.	3	5
Platanus occidentalis	2	2

Tree	Encouraged (# of times)	Discouraged (# of times)
Platanus sp.	4	4
Platanus x *acerifolia*	15	12
Quercus palustris	6	4
Quercus virginiana	15	6
Syringa reticulata	5	3
Tilia cordata	4	4
Tilia sp.	6	8
Ulmus americana	12	5
Ulmus parvifolia	10	6
Zelkova sp.	13	4

When presented with 13 tree species to rate along a Likert scale from "strongly discourage planting" to "strongly encourage planting," survey respondents expressed a wide range of recommendations, with responses falling at each end of the scale for every tree (Figure 6). A total of 742 respondents viewed these questions, though respondents were encouraged to leave blanks for any tree they were unfamiliar with, so the full number of complete responses varies for each tree. *Prunus sargentii* was the most discouraged tree and *Ostrya virginiana* and *Zelkova serrata* were the most encouraged trees, though some respondents strongly disagreed with these recommendations. The most contested trees (with fairly even ratios of respondents who discouraged and encouraged it) were *Gymnocladus dioica*, *Acer miyabei*, *Acer platanoides*, and *Magnolia salicifolia*.

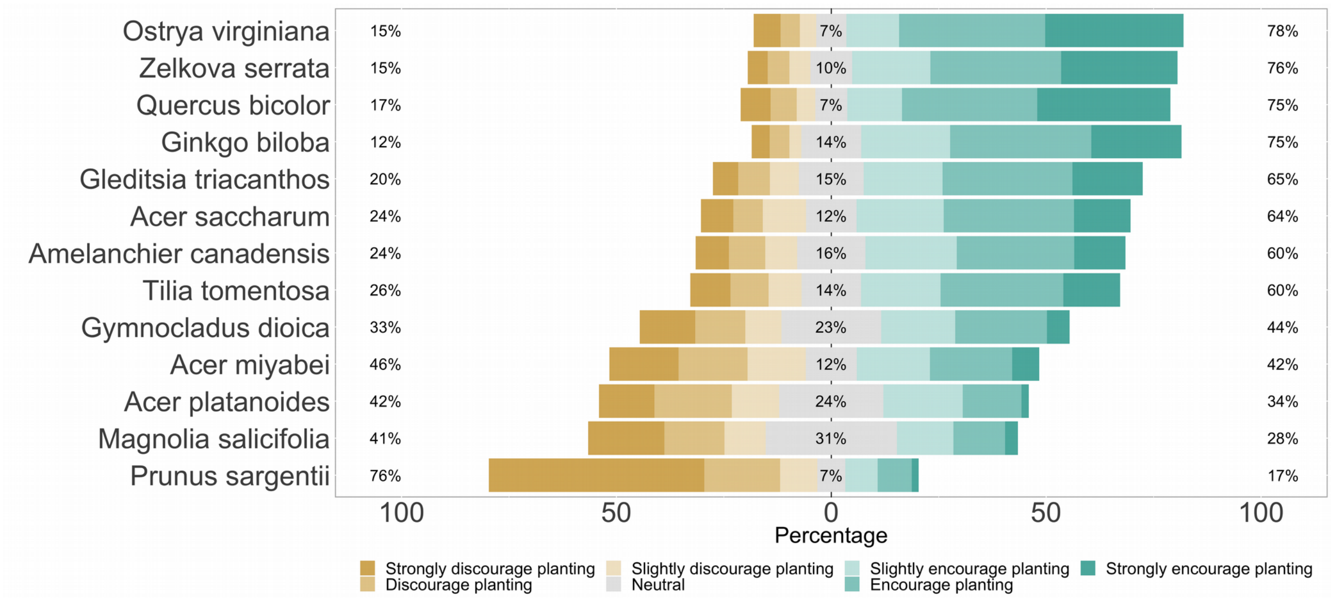

Figure 6: Ratings of 13 tree species along a Likert scale from "strongly discourage planting" to "strongly encourage planting."

3.2.3 Knowledge and Information Access

Self-reported knowledge metrics

Respondents from a variety of fields completed the online survey (Table 2). With the goal of understanding interactions and exchanges of knowledge between these fields, we sought to understand whether respondents from each field had variable knowledge levels and influence on street tree plantings.

The survey respondents were asked to self-report their level of influence on street tree plantings ("About how often do you influence choices about which tree species are planted in your city?") and their knowledge level regarding urban trees ("How knowledgeable are you about urban trees?"). The field of respondents significantly explained their response regarding their influence on tree plantings (Figure 7, p=0.000) as well as their self-reported knowledge level (Figure 8, p=0.001).

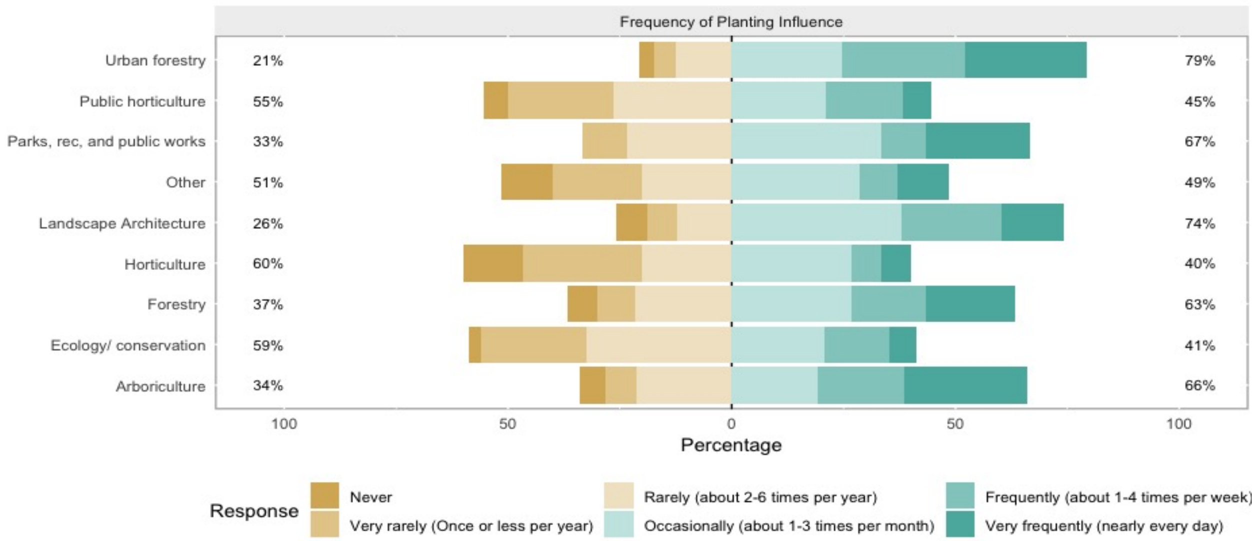

Figure 7: Frequency of planting influence by professional field, p=0.000.

Respondents from the fields of urban forestry, landscape architecture, parks rec and public works, and arboriculture reported the most frequent influence on tree planting, while the fields of horticulture, ecology/conservation, and public horticulture reported the least frequent influence on tree planting decisions (Figure 7).

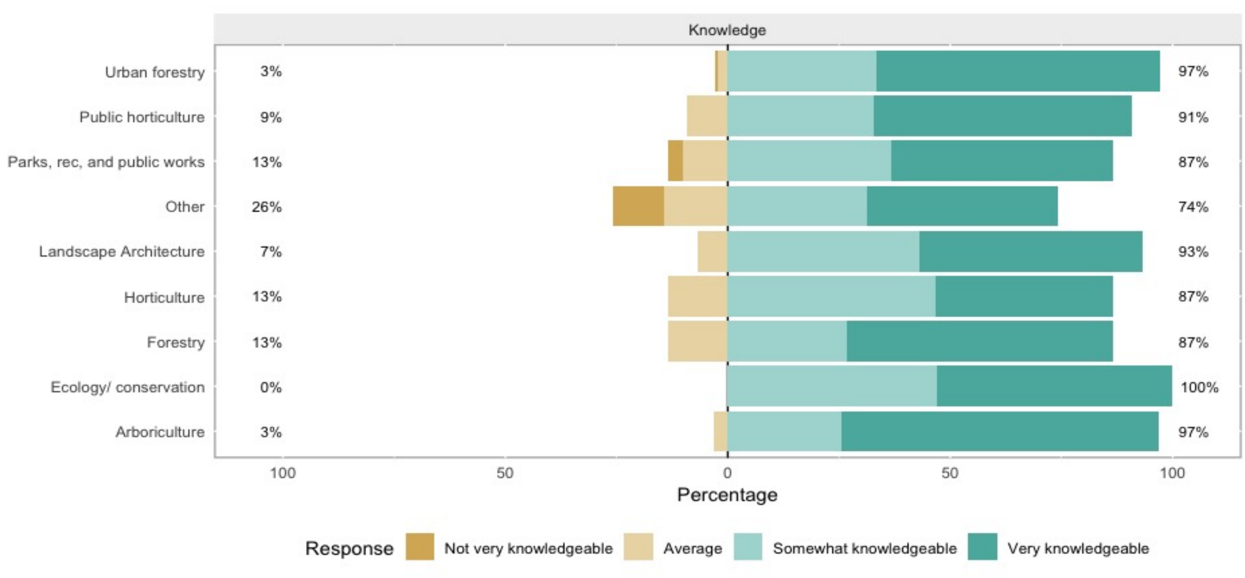

Figure 8: Self-reported knowledge levels, p=0.001.

Overall, all of the groups self-report high knowledge regarding urban trees. The "Other" group has somewhat lower self-reported knowledge than the rest of the groups, likely due to the inclusion of professionals from more peripherally related fields (Figure 8).

Neutral response and non-response knowledge metrics

For pollen production, it seems likely that there is a lack of certainty among respondents regarding how much pollen their encouraged or discouraged trees produced. Respondents were instructed to leave questions blank in this section when they could not rank their tree for a particular criterion, and the pollen question was left blank more often than any other criterion, with 59 blanks for discouraged trees and 49 blanks for encouraged trees (108 total) (Appendix 6). A large percentage (45%) of respondents rated the pollen production of their encouraged and discouraged trees as neutral (Figure 3). This is less likely the case for ease of establishment (31 total blanks), shade tolerance (47 total blanks) and nursery availability (40 total blanks) (Appendix 6).

For the 39 criteria that were rated differently between encouraged and discouraged trees, several criteria were frequently rated as neutral by a large percentage of respondents (Figure 4). In particular, smell, CO_2 sequestration, erosion control, air filtration, storm water mitigation, and urban noise reduction were frequently rated neutrally. In addition, several significant criteria rating questions were left blank by a large number of respondents, including salt tolerance, CO_2 sequestration, air filtration, pH tolerance, storm water mitigation, noise reduction, freezing tolerance, erosion control, and smell (Appendix 6).

Knowledge of ecosystem services and ecological origins

Many interviewed professionals expressed the understanding that larger trees provide more of certain services, with 13 interviewees referencing large trees a total of 35 times:

I wish I could use the same list of like, well these trees are the longest-lived, tallest, widest, most shade producing, provide the most environmental benefits over like 100 years plus, and I wish I could just look to those trees and those qualities, and just pick from that list, put them all as street trees.

Chloe Cerwinka, Landscape Planner, The University of Pennsylvania

… most of those benefits are driven by leaf surface area. So trees that have more leaf surface area are going to have more benefits. So there are trees, like crabapples and hawthorns, that just never get big, so they're never going to have the same ecosystem services as a London Plane.

Jason Henning, Research Urban Forester,
The Davey Tree Expert Company, and USDA Forest Service

… in general it is something I would like to have a conversation about, the bigger tree pits, and the number of small species that are being planted at least through our program makes up a really high percentage. So if our goal is to be increasing tree canopy, which it is, we need to be taking advantage of these areas that could support a large tree, and I don't think that's always the case.

Dana Dentice, Urban Forestry Program Manager,
The Pennsylvania Horticultural Society

I would love to see a lot of large trees, producing a very full canopy over a large portion of the city, which then provides more cooling effects, stormwater reduction, air pollutant reduction, pleasing environments for the residents of the city, and then those things translate into more successful business districts, restaurant districts, shopping districts, business in general succeeds.

Jim Kisker, Sales Manager, Schichtel's Nursery, Inc.

When survey respondents were asked to rank the regulating ecosystem services of the trees they encouraged and discouraged, their responses revealed major uncertainty. Respondents were instructed to leave these questions blank if they felt unable to rate their tree for a particular criterion. For example, when asked to rate the tree they mentioned on a semantic differential scale from 1 to 7 (1:Filters air pollutants more than other trees… 7:Filters air pollutants less than other trees), many respondents did not rate the air filtration services of the tree they discouraged, and still more participants responded neutrally, indicating that the tree they discourage filters a similar amount of air to other trees, or perhaps expressing uncertainty (Figure 9). This large number of neutral responses was strikingly prevalent across many regulating ecosystem services questions, in contrast to questions on urban tolerances.

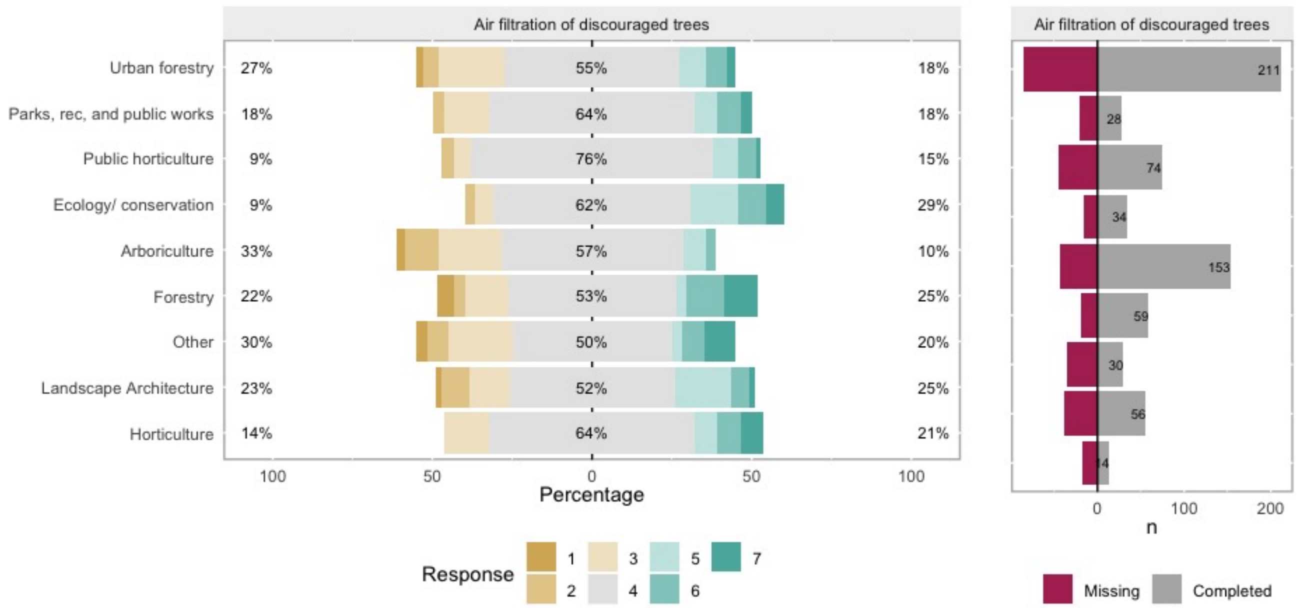

Figure 9: Ratings of the air filtration services of trees that respondents discouraged, by professional field, with associated histogram of complete and missing responses.

Knowledge of rare trees

Survey data showed that respondents from the field of public horticulture were more likely to encourage trees they rated as “rare” than other fields. Meanwhile, the fields of parks recreation and public works, landscape architecture, and forestry most commonly encouraged the trees they rated as more common in their city (Figure 10). The rarity of the recommended trees varied significantly across the various professional fields (p=0.003).

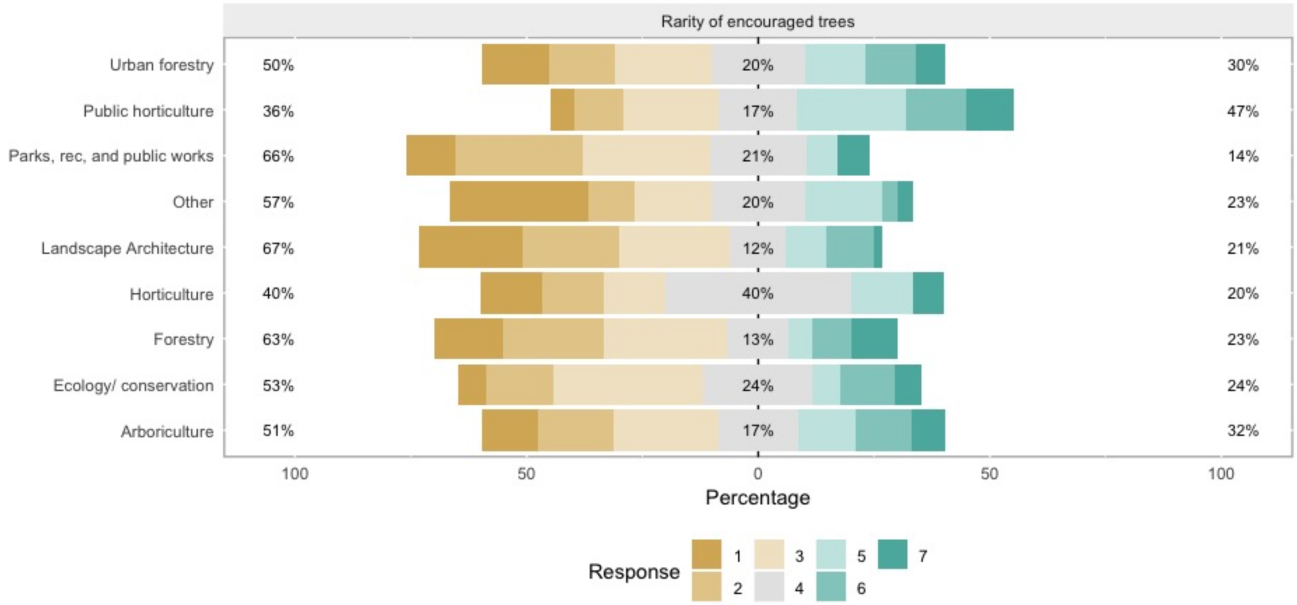

Figure 10: Rarity of encouraged trees, broken down by field, on a semantic differential scale from "1: Common everywhere in my city" to "7: Rare in my city"

When ratings of rarity were averaged by tree for all survey respondents, 42 trees were identified as rare by the survey. Though there was a relatively small number of public horticulture respondents (119) compared to the full number of respondents (979), this field identified 17 "rare" trees (Appendix 7). However, 4 of the trees that were rated as "rare" by public horticulture were rated as common overall by the full group of respondents: *Acer griseum*, *Pistachia chinensis*, *Quercus phellos*, and *Tilia cordata* (Appendix 7). Therefore, of the 42 trees recommended as rare by the full group of survey respondents, the field of public horticulture identified 13. Of these 13 rare trees recommended by public horticulture respondents, 6 were not recommended by respondents in any other field: *Acer triflorum*, *Aesculus flava*, *Carya cordiformis*, *Maackia amurensis*, *Pinus elliottii* var. *densa*, and *Styphnolobium japonicum*.

3.3 Discussion

3.3.1 Urban Tree Selection Criteria

Interpreting selection criteria results

In both the interviews and the survey, the selection criteria professionals utilize when choosing urban tree species were discussed implicitly and explicitly. Survey respondents were asked "Why?" they encourage or discourage a particular tree, and then asked to rate 43 criteria for the tree they encourage and for the tree they discourage. This rating of 43 criteria leaves up to interpretation which criteria were most influential in their decision making, and the "Why?" open response can anecdotally illuminate which criteria (either positive or negative) were important to the respondent. Meanwhile, the ratings of the 43 criteria allow interpretation of:

- Which criteria are positive or negative to respondents (for example, if all encouraged trees were rated as tall while all discouraged trees were rated as short, we would know tall height is positive for street trees).
- Which criteria do not uniformly impact selection decisions (for example, if there is no significant difference between the heights of encouraged and discouraged trees, we would know that tall and short trees might both be useful as street trees, but perhaps in different situations).
- Which criteria are difficult for participants to rank (for example, if most responses are neutral or blank for the height of both encouraged and discouraged trees, even when the height of those trees do vary in reality, we would know that there is insufficient knowledge available on tree height).

For the four selection criteria that did not vary significantly between encouraged and discouraged trees (pollen, establishment, shade tolerance, and nursery availability), we may interpret a variety of findings (Figure 3). For pollen production, it seems likely that there is a lack of certainty among respondents regarding how much pollen their encouraged or discouraged trees produced. Pollen production is infrequently reported for tree species and cultivars. Furthermore, since some commonly planted urban trees are dioecious (with separate male and female trees where only the males produce pollen) (Cariñanos & Casares-Porcel, 2011), this can be a confusing question to answer for dioecious tree species. The pollen question was left blank more often than any other criterion, with 59 blanks for discouraged trees and 49 blanks for encouraged trees (108 total) (Appendix 6). A large percentage (45%) of respondents rated the pollen production of their encouraged and discouraged trees as neutral (Figure 3), which may also indicate uncertainty. This is less likely the case for ease of establishment (31 total blanks), shade tolerance (47 total blanks) and nursery availability (40 total blanks) (Appendix 6).

Instead, these three criteria may be rated similarly for encouraged and discouraged trees due to variable or lower impact on tree selection recommendations. Ease of establishment may not have high impact on tree selection because in street tree sites most trees are difficult to establish and this is mitigated by maintenance including watering more than species selection. The need for shade tolerant street trees will vary from site to site, and therefore shade tolerance may not be uniformly positive or negative for a street tree. Nursery availability also will vary from city to city, and some encouraged trees may be available while others may not; the nursery availability constricts whether or not a tree is actually planted, but not whether a tree is recommended. The ratings of these four criteria that are not significantly different between encouraged and discouraged trees (Figure 3) therefore still illuminate interesting species selection dynamics.

The significantly different ratings of the remaining 39 criteria indicated that the following characteristics are strongly linked to encouraged tree species, and therefore are positive: attractive in the summer, attractive in the fall, attractive in the winter, attractive in the spring, wide canopy form, tall height, air pollution tolerant, soil pollution tolerant, soil compaction tolerant, de-icing salt tolerant, heat tolerant, drought tolerant, freezing tolerant, long life expectancy, clean and tidy, resistant to pests and diseases, good form without pruning, never damages infrastructure, low risk of limb breakage, promotes mental relaxation more than other trees, reduces urban noise more than other trees, provides more shade than other trees, provides high-quality wildlife habitat, native to planting region, rare in planting city, no potential to become invasive, appropriate provenance for planting city, not traditionally planted. The following characteristics are also positive, and while still yielding significant results, they were more weakly linked to encouraged tree species: attractive smell, shade tolerant, tolerant of a wide pH range, slow growth rate, strong rooting system, cools the environment more than other trees, sequesters more CO_2 than other trees, controls erosion more than other trees, filters air pollutants more than other trees, mitigates storm water run-off more than other trees, expensive, and loved by local residents.

The perfect tree

This exhaustive list of positive tree characteristics exemplifies the North American vision of a “perfect” street tree. However, as many acknowledge, a single “perfect” tree species that meets all these criteria does not (and perhaps should not) exist. Several interviewees from Philadelphia commented on the necessary imperfection of urban trees. Trees that are “too good” could be so tough that they are invasive, or so well-liked that they are over planted, decreasing the diversity of the urban forest. One for-profit arborist stated, “there's no perfect tree, and that's good, so then they would be everywhere and then it would be a monoculture again.” This concept, that a “perfect” tree is in some ways undesirable was echoed by Paul Meyer, Executive Director of the Morris Arboretum:

> *Well one of the things that we say is that 'there are no perfect trees'. So there are pros and cons, things are adaptable, there are things that are non-adaptable too, so I think it's on a*

case by case basis. Every tree has... You know, trees are like people, there are no perfect people, there are no perfect trees. But you know as I said before, sort of a generality that I've seen often is that some of the very tough plants tend to be, I mean, another word for a weed is just a very successful plant. And if it's overly successful, then we might say they're weedy.

When trees are extremely tolerant of urban stressors, this “positive” trait becomes a negative trait of high invasive potential. Many other trade-offs exist. For example, a tree with fruit may support more wildlife yet this trait also contributes to messes on sidewalks. It is necessary to acknowledge that every tree has pros and cons and no tree will fulfill every selection criterion or exhibit every positive characteristic. Therefore, the decision process to select a tree must parse out which positive criteria must be fulfilled, which criteria are flexible, and which negative criteria automatically exclude a tree from planting despite other positive characteristics.

Tolerance of urban stressors is often viewed as a prerequisite for any urban tree, because trees planted in cities must first survive before providing benefits. In the case study interviews, Philadelphia professionals noted that the “work” a tree can do or the “net worth” of a tree outweighs any smaller inconvenient characteristics a tree may have. This supports the survey finding that professionals most value the urban tolerances of a tree (which correlates with the “work” a tree can survive to do), followed by the services the tree provides.

We are planting hackberries… They grow fast, they have a nice structure to them, they seem to do a lot of work, they don't take on a whole lot of deadwood, they're not in constant need of maintenance, they don't seem to be up heaving sidewalks, I'm not saying it's the perfect tree but it seems to be working alright for what we're doing.

David Lewis Cupps, District Arborist Supervisor for the Street Tree Management Division of Philadelphia Parks and Recreation

Mindy Maslin, the Project Manager of the Tree Tenders program at the Pennsylvania Horticultural Society, emphasizes the need to plant more trees to combat climate change, and communicates the message to the public that the services trees provide outweigh imperfections like messy disservices:

> *I say often to Tree Tender groups that, where people are saying, ‘Well, it's going to drop leaves and I have to sweep them, the berries, the birds- they poop on my car, it's a big mess!’ So, I tell people, you know, do you have a family, any family members, do you have that one that's kind of annoying? Is it a reason to give up on family? And some people say, ‘Well, yeah!’, which blows the hall down. But I think it's the same thing- that trees are not perfect but the net worth is huge.*

In many cases, larger goals such as climate change mitigation or other ecosystem services outweigh the disservices trees cause. However, this is often a difficult ideal to put into practice, as the disservices caused by trees (such as messy or hazardous debris) are often much more tangible and linked to physical observation of the tree, while the services trees provide (such as carbon sequestration) may be more intangible and may require education on the biology of the tree to understand.

Since no ‘perfect’ tree exists, yet we still strive to optimize street tree planting choices as much as possible, what combinations of criteria/characteristics sum up to a ‘good tree’? The decision process to arrive at a ‘good tree’ choice is extremely subjective and context dependent. The physical site context in particular affects tree selection choices. The phrase “right tree right place” was initially applied in the field of utility arboriculture, indicating that the size, type, and location of trees must be tailored to existing utilities such as overhead wires and other physical infrastructure (Kuser, 2000). Today, this method of thinking has been adopted and expanded by many professionals. However, the subjectivity of determining the ‘right tree’ persists; what one professional may hold a negative opinion of, another might consider the ‘right tree.’ Additionally, conceptions of optimal trees change historically as the social and physical environment shifts and new information is understood about various trees. Early in the history of North American street trees, far fewer selection criteria were considered: “The trees planted along the streets in the early part of the 20th century were chosen because of their availability and hardiness. Little attention was given to their growing characteristics because street tree plantings were as new as the science of urban forestry” (Kuser, 2000, p. 235). Today, vastly more species and cultivars are available, leading to a dizzying array of choices to parse. When developing new urban tree cultivars, primary attention has been given to issues of stress tolerance. In a 1982 publication on the genetic improvement of urban trees (Consortium for Environmental Forestry Studies (U.S.), 1982), the major "kinds of characteristics that are used in choosing species for planting" that are listed are related to stress tolerance and aesthetics:

Table 7: Reproduced data on the "Needs for various types of information that are useful to arborists in choosing species and cultivars for planting, and to nurserymen for planning production and marketing" (Consortium for Environmental Forestry Studies (U.S.), 1982)

	Index of Need	
Information on Tree Characteristics	**Nurserymen (n=52)**	**Arborists (n=93)**
Survival rates in cities	77	62
Air pollution tolerance	75	67
Confined root space tolerance	71	—
Deicing salt tolerance	70	62
Drought tolerance	56	50
Maintenance problems	54	54
Disease resistance	52	36
Insect resistance	48	39
Growth rate	43	36
General health	42	39
Cold tolerance	32	32
Branching habit	14	12
Crown size	19	6
Crown shape	5	1
Flower traits	6	0
Fruit traits	2	0
Leaf traits	2	0

The above historical data show that 'nurserymen' and arborists in the 1980s in North America needed information on tree survival and tolerances more than information on aesthetic traits (Table 7). The historical prioritization of stress tolerance over other selection criteria is strongly echoed in my survey results (Figure 3). However, beyond the all-important survival of a tree, professionals must grapple with a wide range of selection criteria as they choose trees to plant.

Trade-offs and checklists

In an ideal world, what is an optimal checklist for walking through various selection criteria? Various methods and checklists exist to aid in the process of street tree species selection. A classic urban forestry guide for the northeastern USA (Kuser, 2007) details the following steps:

> *1. Define the purpose of the tree in the landscape*
> *2. Evaluate site conditions that will affect the choice*
> *3. Consider arboricultural practices that can impact the tree*
> *4. Develop selection criteria based on purpose, site, and managerial impacts*
> *5. Match characteristics of candidate trees to the criteria to identify suitable varieties, leading to the final choice*

In the above guide, selection criteria are separated from the analysis of the site and from the goals of planting. Some frameworks for tree species selection conceptualize site conditions and the larger goals/objectives/purposes of tree planting as within the realm of selection criteria, rather than as separate or preliminary considerations. In Figure 11 below, various constraints and tree ecophysiology characteristics determine the primary list of tree selections, with ecosystem services and aesthetic traits serving as a secondary filter to arrive at the final tree choice. This model is unique in its emphasis on tree ecophysiology beyond the usual focus on tolerance; the original site that a tree is sourced from and the successional behavior of a tree in its native environment can provide clues to the performance of that tree in an urban environment.

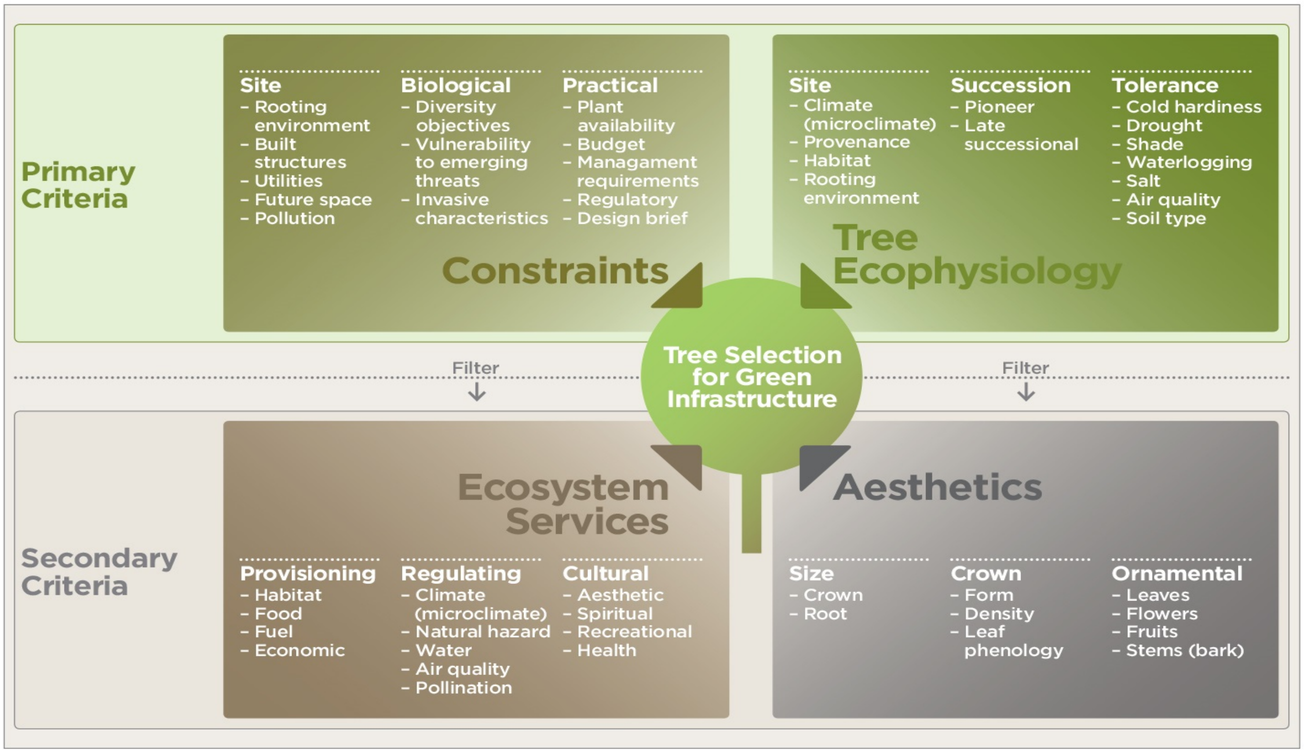

Figure 11: "Factors to consider for effective tree selection" reproduced from Hirons & Sjöman, 2018, originally adapted from Johnston & Hirons, 2014.

Site conditions are commonly viewed as primary criteria, as in the mantra "right plant, right place." Generally, checklists of what to consider begin with space available (i.e. size of soil pit, height unobstructed by utilities or buildings) and the corresponding dimensions of the tree (related to the second step listed above, "evaluate site conditions"). The mature heights of trees are well established and thus relatively easy to match to site conditions, although this characteristic is still easy to spatially underestimate. Moving beyond site conditions to other selection criteria, professionals tend to prioritize the toughness of potential trees (Figure 3). Interviewees echoed this finding, discussing in depth the preeminent importance of tough trees:

> *Well, I think first and foremost you want a tree that's gonna survive, so you want a tree that's tolerant of the conditions that it's being planted in. You know, that you'd have to look at the tolerance of all the stress factors we've talked about; poor drainage, limited soil space, periodic droughts... pollution. Now, what I find in Philadelphia is that pollution is certainly an issue, but it's not as high up there as the soil and water relations issues and*

> *mechanical damage. Below-ground and the mechanical damage are 1 and 2 as I'm concerned on the number 1 killers of trees. So, back to your checklist… Yes, survive, and then flowers, fruit, bark, density of shade, strength you know you don't want Callery Pears that are gonna break up and kill somebody so you want strong wooded trees.*
>
> *Paul Meyer, Executive Director, The Morris Arboretum*

Although professionals agree that street trees must first survive, tough trees may still be excluded due to other negative traits. Certain characteristics of trees (or combinations of characteristics) may automatically exclude them from the planting palette. In the case above, the tough Callery Pear (*Pyrus calleryana*) is excluded due (in part) to its hazardous weak wood. In many cases tough vigorous urban trees may also exhibit invasive behavior which is serious cause for exclusion. Susceptibility to disease, inadequate hardiness, and various disservices may also exclude trees from the planting list.

Developing and prioritizing selection criteria (as in the fourth step listed above) is extremely complex, especially since priorities may often be conflicting and require trade-offs. As actual tree characteristics are matched to selection criteria (as in the fifth step listed above), these trade-offs become clear; there may be no tree that perfectly fulfills all of the most important selection criteria that a professional identifies. It is quite difficult to develop an optimal checklist for tree selection that takes into account the relative weight of various criteria. While some negative characteristics may automatically exclude a tree, are others (for example, messy fruit litter) acceptable if the tree's positive characteristics fulfill certain other criteria? It may only be possible to truly rank the relative importance of conflicting selection criteria in the local context of a particular city's urban forestry goals. Matching tree characteristics to important selection criteria can be partially accomplished using existing tree fact sheets, though this process may exclude new introductions to the urban forest. Many modern urban forestry goals (including diversification and provisioning of ecosystem services) require the creation of tailored guides and checklists for individual cities.

One recent framework for Metro Vancouver, BC, Canada, emphasized the climate adaptation potential of tree plantings and recommended three steps to reach a tree selection: 1. Consider design context, 2. Consider diversity targets, 3. Consider local climate suitability (Needoba et al., 2017). This modern framework emphasized ecosystems services and encouraged the use of "the largest tree suitable for the site," tree stock that maximizes taxonomic, genetic, and age diversity, and modeling the suitability of tree species under future climate scenarios. In contrast, a much older checklist from a pamphlet on tree planting offered the following questions to check-off at the nursery after describing the planting site:

> *What is tree's mature height? What is tree's mature shape? Is it cold hardy for your area? What are the soil requirements? Does it require a shady or sunny site? Does it require a wet or dry site? Is it sensitive to salt? Describe flowers and fruits. What is the autumn/spring color? Is the species unusually susceptible to certain insects or disease, or to storm damage? In a community setting be sure to choose a variety of species. Do not plant large numbers of the same species.*
>
> *(Reynolds & Ossenbruggen, 1991)*

This older checklist heavily emphasized physical tolerances and site considerations, while also nodding to aesthetics and diversity concerns. The pamphlet identified nursery professionals as a source of information on tree species to match characteristics to selection criteria. In contrast, the report for Metro Vancouver established a design guidebook and a database of species with relevant attributes for inclusion in a suitability decision tree (Porter, Needoba, LeFrancois, & Elmore, 2017). Bridging the gap between selection criteria and tree characteristics with reliable information is a crucial step in the tree selection process, especially when there is disagreement on the characteristics of a given tree.

The selection process for urban tree species is complex, and professionals must adapt their prioritized criteria based on the relevant management goals for their city. Though there may be significant variation in how professionals choose to approach this decision process and the trade-offs they encounter, there exists major thematic continuity over the last three decades in how species selection decisions have been approached. In particular, the primary emphasis on site conditions and tree survival shines through. Although aesthetic design considerations may be considered secondary, aesthetics are a constant presence in selection checklists and frameworks. Recent frameworks are more sophisticated in their treatment of site design and diversity issues and add a tone of greater environmental awareness to the picture, incorporating criteria related to climate change adaptation, tree source provenance, and ecosystem services.

3.3.2 Encouraged and Discouraged Street Tree Species

Professional opinions on individual tree species are extremely complex, taking into account a variety of selection criteria, site characteristics, and diversity factors to arrive at a decision on whether to encourage or discourage the planting of any given tree. The historical context shows that opinions on certain trees shifts over time, with certain trees hailed as the “cure-all” or near-perfect at certain points in history, only to be vilified a decade later. These drastic shifts in collective opinion are often due to new information on the tree’s growth performance, the occurrence of new pests or diseases, or the over-use or invasion of a “too good” tree. Ideally, current and future management will proactively evaluate tree species to mitigate the potential of unsafe or excessive plantings. The issues caused by past poor species choices (such as unsafe brittle limbs, die-off of over planted species from pests and diseases, or invasions into natural areas) reverberate into the present with costly implications. The collected survey and interview opinion data may aid in the identification of current or future problematic species, as well as potential species deserving of evaluation.

Which trees do professionals encourage planting in their cities, and why? The variety of opinions that professionals express about trees reflect the current trends and fashions in urban forestry, the current knowledge available on specific trees, the larger goals and values that shape decisions (such as increasing ecosystem services or mitigating risk), and the unique personal preferences that each person holds.

Trees that are mentioned with high frequency by respondents are not necessarily better than trees encouraged with lower frequency. Rather, this metric reveals interesting patterns of which trees are ‘on the tip of the tongue’ for professionals and are major components of today’s urban forestry discourse. Since survey respondents were asked only for a single tree they encourage, their response is also not indicative of the full range of trees they encourage or utilize. Of course, it would have been best to elicit the full species palette available to each professional, ranked by preference, however the survey design compromised this breadth to lower the burden on participants.

3.3.3 Knowledge and Information Access

Thus far, we have discussed the important criteria and optimal characteristics that are associated with recommended tree species for street sites, and then delved into the actual species that professionals encourage and discourage. Given that tree species differ in regards to certain criteria, and that certain characteristics are preferable over others, do professionals sufficiently understand those differences between trees to make informed decisions? If detailed information on tree characteristics exists in the research literature or in practical forms, what professional groups have access to it and what professional groups are involved with sharing it further?

Self-reported knowledge metrics

Despite the high level of expertise of this set of survey respondents, planting decisions may often be made without access to complete, contextual, and comparable information on urban tree species.

Available information on stress tolerance

Information on certain tree characteristics is more concretely established by the research literature and is consequently more readily available to professionals. In particular, since the tolerance of a tree to urban stressors is a major selection criterion and many tolerances may be determined experimentally, urban tree selection literature focuses significant attention on stress tolerance. In a Scandinavian review of the character of available stress tolerance information, “results showed that existing information is piecemeal and that most is either too general (dendrology literature) or too specific or contradictory (scientific literature) to meet the requirements of urban tree planners, while books intended for plant use in cities do not sufficiently integrate the local perspective. Moreover, contextual information local to the Scandinavian region is mainly provided for already much used species” (Sjöman & Busse Nielsen, 2010). This brings to light several important qualities of information on stress tolerance: it should provide a useful level of specificity to inform planting decisions, should be adapted to local geographic regions, and should be revised frequently to include new or infrequently used species.

In the North American context, basic information on tree tolerances of urban stressors is readily available via extension fact sheets and other publications (Gilman, 1997). However, though this information exists and is available, there is room for improvement in the way stress tolerances are described and compared between species. Certain species are popularly ascribed particular (in)tolerances, yet for accurate comparisons across species, intuitive and standardized ratings are rarely made accessible. Additionally, though climate and stressor tolerances are well established for certain trees, this basic information is more difficult to access for trees that are not yet commonly planted in urban areas, making it riskier to plant novel species. Both for known and novel species, information on their native environment should be available and used as a comparison with urban environments to anticipate the tolerances and functions of a given tree.

Available information on ecosystem services and ecological origins

Information on ecosystem services provided by trees (other than aesthetics) and ecological origins of tree species are less frequently broken down by species and made accessible to professionals. This results in lower understanding of how specific trees relate to and function within the urban environment as a whole. Although many ecosystem services vary between species, professionals struggle to classify the services of individual trees, hampering goals of planting trees that will provide increased benefits to their city.

Beyond the understanding that large trees generally provide more regulating services, the benefits provided by a tree can be very intangible to a passerby—how much air is that tree filtering? How much CO_2 is it sequestering? As the modern tree selection discourse shifts to emphasize ecosystem services and climate adaptation, functional resources are not yet available to link these broader goals to concretely applicable tree management and tree planting decisions. Concrete metrics must be calculated and made available to compare the benefits provided by various species.

4. Barriers Against Tree Palettes for a Diverse, Functional, Resilient Urban Forest

4.1 Overview

Tree selection and planting at the site level is often viewed as a way to affect metropolis-wide systems by providing cumulative services and the resilience of a diverse forest (Conway & Vander Vecht, 2015). In order to produce such wide-reaching impacts via tree selection, we must understand the dynamics of the palette of trees in use, including the overarching barriers that restrict that palette. Due to these barriers, professionals make compromises that lower the potential urban forest diversity, functionality and resilience. Significant opportunities exist to diminish the effect of identified barriers, unlock more species selection choices, and share knowledge and successful strategies among actors.

It is important to note that street tree species are just one segment of the overall diversity of the urban forest. Other planting sites such as parks that are more hospitable to trees are able to support a greater diversity of trees by including trees with lower stress tolerances and higher levels of debris production. Species selection decisions for street sites must be made with consideration to the diversity of other street plantings as well as the diversity of the urban forest as a whole.

This chapter looks at the issue of street tree species selection from a zoomed-out view of ecological function and diversity, rather than at the individual tree/site level as in the previous chapter. Since this chapter digs deeply into the broader context of species selection decisions, it relies more heavily on my interview study, and also includes analysis of broader trends in the survey data. To understand the interplay between the species selection choices of professionals and the diversity and function of urban forests, I first use survey data to explore the "palette" of trees identified by various professional fields and in various climate regions across the USA and Canada. The degree to which these tree palettes overlap between fields illuminates which fields should increase their communication with others. The variations in the palette of trees in use across different North American climate regions reveal broad-scale geographic diversity patterns across urban environments. Then, using information from the case study interviews in Philadelphia, I discuss the wide range of barriers that limit which trees professionals consider for planting. These barriers affect the diversity and resilience as well as the ecosystem functioning of urban forests. The interviews illuminate the complexity of choosing species for a diverse urban forest, especially when selection choices are influenced by social, ecological, economic, and legislative factors beyond any characteristics attributable to a tree.

4.2 Patterns in Street Tree Palettes

The set of trees mentioned by professionals in the online survey open responses provides insight on the palette of trees used by groups of respondents. Though this insight on each group's palette is highly interesting, it is a limited picture, and does not represent the "palette" available to any single practitioner in a given professional group. To analyze street tree selection patterns across professional fields and climate regions, I compiled counts of how many times each unique tree species was encouraged and discouraged by respondents from each professional group and respondents from each climate region. These species counts by professional and climate groups were used to compute traditional ecological diversity indices (as though the data were species count by study plot). These indices allow us to standardize uneven sample sizes and reliably compare the diversity of each group's "palette" as well as analyze the overlap between palettes.

4.2.1 Tree palettes across professional fields: Results

The set of trees that respondents encouraged or discouraged varied across professional field in survey results. However, this variation is not explained by professional field at a significant level based on a Kruskal-Wallis test between the potential explanatory variable of professional field and the response variables of encouraged tree choice (p=0.781) and discouraged tree choice (p=0.213). Despite the lack of statistically significant variation in which species each field chose, I examined variation across fields in palette diversity and analyzed the similarities and overlaps between the palette of each field.

The results of species richness calculations (Table 8) reveal that the richness of species “palettes” varies across professional fields. The field of forestry encourages the highest richness of trees, followed by “Other”, then urban forestry, landscape architecture, arboriculture, public horticulture, parks recreation and public works, ecology/conservation, and finally horticulture. Overall, the species richness of the palette for discouraged trees is much lower than for encouraged trees, with the exception of the field of landscape architecture which discouraged a palette of trees with higher species richness.

Table 8: Species richness counts (S) and Menhinick’s richness index (Dmn) calculated across professional fields based on trees encouraged and discouraged by survey respondents.

		Richness count (S)		**Menhinick’s richness index (D_{mn})**	
Field	**n**	**Encouraged trees**	**Discouraged trees**	**Encouraged trees**	**Discouraged trees**
All Fields	979	144	121	5.27	4.45
Forestry	78	41	25	5.12	3.08
Other	66	30	23	5.00	4.07
Urban forestry	296	76	60	4.91	3.88
Landscape Architecture	94	38	40	4.61	5.00
Arboriculture	197	58	52	4.53	4.02
Public horticulture	119	41	32	4.40	3.45

Parks, rec, and public works	48	26	20	4.39	3.38
Ecology/ conservation	50	24	16	4.00	2.67
Horticulture	31	12	11	3.00	2.75

The differences in palette species richness between fields is also apparent when viewing the rarefaction curves for each field (Figure 12, Figure 13). Each curve displays the increase in number of unique tree species as the number of respondents increases for each field. Since none of the plotted curves have reached an asymptote (slope of zero), it is clear that the sample size for each professional field was insufficient to reach saturation; more survey responses would likely continue to yield more species recommendations. However, the different slopes allow for visual interpretation that some fields have larger palettes than others. This plot visually reiterates the findings presented in (Table 8), while making clear the large differences in sample size.

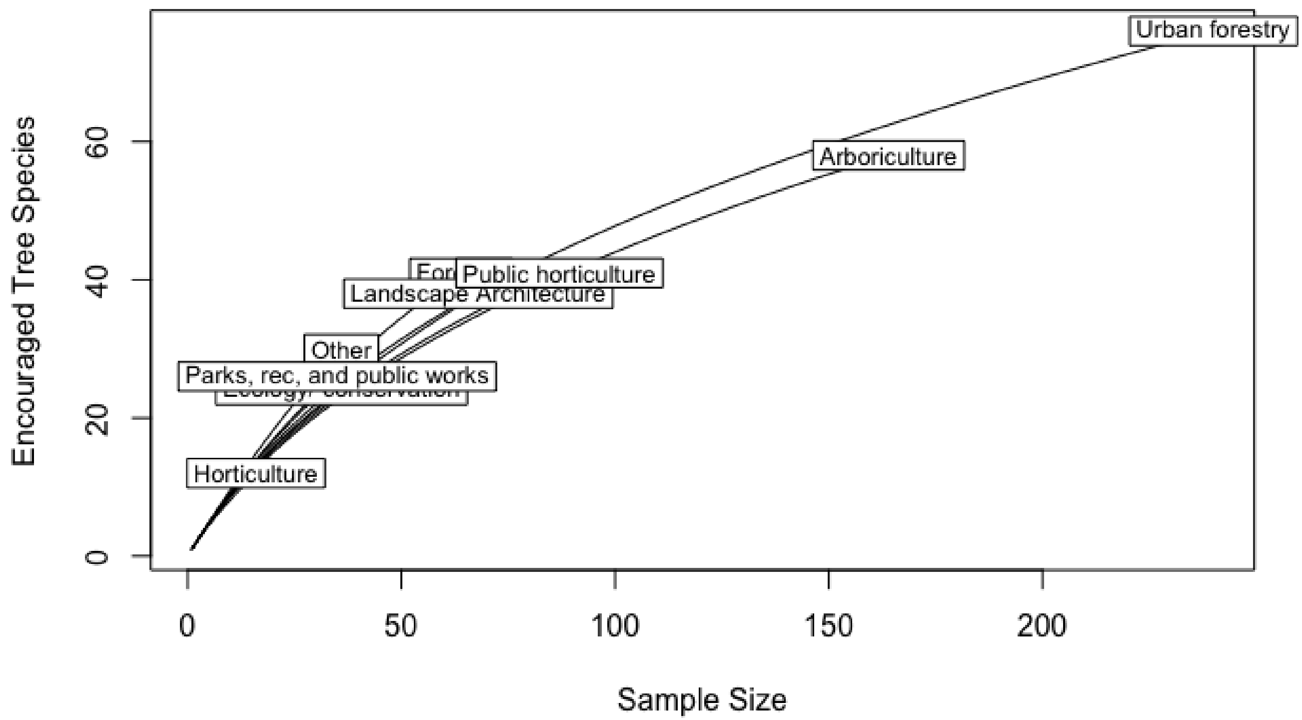

Figure 12: Rarefaction curves for the palettes of encouraged tree species identified by each professional field.

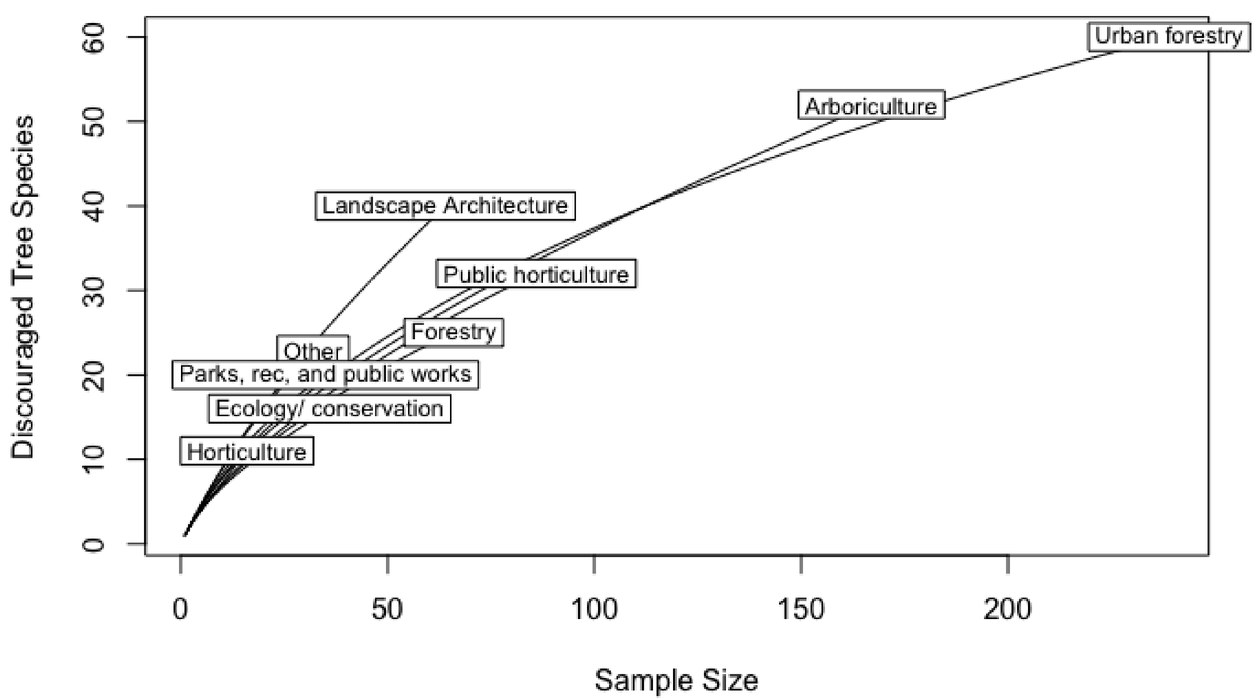

Figure 13: Rarefaction curves for the palettes of discouraged tree species identified by each professional field.

The Shannon-Wiener Index ranges from 0 to 5 (typical values 1.5 to 3.5) with higher values indicating greater diversity. Calculations of the Shannon-Weiner index and diversity numbers revealed that the field of urban forestry has the most diverse palette of encouraged trees, followed by arboriculture and forestry. For discouraged trees, the palette of the landscape architecture field was the most diverse, followed by urban forestry and arboriculture (Table 9).

Table 9: Shannon-Weiner diversity metrics for encouraged and discouraged trees across fields.

	Shannon-Weiner Index (H')		Shannon-Weiner Diversity Numbers (eH')	
Field	**Encouraged trees**	**Discouraged trees**	**Encouraged trees**	**Discouraged trees**
All Fields	4.14	3.54	62.9	34.46
Urban forestry	3.87	3.32	48.1	27.68
Arboriculture	3.57	3.19	35.6	24.33
Forestry	3.54	2.62	34.6	13.72
Public horticulture	3.41	2.78	30.3	16.16
Landscape Architecture	3.39	3.46	29.6	31.73
Other	3.35	3.00	28.6	20.08
Parks, rec, and public works	3.14	2.82	23.2	16.78
Ecology/ conservation	3.04	2.34	20.9	10.43
Horticulture	2.34	2.10	10.4	8.17

Bray-Curtis dissimilarity tests describe how much overlap exists in the identity and frequency of species recommended by each field by computing the distance between each pairing of fields, and results are presented as a matrix in (Table 10, Table 11). Small values indicate low dissimilarity (or high similarity), while values approaching 1 indicate high dissimilarity (or low similarity). Thus, the field of Arboriculture's tree palette compared to itself is completely similar (dissimilarity value = 0.000), while fields with dissimilar encouraged tree palettes such as Horticulture and Urban Forestry have a high dissimilarity value (0.906).

Table 10: Bray-Curtis dissimilarity matrix for encouraged trees by field.

	All Fields	Arboriculture	Ecology/conservation	Forestry	Horticulture	Landscape Architecture	Other	Parks/rec/public works	Public horticulture	Urban forestry
All Fields	0.000	0.640	0.908	0.842	0.958	0.833	0.908	0.910	0.791	0.513
Arboriculture	0.640	0.000	0.750	0.614	0.889	0.638	0.750	0.769	0.618	0.386
Ecology/ conservation	0.908	0.750	0.000	0.560	0.769	0.731	0.639	0.746	0.805	0.819
Forestry	0.842	0.614	0.560	0.000	0.800	0.652	0.620	0.616	0.616	0.664
Horticulture	0.958	0.889	0.769	0.800	0.000	0.690	0.654	0.765	0.806	0.906
Landscape Architecture	0.833	0.638	0.731	0.652	0.690	0.000	0.654	0.786	0.665	0.675
Other	0.908	0.750	0.639	0.620	0.654	0.654	0.000	0.662	0.789	0.797
Parks, rec, and public works	0.910	0.769	0.746	0.616	0.765	0.786	0.662	0.000	0.689	0.818
Public horticulture	0.791	0.618	0.805	0.616	0.806	0.665	0.789	0.689	0.000	0.602
Urban forestry	0.513	0.386	0.819	0.664	0.906	0.675	0.797	0.818	0.602	0.000

Most similar	0.0 to 0.55	0.56 to 0.65	0.66 to 0.75	0.76 to 0.85	0.86 to 0.95	0.95 to 1.0	Least similar

For encouraged trees, the cumulative palette of all the fields put together is most similar to urban forestry and arboriculture, though generally this full set of encouraged trees is dissimilar to the trees encouraged by any single field. The most dissimilar pairings of fields are: horticulture and urban forestry, horticulture and arboriculture, urban forestry and ecology/conservation, urban forestry and parks/recreation/public works. The two fields with the most similar palettes of encouraged trees are arboriculture and urban forestry.

Table 11: Bray-Curtis dissimilarity matrix for discouraged trees by field.

	All Fields	Arboriculture	Ecology/conservation	Forestry	Horticulture	Landscape architecture	Other	Parks/rec/public works	Public horticulture	Urban forestry
All Fields	0.000	0.632	0.907	0.836	0.958	0.841	0.917	0.910	0.792	0.512
Arboriculture	0.632	0.000	0.724	0.545	0.858	0.688	0.809	0.733	0.455	0.369
Ecology/ conservation	0.907	0.724	0.000	0.490	0.615	0.660	0.647	0.634	0.574	0.767
Forestry	0.836	0.545	0.490	0.000	0.756	0.585	0.673	0.624	0.447	0.613
Horticulture	0.958	0.858	0.615	0.756	0.000	0.700	0.625	0.608	0.745	0.898
Landscape Architecture	0.841	0.688	0.660	0.585	0.700	0.000	0.688	0.576	0.573	0.710
Other	0.917	0.809	0.647	0.673	0.625	0.688	0.000	0.552	0.661	0.815
Parks, rec, and public works	0.910	0.733	0.634	0.624	0.608	0.576	0.552	0.000	0.620	0.796
Public horticulture	0.792	0.455	0.574	0.447	0.745	0.573	0.661	0.620	0.000	0.551
Urban forestry	0.512	0.369	0.767	0.613	0.898	0.710	0.815	0.796	0.551	0.000

Most similar	0.0 to 0.55	0.56 to 0.65	0.66 to 0.75	0.76 to 0.85	0.86 to 0.95	0.95 to 1.0	Least similar

The palette overlaps for discouraged trees are very similar to the palette overlaps for encouraged trees. For discouraged trees, we also find that the cumulative palette of all the fields put together is most similar to urban forestry and arboriculture, and that generally this full set of discouraged trees is dissimilar to the trees discouraged by any single field. The most dissimilar pairings of fields are: horticulture and urban forestry, horticulture and arboriculture, “other” and urban forestry, and “other” and arboriculture. The two fields with the most similar palettes of discouraged trees are arboriculture and urban forestry.

To visually represent the Bray-Curtis dissimilarity distances between the encouraged tree palettes for each field, I computed a Non-Metric Multidimensional Scaling (NMDS) plot (Figure 14). The spacing between the professional fields represents how close or far apart their species recommendations are. The species recommendations are placed in proximity to the appropriate field(s). This plot paints the same picture as above, that the palette of trees encouraged by the field of urban forestry is most similar to all fields combined, and also quite similar to the field of arboriculture. Meanwhile, tree recommendations from the field of horticulture are quite dissimilar from other fields.

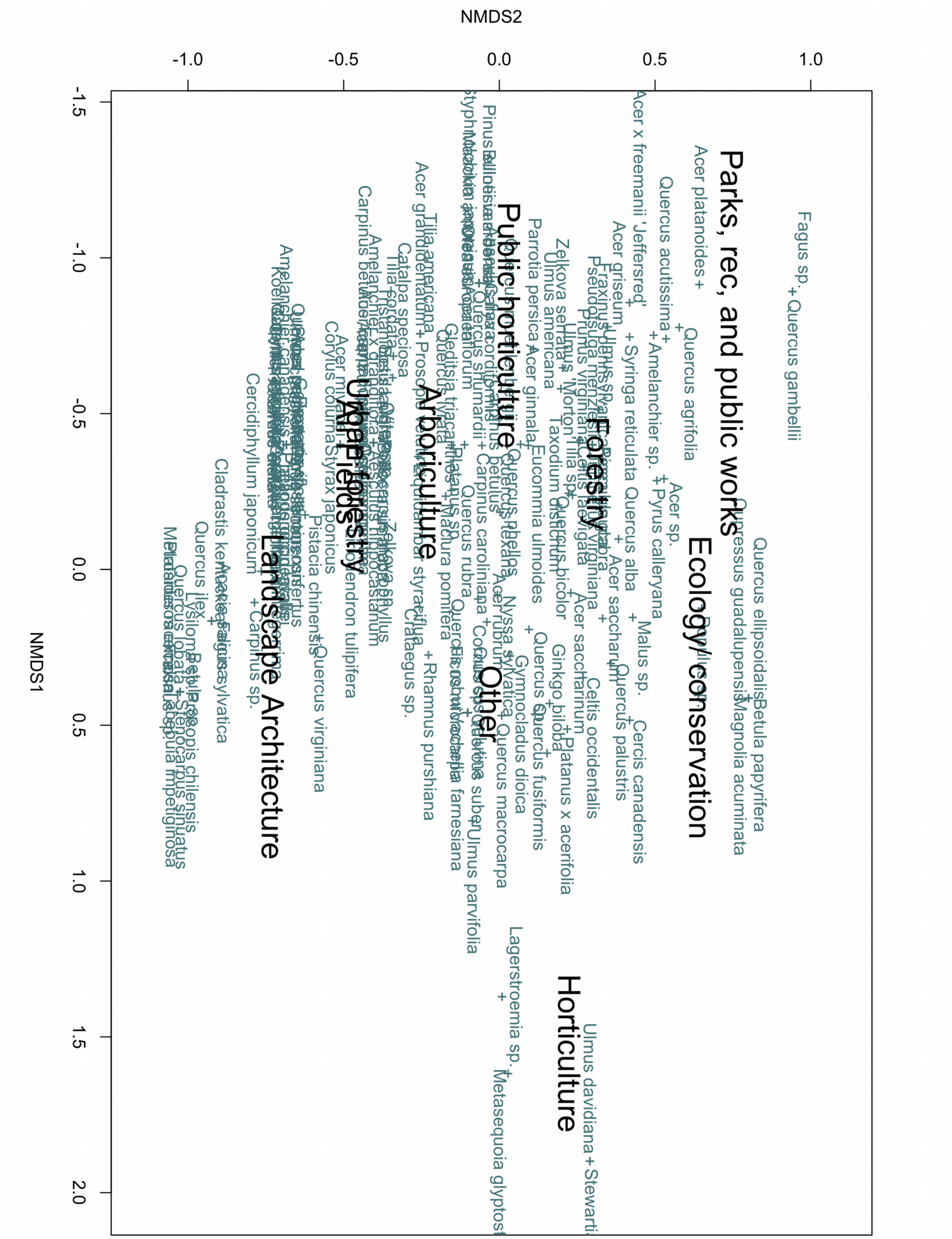

Figure 14: A Non-Metric Multidimensional Scaling (NMDS) plot visualizing the trees encouraged by various professional fields, and the overlap vs. dissimilarity in the palettes of the professional fields.

4.2.2 Tree palettes across professional fields: Discussion

Certain professional groups are often anecdotally linked to preferences for particular tree species or tree characteristics. When we tested this common wisdom by comparing species recommendations across surveyed professional fields, we found that some fields had highly similar responses to each other while other fields differed in their recommendations. While no statistically significant difference was found between the species recommendations across all fields, we can still glean descriptively interesting differences in palette diversity between fields. Additionally, the overlaps in tree recommendations between certain fields paint an intuitively sensible picture of which fields share similar preferences. By examining overlaps between the palette of trees that we can link to each professional field, we can perhaps infer something about which groups “talk to each other.”

Noticeable overlaps between the set of trees recommended by each professional group may correspond to similarities in training and professional practice between groups. Meanwhile, professional groups with more divergent opinions may have received different training or may emphasize different selection criteria and tree species based on their professional culture and daily activities. The high degree of similarity between the tree palettes of the arboriculture field and the urban forestry field (Table 10), and (Figure 14) intuitively makes sense; in North America, the field of urban forestry was primarily born out of the field of arboriculture (Konijnendijk et al., 2006). Today the education and credentials of urban forestry and arboriculture professionals overlap, with both groups commonly holding the International Society of Arboriculture (ISA) Certified Arborist credential (O’Herrin et al., 2019). The result that these two groups were more similar than other individual fields to the sum total of the planting recommendations from all the fields combined indicates that urban forestry and arboriculture are central in setting the narrative of which trees are suitable for street tree sites.

The recommendations from other fields encompass more tree recommendations that are outliers. For example, the fields of horticulture, ecology/conservation, and parks/recreation/public works encourage trees that are more dissimilar to the typical recommendations across all fields combined (Table 10, and (Figure 14). These “outlier” recommended species may be viewed as more unusual choices for a street tree; perhaps they are in some way unsuitable and thus rarely recommended, or perhaps they are uncommon yet good trees and should be evaluated for increased use to diversify the current palette of more commonly used trees. To see examples of some of the potentially unique/under-utilized suggestions that these fields offer, we can look at the groupings of encouraged tree species in Figure 14. The outlier species grouped with the field of horticulture are *Ulmus davidiana*, *Metasequoia glyptostroboides*, *Lagerstroemia* sp., and *Stewartia pseudocamellia*. The outliers closest to the field of parks/recreation/public works are *Fagus* sp. and *Quercus gambelii*. Finally, the trees grouped closest to the field of ecology/conservation are *Betula papyrifera*, *Cupressus guadalupensis*, *Magnolia acuminata*, *Populus* sp., and *Quercus ellipsoidalis*. Some of these recommendations are more realistic for street tree plantings than others; for example *Quercus gambelii* is sensitive to disturbance and forms thickets, making it likely a poor choice for most street plantings, while *Q. ellipsoidalis* is a small stature oak native to dry upland woods in North America and could be planted more frequently in street sites. Uncommon tree recommendations would add more diversity to the urban forest in many cases, but may be unsuitable based on other important criteria.

While “outlier” encouraged tree species should be taken with a healthy degree of skepticism, these recommendations highlight the potential to diverge from the common and expected palette of trees that are typically planted. Turning to colleagues in other fields may reveal new viewpoints and potential tree choices. The differences in tree species palettes between fields indicates there is need for communication among professionals to spread knowledge on the full range of potential species choices.

4.2.3 Tree palettes across climate regions: Results

The set of trees that respondents encouraged or discouraged varied across climate region in survey results. This variation is explained by climate region at a significant level based on a Kruskal-Wallis test between the potential explanatory variable of climate region and the response variables of encouraged tree choice ($p=0.001$) and discouraged tree choice ($p=0.000$).

Using geographic data provided by respondents (ZIP and postal codes), I found the Köppen-Geiger climate region for each respondent (Kottek et al., 2006). I examined variation across climate regions in palette diversity and analyzed the similarities and overlaps between the palette of each region. The same metrics (as were used above to compare palettes across professional fields) of species richness, rarefaction, diversity, and overlap were applied to the palettes of encouraged and discouraged trees from each climate region.

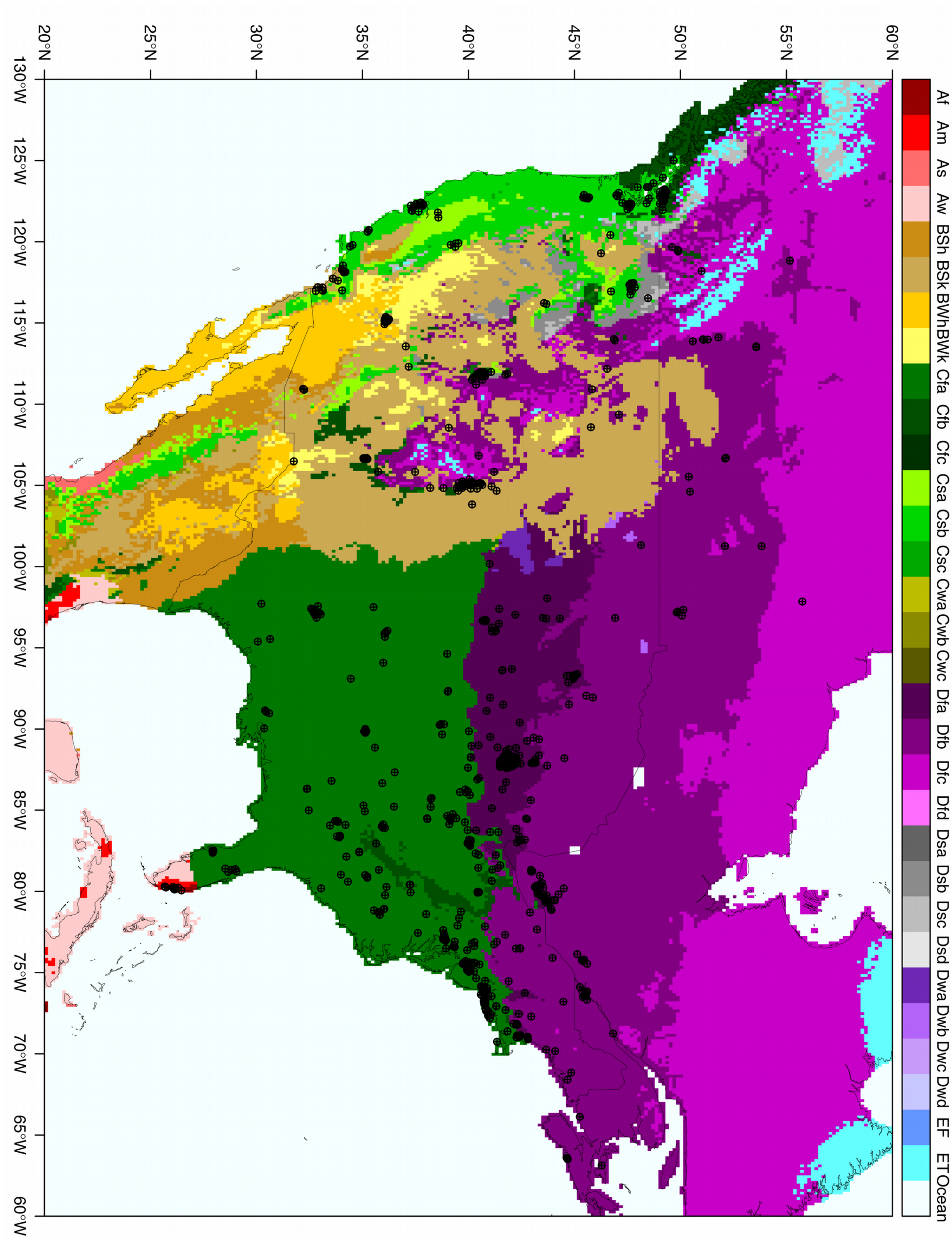

Figure 15: A map of the locations of survey respondents from the USA and Canada and their Köppen-Geiger climate regions.

Figure 15 shows the locations of 975 survey respondents, superimposed on the map of Köppen-Geiger climate regions (Kottek et al., 2006). The climate regions represented in the survey are as follows: Am (equatorial monsoon), As (equatorial savannah with dry summer), BSh (hot steppe climate), Bsk (cold steppe climate), BWh (hot desert climate), Bwk (cold desert climate), Cfa (warm temperate climate, fully humid, hot summer), Cfb (warm temperate climate, fully humid, warm summer), Csa (warm temperate climate with dry summer, hot summer), Csb (warm temperate climate with dry summer, warm summer), Dfa (snow climate, fully humid, hot summer), Dfb (snow climate, fully humid, warm summer), Dfc (snow climate, fully humid, cool summer and cold winter), Dsc (snow climate with dry summer, cool summer and cold winter). Note that one point in Hawaii (As) and 7-points in Alaska (Cfb, Dfb, Dfc, and Dsc) are excluded from the extent of this map.

The sampling of respondents from each climate region (n) was extremely uneven (Table 12). The largest number of respondents were sampled from the Cfa climate, which is a warm temperate fully humid climate with a hot summer. Table 12 is sorted by the Mehinick's richness index values for the trees encouraged in each region, to illustrate the species richness for each region accounting for sample size. The species richness of encouraged trees is highest for the cumulative set of all represented Köppen-Geiger regions. The individual regions with the highest species richness are Csb (warm temperate with dry warm summer) and Cfa (warm temperate with humid hot summer). Meanwhile for discouraged trees, the species richness for Cfb (warm temperate with humid warm summer) exceeds the cumulative richness across all regions. The regions with the next-highest richness of discouraged trees are also Csb and Cfa.

Rarefaction curves visually reiterate the variation in sample size and species richness between Köppen-Geiger climate regions (Figure 16, Figure 17).

Table 12: Species richness counts (S) and Menhinick's richness index (Dmn) calculated across represented Köppen-Geiger climate regions for trees encouraged and discouraged by respondents.

			Richness count (S)		**Menhinick's richness index (D_{mn})**	
Köppen-Geiger region	**n**	**Description**	**Encouraged trees**	**Discouraged trees**	**Encouraged trees**	**Discouraged trees**
All Regions	975		144	120	5.279	4.414
Csb	91	Warm temperate climate with dry summer, Warm summer	42	28	5.250	3.528
Cfa	352	Warm temperate climate, fully humid, Hot summer	70	57	4.325	3.508
Bsk	83	Cold steppe climate	32	24	3.881	2.910
Cfb	44	Warm temperate climate, fully humid, Warm summer	20	26	3.651	4.596
Dfa	176	Snow climate, fully humid, Hot summer	42	23	3.628	1.994
Dfb	167	Snow climate, fully humid, Warm summer	39	30	3.382	2.611
BWh	21	Hot desert climate	12	13	2.910	3.250
Csa	11	Warm temperate climate with dry summer, Hot summer	8	7	2.828	2.475
Dsc	6	Snow climate with dry summer, Cool summer and cold winter	6	2	2.449	0.894
Bwk	4	Cold desert climate	4	3	2.000	1.500
Dfc	5	Snow climate, fully humid, Cool summer and cold winter	4	4	2.000	2.000
Am	12	Equatorial monsoon	5	5	1.508	1.890
As	1	Equatorial savannah with dry summer	1	1	1.000	1.000
BSh	2	Hot Steppe climate	1	2	0.707	1.414

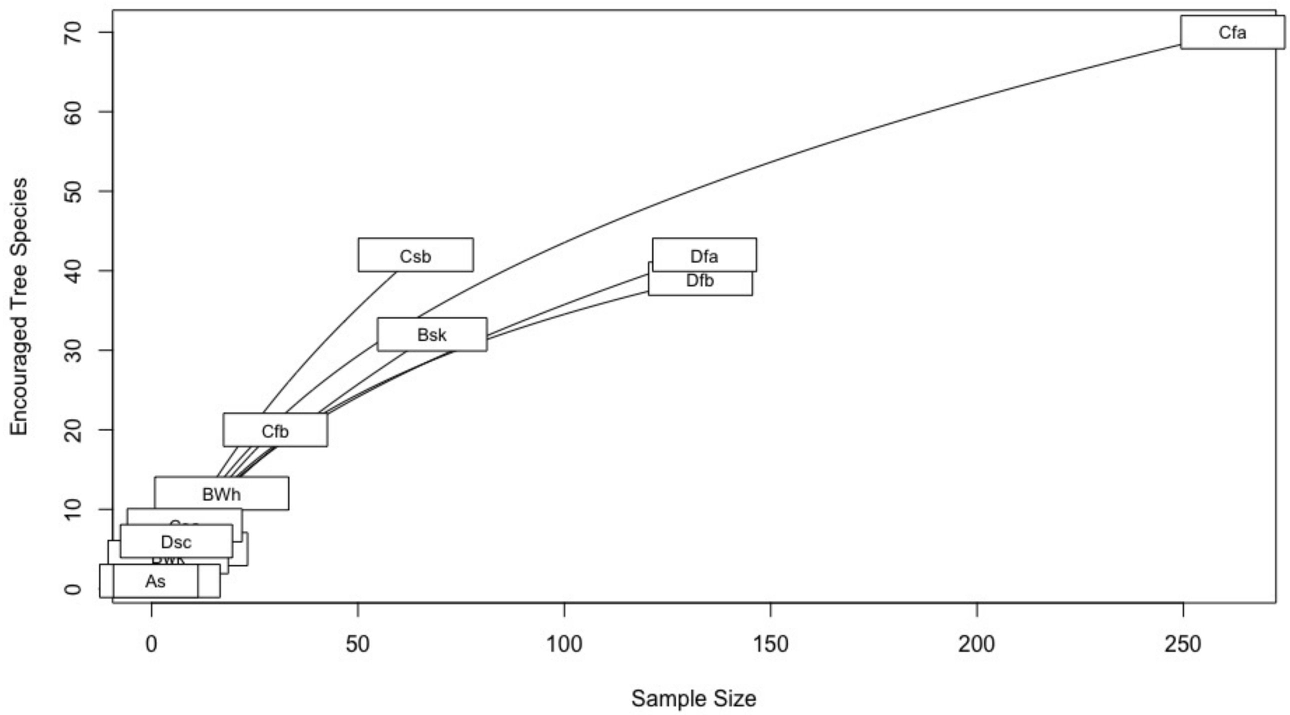

Figure 16: Rarefaction curves for the palettes of encouraged tree species identified for each climate region.

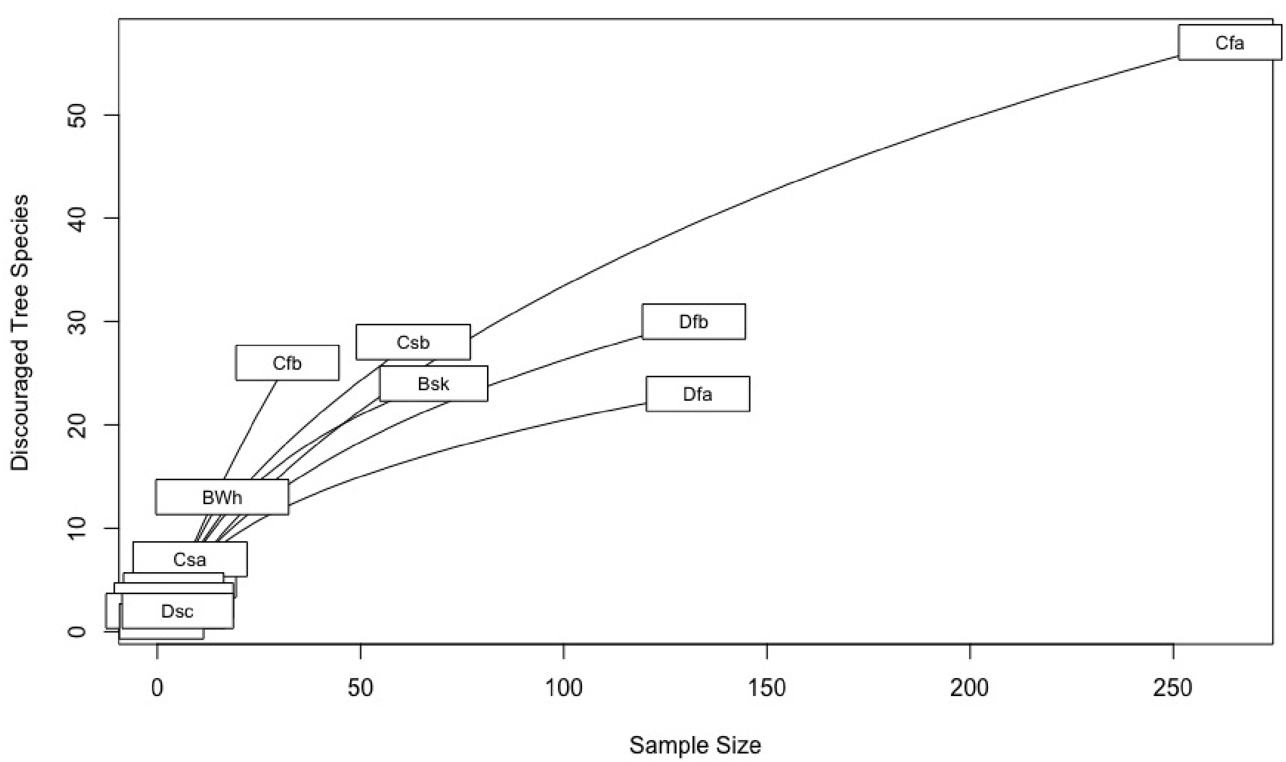

Figure 17: Rarefaction curves for the palettes of discouraged tree species identified for each climate region.

Calculations of the Shannon-Weiner index and diversity numbers, broken down by Köppen-Geiger climate region (Table 13), revealed that the palette of encouraged trees is most diverse in the Cfa region (warm temperate with humid hot summer) followed by Csb (warm temperate with dry warm summer) and Dfb (snow climate with humid warm summer). For discouraged trees, the most diverse region was Cfb (warm temperate with humid warm summer) followed by Csb and Cfa. For several regions, the sample sizes were too small to accurately compute these indices.

Table 13: Shannon-Weiner diversity metrics for encouraged and discouraged trees across Köppen-Geiger climate regions.

	Shannon-Weiner Index (H')		**Shannon-Weiner Diversity Numbers (eH')**	
Climate region	**Encouraged trees**	**Discouraged trees**	**Encouraged trees**	**Discouraged trees**
All Regions	4.14	3.536	62.92	34.33
Cfa	3.74	2.887	42.15	17.93
Csb	3.60	2.983	36.53	19.75
Dfb	3.24	2.639	25.53	14.00
Dfa	3.22	2.459	25.05	11.70
Bsk	3.01	2.862	20.20	17.49
Cfb	2.76	3.189	15.84	24.28
BWh	2.34	2.513	10.42	12.34
Csa	2.08	1.906	8.00	6.73
Dsc	1.79	0.673	6.00	1.96
Bwk	1.39	1.040	4.00	2.83
Dfc	1.39	1.386	4.00	4.00
Am	1.16	1.550	3.19	4.71
As	0.00	0.000	1.00	1.00
BSh	0.00	0.693	1.00	2.00

Next, I computed Bray-Curtis dissimilarity tests to describe how much overlap exists in the identity and frequency of species recommended by each region. In the matrix of distances between each pairing of regions (Table 14, Table 15), small values indicate low dissimilarity (or high similarity), while values approaching 1 indicate high dissimilarity (or low similarity). I performed these tests for “All regions” and the six climate regions with the largest sample sizes. Of these six, BWh (hot desert climate) has the smallest sample size, with only 21 respondents. The palettes of encouraged and discouraged trees for the BWh climate zone are overall the most dissimilar to the other climate regions. The palettes of encouraged (Table 14) and discouraged (Table 15) trees follow similar patterns of overlaps and dissimilarities between climate regions. For example, when comparing Dfa (Snow climate, fully humid, hot summer) and Dfb (Snow climate, fully humid, warm summer), the palettes of encouraged trees are very similar and the palettes of discouraged trees are also very similar. Meanwhile, the snow climate of Dfb is consistently dissimilar to the hot desert climate of BWh for both encouraged and discouraged tree palettes.

Table 14: Bray-Curtis dissimilarity matrix for encouraged trees by climate region.

	All Regions	Cfa	Dfb	Dfa	Cfb	Bsk	BWh	Csb
All Regions	0.000	0.479	0.697	0.695	0.922	0.833	0.955	0.842
Cfa (Warm temperate, humid, hot summer)	0.479	0.000	0.575	0.490	0.911	0.733	0.978	0.828
Dfb (Snow, humid, warm summer)	0.697	0.575	0.000	0.401	0.865	0.572	0.987	0.777
Dfa (Snow, humid, hot summer)	0.695	0.490	0.401	0.000	0.890	0.564	0.987	0.798
Cfb (Warm temperate, humid, warm summer)	0.922	0.911	0.865	0.890	0.000	0.857	0.957	0.638
Bsk (Cold steppe climate)	0.833	0.733	0.572	0.564	0.857	0.000	0.906	0.712
BWh (Hot desert climate)	0.955	0.978	0.987	0.987	0.957	0.906	0.000	0.877
Csb (Warm temperate, dry, warm summer)	0.842	0.828	0.777	0.798	0.638	0.712	0.877	0.000

Most similar	0.0 to 0.55	0.56 to 0.65	0.66 to 0.75	0.76 to 0.85	0.86 to 0.95	0.95 to 1.0	Least similar

Table 15: Bray-Curtis dissimilarity matrix for discouraged trees by climate region.

	All Regions	Cfa	Dfb	Dfa	Cfb	Bsk	BWh	Csb
All Regions	0.000	0.474	0.697	0.695	0.917	0.831	0.958	0.843
Cfa (Warm temperate, humid, hot summer)	0.474	0.000	0.646	0.526	0.905	0.831	0.979	0.829
Dfb (Snow, humid, warm summer)	0.697	0.646	0.000	0.464	0.829	0.610	0.959	0.764
Dfa (Snow, humid, hot summer)	0.695	0.526	0.464	0.000	0.867	0.622	0.946	0.776
Cfb (Warm temperate, humid, warm summer)	0.917	0.905	0.829	0.867	0.000	0.820	0.958	0.747
Bsk (Cold steppe climate)	0.831	0.831	0.610	0.622	0.820	0.000	0.929	0.710
BWh (Hot desert climate)	0.958	0.979	0.959	0.946	0.958	0.929	0.000	0.949
Csb (Warm temperate, dry, warm summer)	0.843	0.829	0.764	0.776	0.747	0.710	0.949	0.000

Most similar	0.0 to 0.55	0.56 to 0.65	0.66 to 0.75	0.76 to 0.85	0.86 to 0.95	0.95 to 1.0	Least similar

To visually represent the Bray-Curtis dissimilarity distances between the encouraged tree palettes for each climate region, I computed a Non-Metric Multidimensional Scaling (NMDS) plot (Figure 18 & Figure 19). The spacing between the climate regions represents how close or far apart (similar or dissimilar) their species recommendations are. The species recommendations are placed in proximity to the appropriate climate(s). For the first NMDS plot (Figure 18), I included all climate regions surveyed, even those with low sample sizes. For the second NMDS plot (Figure 19), I zoomed in to the congested center of the entire plot, where we see that six of the climate regions presented in matrices above are clustered yet are still dissimilar.

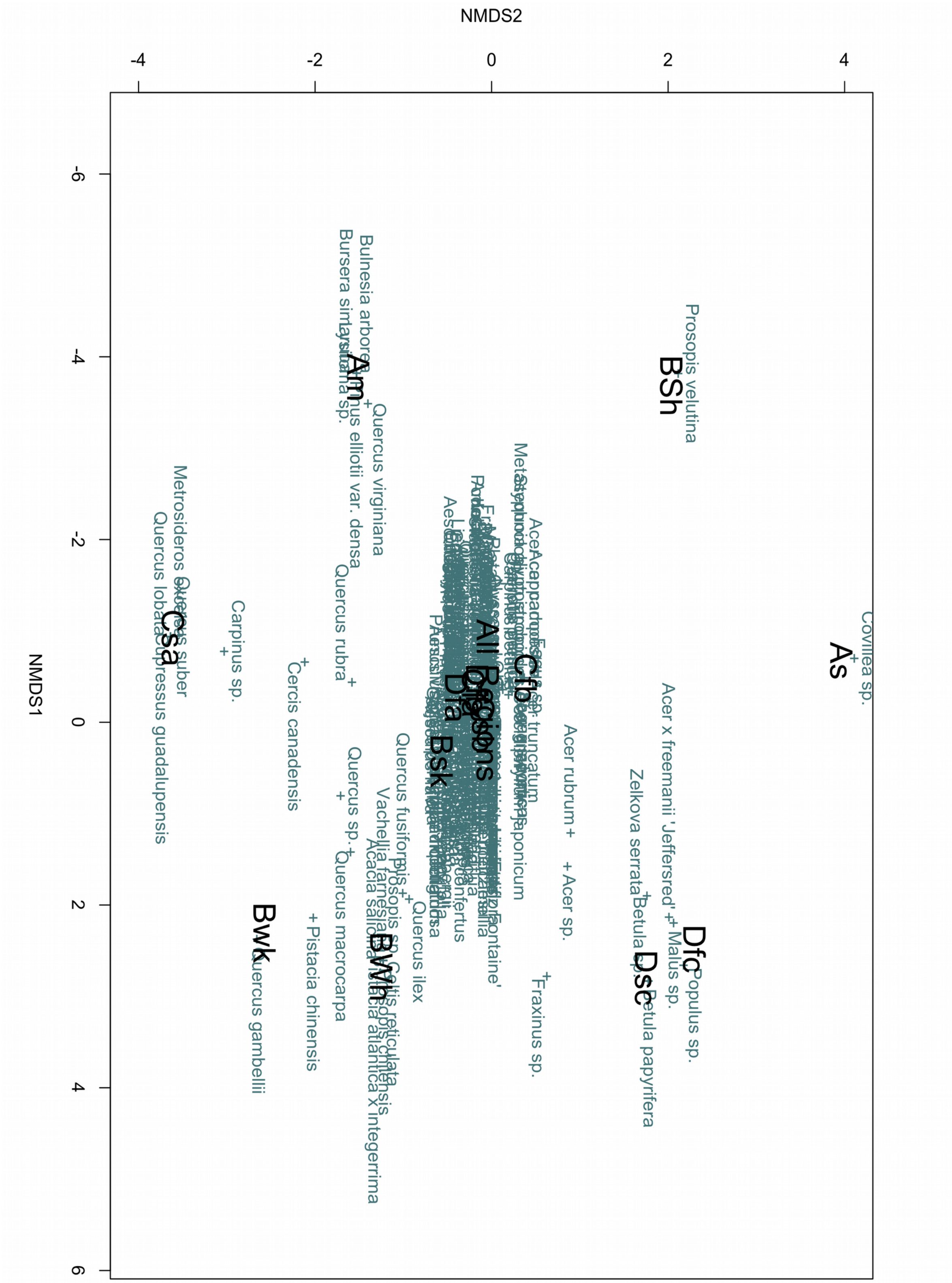

Figure 18: An NMDS plot showing the distance between encouraged tree palettes across all surveyed Köppen-Geiger climate regions.

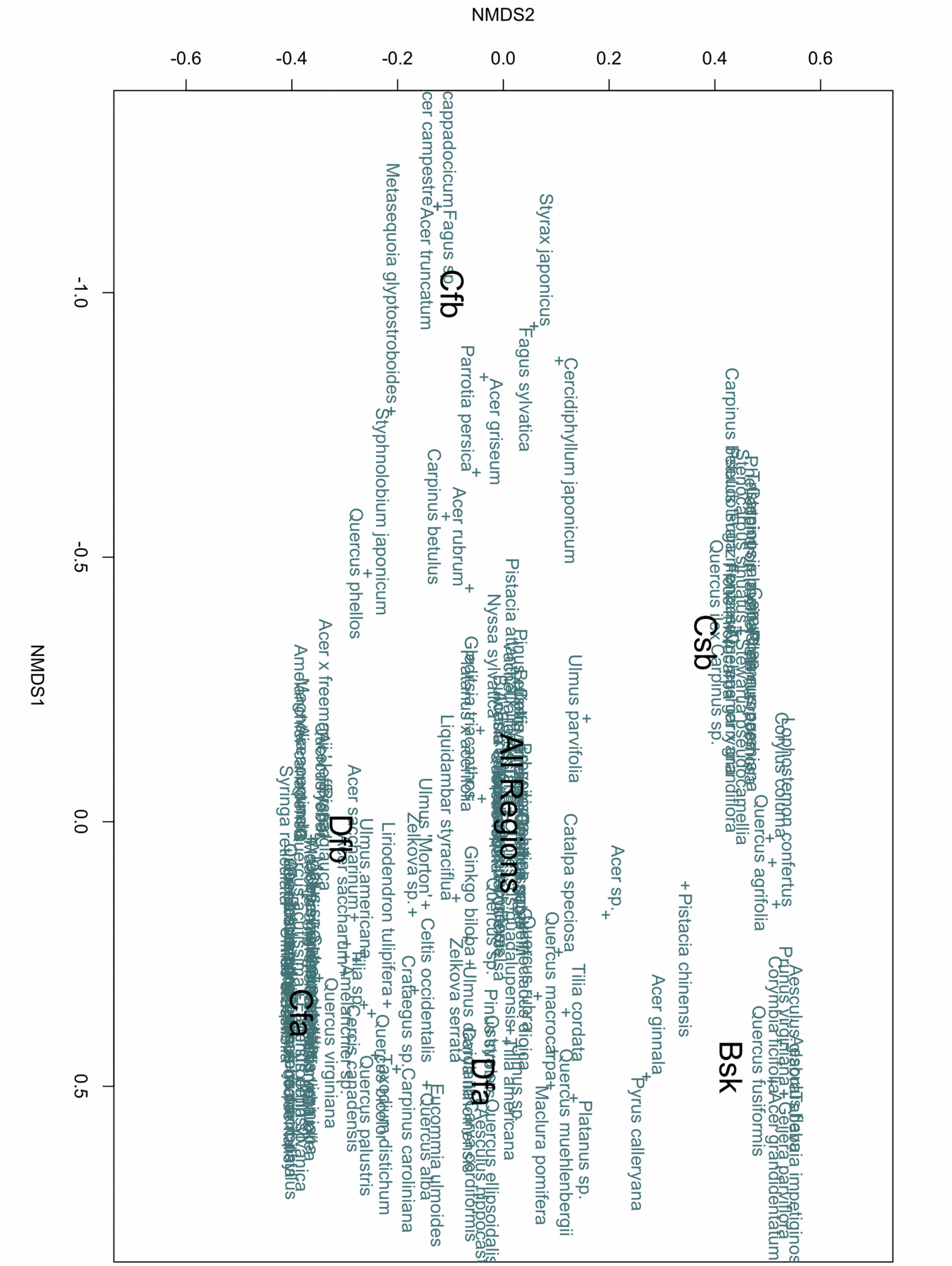

Figure 19: A re-calculated, zoomed-in NMDS plot for the encouraged tree palettes of the 6 similar Köppen-Geiger climate regions with larger sample sizes (Bsk, Cfa, Cfb, Csb, Dfa, and Dfb, plus All Regions).

4.2.4 Tree palettes across climate regions: Discussion

Since tree species are adapted to particular temperature and moisture regimes, it seems to be a reasonable hypothesis that palettes of urban tree species would vary across climate regions. Survey data revealed that respondents' species recommendations (both encouraged and discouraged trees) varied significantly across climate region. Looking at the NMDS plot (Figure 18), it appears that the variation for encouraged tree species is driven by the eight climate zones with very low sample sizes: Am (equatorial monsoon, n=12), As (equatorial savannah with dry summer, n=1), BSh (hot steppe climate, n=2), Bwk (cold desert climate, n=4), BWh (hot desert climate, n=21), Csa (warm temperate climate with dry summer, hot summer, n=11), Dfc (snow climate, fully humid, cool summer and cold winter, n=5), and Dsc (snow climate with dry summer, cool summer and cold winter, n=6). Though there were small sample sizes for these climate zones, these were also the more extremely hot, dry, or cold climates and tree recommendations for these climates were more unique. The divergence of species selections for these extreme climates from the overall pool of species supports the simple hypothesis that urban tree species vary across climate regions.

However, for the Köppen climate regions with a greater sample size, we can see that the encouraged tree species choices are relatively similar and tightly clustered together (Figure 18) although they still differ (Figure 19), (Table 14). These regions with relatively similar tree palettes are: Bsk (cold steppe climate, n=83), Cfa (warm temperate climate, fully humid, hot summer, n=352), Cfb (warm temperate climate, fully humid, warm summer, n=44), Csb (warm temperate climate with dry summer, warm summer, n=91), Dfa (snow climate, fully humid, hot summer, n=176), Dfb (snow climate, fully humid, warm summer, n=167), and the grouping of all regions combined. There are likely larger sample sizes for these six regions because these regions compose the majority of the land area in the USA and southern Canada (Figure 15). Therefore, the pattern of these six regions sharing a majority of their tree palettes is a result with continental-scale implications.

Although the native forest and vegetation types in these six regions are widely different (shrubby steppe, southeastern mixed evergreen forest, eastern deciduous forest, coniferous forest, etc.) the relatively large overlap between their urban tree palettes indicates that the process of biotic homogenization is underway in North American urban areas. Biotic homogenization is “the process by which the genetic, taxonomic, or functional similarities of regional biotas increase over time” in many cases involving the establishment of exotic species leading to an increase in local or alpha diversity, with a simultaneous decrease in beta diversity across regional gradients (Olden & Rooney, 2006). When humans introduce exotic (sometimes invasive) plants into urban landscapes, these same choices are often replicated in other cities and in other regions, overall reducing regional distinctiveness. Broad networks of nursery supply companies aid in spreading these patterns. The homogenization of urban plant species across cities is in large part due to the environmental characteristics cities share, from spatial fragmentation to frequent disturbance to the heat island effect (Williams et al., 2009); since only a few species may survive tough urban conditions, the same palette of trees is planted over and over.

Among the six similar regions (Bsk, Cfa, Cfb, Csb, Dfa, and Dfb) the Bray-Curtis dissimilarities are overall fairly low, although Cfb (warm temperate climate, fully humid, warm summer) is more dissimilar to several other regions (Table 14). Overall, the similarity in palettes across these widely different climate regions indicates that urban tree species choices are linked to the pattern of biotic homogenization.

4.3 Barriers Limiting Street Tree Palettes: Results & Discussion

Interviews in the case study city of Philadelphia revealed numerous barriers that inhibit the selection of street tree species that would increase diversity and ecosystem function. Here I discuss barriers including funding, nursery availability, planting site condition, inventory lists and data, public perception, and the lack of research and knowledge transfer. Many interviewees expressed awareness and understanding of species diversity issues, and many expressed the desire to expand the palette of species available for planting. However, overarching barriers that shape and restrict species selection decisions were repeatedly mentioned by interviewees. Though some conceptualize these issues as selection criteria, I view these issues as “gates” that must be unlocked to allow for the full consideration of selection criteria. When these issues are resolved, the full, species selections decisions become less constricted and a fuller palette of species choices becomes available.

4.3.1 Funding

One of the most important barriers facing interviewees in Philadelphia was the issue of funding for tree planting and maintenance. Financial constraints were linked to many other barriers, including the capacity of organizations to maintain planted trees through establishment and beyond, procure contract-growing arrangements with nurseries, proactively manage for future urban forest diversity, and mitigate stressors at planting sites. When asked what barriers face street trees in Philadelphia, many respondents quickly identified funding as an issue, for example one respondent said, “Can I jump out and say funding? Because money gets things done. If we had a greater share of the budget allocated for trees, we could get a lot done” (Lori Hayes, Director of Urban Forestry, Philadelphia Parks and Recreation). With greater funding, more trees could be planted every year in Philadelphia, since the demand exists from residents for trees. The TreePhilly program deals primarily with trees in residential yards as opposed to street trees, supplying Philadelphia residents with free trees: “we had a long waiting list of people who want trees to be planted, and that budget is a separate line item, but is also lower than we need it to be. I mean, we currently have about 800 people, more than 800 people, on the waiting list" (Erica Smith Fichman, TreePhilly Program Manager, Philadelphia Parks & Recreation). Lack of funding concretely inhibits the number of trees that can be planted and properly maintained.

Instability of funding from year to year impacts the ability of professionals to plan ahead and this is a significant barrier when considering issues of urban forest diversity. One interviewee referenced work (Ries, Hauer, & Peterson, 2016) on the benefits of proactive management, linking Philadelphia's reactive urban forest management to lack of funding stability:

> *...this idea of proactive vs. reactive management. So reactive management is all that response to just emergencies and storms, the latest pest challenge. And it's the way that Philadelphia's had to operate cause we didn't have an inventory and didn't have the money. Versus proactive management which is things like you have your inspection cycle. But proactive management is also, 'let's think ahead about our species mix, let's think ahead about everything,' from these issues of are we using too many little trees? So we're not going to have the same nice canopy lined streets of tall shade trees. Are we using too little genetically diverse stock, but also what can we do in advance with the nurseries? I mean, that's a lot of forward thinking. And when you think about the way that city budgets work, with mayoral time limits, and the unpredictability in some ways of city budgets, and of the grants that they might get from the outside.*
>
> *Anonymous Researcher*

In Philadelphia, efforts are currently underway to complete a comprehensive inventory of street trees across the city for perhaps the first time, following a digital effort to map tree stems and empty tree pits in recent years. Additionally, a strategic plan for urban forestry will reportedly be undertaken in Philadelphia in the near future. Tree inventories and strategic plans are useful tools when setting urban forestry diversity goals and shaping the palette of trees for planting in future years. Despite lacking the funding to create these tools up until this point, interviewees pointed out that professionals in Philadelphia have responded to scarcity by creating innovative programs and partnerships to accomplish their goals:

> *And in some ways actually I think that the lack of money in Philadelphia makes for a lot of innovation… I mean, the program that Erica Smith Fichman runs for yard trees, really innovative stuff that in some ways happens because you are so resource limited, you HAVE to work with your partners.*
>
> *Anonymous Researcher*

Funding issues have also been partially mitigated in Philadelphia by using volunteer planting and maintenance programs, such as the PHS Tree Tenders program, which distributes free street trees to trained community-based volunteer groups who plant and monitor the trees.

One arena affected by the uncertainty of funding from year to year is the type of purchasing power that cities have when dealing with nurseries. Cities with stable predictions of their future budget for tree planting are able to engage in contract growing and specify the quantity, species, size, pruning, and root training requirements for the trees they will purchase multiple years in advance.

> *So, contract growing… would be awesome. New York City does it, and that is because they have a consistent funding source, and they can predict several years out how much money they will have, and we do not have that. So I think we would love to do that, just adore being able to do that, and say, 'here is exactly what they should look like.'… We wouldn't be able to guarantee a grower the money.*
>
> *Erica Smith Fichman, TreePhilly Program Manager,*
> *Philadelphia Parks & Recreation*

Since trees inherently take longer to grow (than for example herbaceous flowers), cycles of planning must occur three to five years in advance of the intended planting date. If cities hope to have specific input on the supply that is available to them, they must engage directly with nurseries in this planning process. However, financial restrictions and funding uncertainties limit the ability of cities to take on this proactive management approach.

4.3.2 Nursery availability

Nursery availability is frequently cited as a barrier in the process of tree species selection and urban tree planting. Sydnor et al. (2010, p. 47) described the “continuing disparity between what urban foresters say they request for community plantings and the stock availability from nurseries.” Their study in Ohio, USA identified species that were supplied in excess of demand and species that were lacking in availability. This issue often appears to be an infinite and unsolvable loop of supply and demand; should the suppliers or purchasers be responsible for driving change in tree availability? Tree procurers express frustration when the trees they request are unavailable and they must substitute an undesired tree, while nursery growers insist they indeed respond to demand and will grow trees their clients desire. The slow growth cycle of trees may create lags in response times to demands, yet this does not adequately explain the disparity between requested trees and nursery availability.

Professionals in Philadelphia expressed similar issues to this common narrative. When seeking to diversify their tree selection choices, professionals are often met by limitations at the nursery and forced to plant more typical species. Professionals at the University of Pennsylvania encountered this issue: “you go back to the nurseries, you may say ‘we love all these things,’ and they say 'Sorry, not available, what's your substitute?' And so, then what? Then you're like ‘ok, we'll plant Honey Locust, Zelkovas, Callery Pears…’ no, just kidding! Just kidding, tape recorder!” (University of Pennsylvania Landscape Architect). This humorous example illustrates the extreme possible outcome of lack of diverse nursery options, though in reality this group would not plant the denigrated Callery Pear (*Pyrus calleriana*). Over planted species may become increasingly over planted as a result of nursery trends and the influence of available supply. In Philadelphia, many large tree planting organizations such as Philadelphia Parks and Recreation (PPR), the Pennsylvania Horticultural Society (PHS), and the non-profit UC Green source their trees from Schichtel's Nursery in upstate New York. Though PHS and UC

Green coordinate many aspects of tree planting in various neighborhoods, the City Arborist for each district makes all tree species selections after visiting the planting site. Though these organizations communicate with each other on planting priorities, all species selection decisions are ultimately bound to the rule of nursery availability. Schichtel's Nursery carries a substantial supply of Japanese Tree Lilac (*Syringa reticulata* 'Ivory Silk') and this availability affects planting choices:

> *[T]hey've been selecting a lot of Japanese Tree lilac, for the tree tender plantings at least, so in the last 5 years, that's generally the number one species we are planting. And granted, it does super well here, it does very well, and our nursery, you know some of it's dependent on what our nursery has. So, [we] sometimes have to get substitutions for what the city arborist originally requested. We have to substitute that.*
>
> *Dana Dentice, Urban Forestry Program Manager,*
> *The Pennsylvania Horticultural Society*

Tree availability becomes even more limited when considering the cultural treatments of trees in nurseries. Often, street tree planting projects require a particular caliper (size of the tree sapling at its base) and pruning (to begin lifting branches off the streetscape). Additionally, healthy root systems are key, and require careful practices in the nursery to maintain a root flare above the soil level and avoid girdling roots. For large street tree plantings in Philadelphia, trees are ordered bare-root from the nursery rather than balled-and-burlapped, which can occasionally limit the availability of species.

For nurseries, there are inherent business risks involved in choosing to plant less common, more diverse species selections, especially when the popularity and performance of those trees are unproven. Contract growing provides a guarantee to nurseries that their trees will be purchased, and thus reduces the risk they experience, passing more financial risk to the client. When contract growing is impossible for cities to take on, however, there are still opportunities for direct communication and expression of planting preferences and goals to the nursery. Schictels nursery spoke to their approach on this issue:

> *You know, there is some risk that something like that bears to growers such as us. I guess a little bit of it depends upon the customer who is making those inquiries. If it's a customer that we have worked with successfully for some time, and I don't know what 'some' means, but you know we've got a good working relationship, then the things that they inquire*

about, and maybe ask for, and it's in a reasonable quantity, you know if it's a quantity of 50 trees a year, that's not too high of a risk. If someone's asking for 500 trees of one kind in a year, you know that might be a little bit more of a risk, so we have to figure out how we handle a situation like that, to make sure that both us and the customer would then share that risk in some way. But we certainly do listen to customers, you know, that we've worked with closely for some extended period of time, trying to grow the things that they would like to have. You know, it becomes a win-win situation both for us and for them. For them to help diversify their street tree populations, and for us to have a sale for something that we're growing. So that's a win-win for everyone. So we work with people, and then if we hear several communities that are asking for the same thing, than we plant out 50 or 100 or 200 of something, then we will feel the risk is a lot less to us, because there's more than one person that's asking for the same thing, and the chances are we're going to sell this new kind of tree in a greater quantity is pretty high.

Jim Kisker, Sales Manager, Schichtel's Nursery, Inc.

In regards to diversification of the urban forest, both nursery suppliers and tree purchasers must work together to adopt good new species and demote over planted or problematic species. Nurseries can play a role by not only responding to demand for individual trees, but by educating consumers on issues of diversity and highlighting diverse selections. Commonly the nursery industry relies on cultivars for ease of propagation and marketing.

I think it's just one or two types, varieties of London Plane that get planted now. So like when I planted trees in my yard, right outside Philadelphia, we purposely went to one of these native plant nurseries and bought the straight species. But if you go to a lot of nurseries, they'll just sell you the cultivars.

Anonymous Researcher

Nurseries can further support genetic diversity by de-emphasizing the production of cultivars when possible and educating consumers to strengthen the already increasing market for straight species trees. Schichtel's Nursery estimates that roughly two-thirds of their sales are cultivars, and notes that:

there certainly has been an increase in requests for species only. So people that are requesting Acer rubrum and not its cultivars, Acer saccharum and not its cultivars, Tilia americana and not its cultivars, those types of trees were almost always sold as cultivars, and now we're seeing those types of trees being requested for the species only.

Jim Kisker, Sales Manager, Schichtel's Nursery, Inc.

When growing straight species, transparency in seed provenance would also be an excellent step for the nursery industry to take in support of genetic diversity.

One final note is that nursery availability is limited by the growing region of the nursery. In the case of Schichtel's Nursery, the nursery growing region in upstate New York is much colder than the Philadelphia growing region. Jim Kisker, Sales Manager, Schichtel’s Nursery, Inc., noted that this provides an advantage for prompt spring planting, allowing the nursery to send dormant trees to Phildelphia when it is already warm enough to plant. For fall plantings, trees at the nursery go dormant earlier in the season, allowing them to be shipped before the weather is unpleasantly cold for planting. Though the nursery’s cold climate provides these advantages, there are also disadvantages. In particular, the cold nursery climate means that Philadelphia cannot procure southern species that may be advantageous to plant in the face of climate change as well as the urban heat island effect. To mitigate this issue, trees may be sourced from more than one nursery. Though the loop of supply and demand seems interminable, nurseries and tree purchasers must work together to drive change in the industry and increase the availability of diverse tree selections.

4.3.3 Planting site conditions

While we often view stressful urban site conditions as a given condition for street tree plantings, in fact many technological developments are available to remediate these sites (*City of Philadelphia Green Streets Design Manual*, 2014; Ely, 2009). Poor site conditions act as a barrier to accessing a complete palette of potential tree diversity and functionality, since relatively few trees survive and thrive under this extreme adversity. The underground structure of a planting site often receives the least attention, yet may be the most important component to improve. As discussed at length in the introduction, urban trees often experience highly compacted, poorly draining soils in tree pits with extremely limited rooting volume. In Philadelphia, the city's specifications for street tree pits are shaped by typical sidewalk widths, ADA accessibility, utility locations, and other nearby features such as doors, driveways, and intersections (*Philadelphia Complete Streets Design Handbook*, 2014). The process of creating new street tree planting sites is complex, and barriers to tree planting caused by existing physical infrastructure are difficult to mitigate on a routine basis:

> *We have a minimum size tree pit, 3 x 3, which is only going to take a minimum size tree. The bigger the pit, the bigger the tree, depends on the surroundings. We are very much about the right tree in the right site for the right reason. We hate to say no, because we love to plant trees, unfortunately you are in a city setting, the urban environment, the urban landscape, it's in close proximity to a lot of things that's trees just don't work well with. It's very unfortunate, I wish we could adopt some principles and some infrastructure that other cities have adopted where they have further set backs for buildings, wider planting strips, less utility interference, things like that. We don't have that in the city of Philadelphia.*
>
> *David Lewis Cupps, District Arborist Supervisor for the Street Tree Management Division of Philadelphia Parks and Recreation*

Poor planting site conditions may seem to be an entrenched and intractable barrier given the magnitude of the problem. However, early adoption of modern techniques to renovate, protect, and maintain planting sites would create progress and change. These techniques include larger pits and continuous planting trenches to increase rooting volume as well as tree cells and structural soils to decrease compaction. Renovation of below-ground utilities is sometimes needed to mitigate gas and steam leaks (which can be fatal to trees). Well-draining tree pit systems can also be constructed to feed into storm drains, acting as part of a stormwater mitigation system. New techniques are always developing, and studies to compare the tree survival in various sizes and types of tree pits and soils are needed. In Philadelphia, many professionals are aware of the benefits of these techniques and utilize them when possible:

> *… if we start investing more in the planting sites, we can do so much better. And I can't claim to be in any better shape than a lot of people in that respect. When we're doing new projects now, big new construction, we'll do things like continuous trenches, structural soil, or even use some sort of anti-compaction cages … You know those things all cost money*

> *but it's an investment, an under-ground investment. I think that that would be great, if where we can afford to, if we stop just taking out a sidewalk panel and digging a hole in whatever's there and plopping a tree in and backfilling with whatever was there. Because that, other than the toughest species, the other species at the best they kind of do mediocre. So that would be starting from the roots up, right? That would be my first thing.*
>
> *Associate Director of Grounds Operations, Temple University*

Choosing to renovate a tree pit is a costly proactive measure to increase urban forest survival, functional performance, and diversity. By improving site conditions, we can unlock a wider variety of tree species for urban use. This is highly related to our survey finding that professionals prioritize tree tolerance of urban stressors above other selection criteria; trees must first survive the rigors of the urban environment. However, if by improving below-ground site conditions we can give every street tree the best chance, more tree species will fulfill the all-important requirement that “it survives.” Improving planting sites should be included in proactive urban forestry management, decreasing the future reactive maintenance and removal of stressed trees. The high up-front costs of labor and materials may deter many managers from choosing to make planting site improvements. Therefore, the barrier of funding is a prerequisite obstacle to tackle before overcoming the barrier of planting site conditions.

4.3.4 Inventory lists and data

Street tree inventories help determine the current species composition of urban forest, and thus to adjust planting ratios for the greatest possible diversification. Inventories are also useful for scheduling maintenance, monitoring tree conditions, evaluating age diversity, and monitoring for pests and diseases (Nielsen, Östberg, & Delshammar, 2014). Inventories also contribute information useful in tree mortality research. However it is difficult to parse out the cause of death for street trees since there are often many possible contributing factors or reasons for the death of an urban tree. Chloe Cerwinka, Landscape Planner for the University of Pennsylvania stated, “It's hard to tell because there's so many variables that we just don't know about. It's like when a tree doesn't make it, did it not make it because the contractor didn't actually water that tree even though they said they did?” Urban Forestry Assistant Trish Kemper added, “Or was the root system poor, or was it deep in the root ball? I mean, because we're not able to dissect every tree that dies, you know. Yeah, so, a lot of different variables.” Mortality data is useful when choosing which trees to plant in tough environments because, ideally, professionals could use this information to choose tree species with empirically lower mortality rates and longer life expectancies in their cities. Though cause of death may be unrelated to the identity of the species, especially during the tree’s establishment phase (Roman et al., 2015), an inventory with species information (and perhaps even site and maintenance information) aids in the evaluation of tree species survival rates.

Many organizations in Philadelphia have some version of a tree inventory for the geographic area in which they operate. The University of Pennsylvania uses a BG-Base and BG-Map system to inventory trees on its campus, and has a dedicated technician (Urban Forestry Assistant Trish Kemper, who also works with the Morris Arboretum Urban Forestry Consultants) to maintain the database as trees are planted and removed. This data contributes to the online public tool “Penn Plant Explorer,” through which students and visitors to campus may explore the campus flora. Temple University has inventoried portions of its campus through the help of student projects, though there is no ongoing maintenance of a database, mostly due to staffing and funding restrictions. Despite this limitation, the grounds manager reports successful monitoring, hazard mitigation, and diversification efforts:

> *No one's ever wanted to fund a comprehensive data base of every tree on campus. It's a lot of money. And I've never been able to get any traction on that. But then, you know, also it's like, well how do you get traction on something like that? You have to show how that's going to save us money in the long run, improve our tree management, and save us money. And frankly, from the tree surveys that we had, you know what they vetted? Is that we're already doing a good job. That's what came out of it, and I knew that already, like when they said, 'Oh yeah, your tree species by family, and by genus, is like, everything's where it's...' and I'm like 'Yeah!' Well I know this campus, I know what's out there, I know I don't*

> *want to plant any more pea family trees if I can avoid it cause we're heavy on that. I know what we're heavy on, I know what we're light on… I know that we want diversity of species and then the thing that is less talked about, is that all-important diversity of age.*
>
> *Associate Director of Grounds Operations, Temple University*

While monitoring the species diversity and tree maintenance on the scale of a university campus may plausibly be successful without an updated tree inventory, on the scale of an entire city it is impossible for arborists to monitor all tree issues or investigate larger patterns of diversity without database tools.

The City of Philadelphia is currently completing a street tree inventory, for the first time since 1912. In 2016, Philadelphia Parks and Recreation (PPR) mapped the locations of all street trees using the virtual tool CycloMedia, resulting in an inventory of 112,000 dead and alive trees (Carolan, 2016). This initial data is currently available to the public. To complete the initial inventory, teams of interns are visiting the mapped trees to ground-truth, identify the species, and measure the diameter at breast height (DBH). This inventory will be housed in an ArcGIS database to aid the management of Philadelphia's street trees:

> *[D]own the road, we're going to be able to pull this data right from the computer. How many trees got planted of that species? Not just in Excel spreadsheets, you're going to be able to filter through a system that's doing it all, planting, pruning, removal. All on a map. You're going to be able to pull up the ZIP Code and see, like, cancel out different points, and see how many species you have in that ZIP Code? How are we doing our job at not monoculturing? How are we doing our job when it comes to the EPA and the water department and all asking us about storm water mitigation? How are we doing our job when it comes to increasing our tree canopy? Which is paramount for our department. We are trying to go from 20% to 30% tree canopy.*
>
> *David Lewis Cupps, District Arborist Supervisor for the Street Tree Management Division of Philadelphia Parks and Recreation*

In addition to the official PPR inventory, a crowd-sourced inventory, "PhillyTreeMap" was developed starting in 2010 to allow organizations and individual residents to contribute to a map of Philadelphia's trees (Azavea, 2019). With nearly 24,000 trees mapped, this map is currently less complete than the CycloMedia supported inventory. Another crowd-sourced effort is the Pennsylvania

Horticultural Society’s (PHS) Urban Forest Cloud, which enables citizen scientist “Tree Checkers” to visit, maintain, and record data on trees planted by PHS Tree Tender volunteer groups (Pennsylvania Horticultural Society, 2019). This program provides post-planting follow-up on young trees: “we check for mortality status, crown… is ranked from 1 to 4, one being full, and four almost dead, at twenty five percent intervals of coverage. DBH, mulching, weed stress, soil. So this is where we get that information about mortality and why things die. And then obviously there's homeowner engagement, like if something was wrong. And then there's the pruning” (UC Green Program Coordinator). With the goal of increasing resident engagement with their neighborhood trees and increasing tree survival, the Tree Checkers project also has the potential to accumulate useful data on which indicators of failure (from poor watering to weeds) affect tree species mortality. Keeping complete, updated records and maps of trees planted by volunteers in Philadelphia will also aid in the planning of future plantings.

Tree inventories and keeping these databases updated are a major financial commitment, requiring both significant labor and technological resources. Training volunteers to perform some of this data collection is one way to reduce financial barriers to maintaining inventories. “When you talk about challenges, this lack of data is a major challenge, they're finally catching up, I mean through no fault of any particular staff person, it's just budget problems” (anonymous researcher). On city-wide scales, overcoming the barrier of maintaining a tree inventory is an important step towards making strategic planting choices. By combining a tree inventory with socio-economic data, cities can identify areas of greatest need for planting efforts and address green space inequity. A maintained inventory can also aid professionals to proactively plan and make educated species recommendations based on current diversity levels, rather than making the same planting decisions over and over based on anecdotal impressions of what species are over planted.

4.3.5 Public perception

Members of the public in urban areas often influence the selection of urban tree species. In some cases, public opinions act as a barrier to goals of urban forest diversity and function, for example when the public prefers trees that are familiar, small, and aesthetically pleasing, or when residents and developers prefer other land uses over planting trees. Through both complaints and requests, residents notify tree planting professionals of their preferences, which may lead professionals to alter their planting decisions. In return, professionals attempt to influence the opinions that residents hold of trees, educating the public on tree benefits and care.

> *But what people like, inevitably, they want a small flowering tree. Except for the people that think about it or, sometime when you explain to them the value of a large tree is so much greater. For health benefits, for economics for them, for their property, for sequestering stormwater, all these reasons, birds. When you start getting into that with people, sometimes they'll bite.*
>
> *Mindy Maslin, Tree Tenders Project Manager,*
> *The Pennsylvania Horticultural Society*

This is an issue that is almost as circular as the nursery supply and demand loop, as professionals and residents negotiate tree planting preferences and decisions. In the end, residents hold the power to remove (or simply neglect) newly planted trees they do not like, and professionals must consider their opinions when planting trees. Many professionals are beginning to embrace the understanding that residents may not share their perception that trees are wonderful; in fact, residents may have extremely valid fears and feelings of discomfort in relation to trees. Trees can be dangerous to homes and humans, and cause expensive damage that many can not afford to prevent or repair. Their inconvenient disservices are numerous, especially to people who value clean and tidy aesthetics, have severe allergies, or prefer to avoid wildlife encounters.

Professionals described their anecdotal perceptions of public tree opinions in several ways. Many interviewed professionals in Philadelphia expressed understanding and sympathy for residents who have negative opinions of urban trees:

> *… sometimes, people have trees in their backyards, like the ones that are invasive, like the Paulownia, and the Tree of Heaven, primarily that get really big and just kind of disrupt things and overgrow and they can't afford to remove it. So, 'I'm having this tree issue already, I don't want another tree.'*
>
> *Dana Dentice, Urban Forestry Program Manager,*
> *The Pennsylvania Horticultural Society*

> *I get what people complain about. Not everybody's in the school of thought that you and I are in that we love trees. Some people are like, 'mmm well if I want a tree I will go to the park, I'll walk my dog in the park, and I'll come home and I don't need any trees around here.' It's hard to sell people in the inner city on trees. And then it's hard for some people and the inner city, they wants trees so bad that if you tell them, 'we can't because you're next to a stop sign' or 'we can't because you have your utilities, your steps, and we have to be 5 feet away from the apron of your driveway, you can't get a tree.' And they're sick over it.*
>
> *David Lewis Cupps, District Arborist Supervisor for the*
> *Street Tree Management Division of Philadelphia Parks and Recreation*

Some professionals understand that planting trees is inherently a decision that must be made with community members, rather than for community members. In order to be equitable, greening movements must have grass-roots energy and fully engage stakeholders. Prescriptive, top-down, charitable tree plantings cause conflict and ill will and should never be the mode of operation. Many professionals understand this in concept, but as tree lovers themselves, still find it difficult to put themselves in the shoes of a resident who doesn't want a large tree or a tree at all. All groups must work together to bridge these gaps of misunderstanding. Professionals can certainly attempt to respectfully educate residents, as long as they will also truly listen in return. Some interviewees identified a need for increased education of the public, while others reported that the public is already increasingly knowledgeable about the benefits of trees:

> *[W]hat I think we need is some sort of massive public education campaign just to increase people's awareness. You know, people are afraid. They see a tree fall down and they think,*

> *"Oh, I don't want one of those. It's going to fall on my car or on my house." The funny part of it is that the only way to, these trees are falling because of climate change and the only way to combat climate change economically is by planting more trees. So, we just have to do it right and do it with the right materials and the right way and right place and hopefully we won't have trees falling but there's nothing else we can do as citizens to stop the climate change that's causing all these problems.*
>
> *Mindy Maslin, Tree Tenders Project Manager,*
> *The Pennsylvania Horticultural Society*

> *[T]he average person's knowledge now is I think much more. Things like biodiversity, it's a word that people know. So you don't get the kind of questions that you used to, like people like 'oh, well why don't you do the whole treescape in that', or 'I like that tree, why don't you just do a double row all the way down,' like people don't even ask that anymore, I think they've absorbed enough that they're a little more savvy than that now. And that makes it easy to do the right thing, too, when you're not fighting.*
>
> *Associate Director of Grounds Operations, Temple University*

It is difficult for professionals to address goals of improving biodiversity and supporting ecosystem services (including climate change mitigation) when the public is more concerned about particular aesthetics in their neighborhoods or the risky hazards that trees may present. Education and outreach is one way to at least balance negative opinions of trees with information on the benefits of trees; however, knowledge of the benefits of trees can not be expected to relieve resident fears about the very real negative aspects of trees:

> *So when somebody has something in their mind, it's really, you can't convince them otherwise. Maybe you can plant a seed, you know and let them sort of sit on it maybe they will start reconsidering, but really in the moment they're not going to change their mind. I don't know I think there's just overall a big fear of the large trees, and the potential damage and liability they pose.*
>
> *Dana Dentice, Urban Forestry Program Manager,*
> *The Pennsylvania Horticultural Society*

In order to mitigate the disservices and liability that trees pose to the public, strategies beyond education are necessary. In particular, addressing interrelated barriers (discussed above) may improve public experiences with trees, making space for professionals and the public to work together on urban forestry goals of improved diversity and function. In Philadelphia, homeowners are financially responsible for the repair of any sidewalk defects in front of their home, even when caused by city-planted trees; this financial burden is a major disincentive for homeowners to plant street trees. Mitigating this financial barrier would improve public perception of tree planting. Furthermore, investing financially in the health and maintenance of trees (by renovating planting site conditions and proactively pruning) would reduce risks to residents.

4.3.6 Research, evaluation, and knowledge transfer

Especially in regards to urban forestry goals of increasing biodiversity and resilience, planting "new," under-utilized, or rare trees is an important tool. While no new tree should be planted at excessive ratios, adding new species to the palette of options allows for greater balance when professionals plan their planting lists and ratios. However, there is a lack of reliable information on these new species and cultivars, and professionals are less willing to risk planting such an unknown tree. The history of supposedly excellent introductions such as the Callery Pear (*Pyrus calleriana*) and its cultivars becoming invasive and exhibiting dangerously brittle branch structure with age teach a lesson of caution. Some of these characteristics are difficult to evaluate in advance of release; for example, *Pyrus calleriana* only began to invade in the USA after multiple cultivars were released, allowing fertile intraspecific hybridization (Culley & Hardiman, 2007). Though methods and indicators exist for predicting invasions of woody plants (Reichard & Hamilton, 1997), some uncertainty may continue to exist:

> *Well, things like their invasiveness, people don't always pr... I mean there are ways of kind of predicting if a tree, based on how it performs in its native habitat, might be turn out to be more weedy, so to speak, here. But whether that's really feasible to evaluate for every new thing coming out of nurseries, I don't know.*
>
> *Anonymous Researcher*

When a tree is planted, professionals want to be sure that it will be safe, it will perform well, it will not become invasive, and it will likely not succumb to pests and diseases. At Temple University, one interviewee has been experimenting with planting new Dutch elm disease resistant cultivars of American elm (*Ulmus americana*):

> *I wanted to start trying some of the new American elms on campus, so in front of that building over there, the streetscape up there is Valley Forge American elm, and other than a web worm caterpillar one year, they've been fine for you know the four years that they've been in.*
>
> *Associate Director of Grounds Operations, Temple University*

The Valley Forge American elm (*Ulmus americana* 'Valley Forge') was released by the U. S. National Arboretum in 1995. Though it has been available for 23 years and it appears on the Philadelphia Parks and Recreation approved street tree list (*Approved Street Trees*, 2017), the interviewee still approaches this "new" tree with caution. The same interviewee also described a willingness to take some risks and plants new trees as one strategy to diversify the species palette, despite experiencing social pressure to the contrary:

> *[T]hen there's new cultivars coming out all the time, new hybrids, and also just more experimentation. Some people thought I was crazy when I put the Yellowoods in the curb, I'm like I don't know, there doesn't seem to be a whole lot written about using them as a street tree but let's see what happens, and they were fine. So, I think that's part of it too is just trying things, you can't be afraid to fail.*
>
> *Associate Director of Grounds Operations, Temple University*

Trying new trees in the urban forest, and therefore increasing the diversity of the urban forest, is impeded by a lack of information on some of these trees, which increases risk. Nurseries and other institutions that release new species and cultivars should provide standardized information on the characteristics of the tree in multiple settings and climates, or partner with researchers to do so. This is yet another arena in which proactive rather than reactive management would greatly improve results; strategically planning long-term monitoring and evaluation of trees in multiple climates and releasing standardized, comparable information in order to compare trees will greatly reduce the risk of planting new trees and support urban forestry diversity goals.

The survey results show that despite the expertise of respondents, professionals often lack species-specific information on the ecosystem services that trees provide. For rare and unusual trees, the usually accessible information on tolerances of urban stressors may be unavailable. Furthermore, there is some evidence that when some groups have access to information on urban tree species, this knowledge is not adequately transferred to other professional groups involved in selecting tree species. Based on these findings, I make the following specific recommendations:

- Nurseries and other professional groups traditionally allied with urban forestry should increasingly collaborate with nearby public gardens to identify potential new tree urban tree species, trial those trees, and educate the public and professionals about those trees (Appendix 8).
- Researchers evaluating and developing new tree species and cultivars for the urban environment should engage nurseries and other professionals in their trials from the beginning, to increase the familiarity of the industry with the characteristics of excellent new trees.
- Nurseries should take an active role in evaluating trees and educating their clients on important characteristics of urban trees including genetic diversity. Conversely, tree purchasers should clearly express their goals and vocally advocate for high quality planting stock that increases genetic diversity and provides ecosystem services in their regions.
- Municipal street tree planting lists and guides should be expanded (Appendix 9) to include information on:
    - The provisioning, regulating, supporting, and cultural services that particular tree species provide.
    - The disservices that particular tree species cause.
    - Stress tolerances and vulnerabilities of each tree species, including drought, heat, and compaction, based on physiological indicators and experimental data.
    - Pest and disease concerns, with regionally specific projections for current and potential pests.
    - The current age class diversity for each tree species and the percentage of the urban forest that the tree species currently comprises in a given city.
    - When applicable, a list of the cultivars that are already planted in a given city, and an alternate list of cultivars for future planting to increase the genetic diversity of each species.
- Information on street trees should be presented using standardized and intuitively comprehensible scales:
    - While tools such as iTree are designed to provide estimates and dollar value equivalents of pollution reduction, public health impacts, carbon storage and sequestration, and avoided storm water runoff, and potential pest impacts for urban trees, these tools require the input of location, species, and size data for individual trees (*I-Tree Eco*, n.d.). Base data on the qualities of tree species should be available for planting purposes, in addition to these inventory evaluation tools.
    - As in Hirons & Sjöman, 2018, experimentally determined drought survival rates and plant traits may be used to rank the drought tolerance of a species on a four-level scale from

"tolerant to drought" to "sensitive to drought" with corresponding icons to facilitate easy use.

The lack of research and accessible information on tree species characteristics is one of many barriers impeding the selection of optimal street trees that support urban forest diversity and function. Mitigating the risk of the unknown by providing applicable and standardized information on all tree species, but especially new tree species, will support urban forestry goals.

4.3.7 Moving beyond barriers

Here we have identified multiple barriers that get in the way of planting a diverse, functional, and resilient urban forest, including restricted funding, poor nursery availability, difficult planting site conditions, incomplete inventories, negative public perception, and inadequate knowledge transfer. These overarching systemic "gates to unlock" limit the possible tree species for professionals to plant. Additionally, these barriers limit the way that professionals balance trade-offs between selection criteria, leading to reactive risk-averse choices rather than opening the door to proactive planning. Once we unlock these gates, we may allow the full range of tree selection choice and open unconstricted access to the full potential palette of street trees.

To many, these barriers seem in some ways insurmountable: these issues are large, difficult to solve, and highly interconnected. They stand in the way of urban forest diversity and function. They are not the fault of any one person, institution, or professional field, but rather part of a larger system that individuals and organizations operate within. The changes required are both large and small scale, from changing funding structures, to increasing collaboration (Appendix 8), to using inventory data to select diverse species and choose planting ratios (Appendix 9). While this project can not provide perfect solutions to overcome these barriers, identifying barriers and their impacts is an important first step. Shedding light on these barriers and their impacts illuminates the complex context in which professionals make species selection decisions. In the next section, I examine the dynamics of urban forest diversity and function as limited by these barriers. Though professionals are motivated to increase the species and age diversity of urban forests, and motivated to increase the provisioning of ecosystem services, their hands are often (visibly or invisibly) ‘tied’ by the barriers discussed here. Creative, collaborative, proactive, equitable, and well-informed solutions to these barriers are needed.

4.4 Do Current Species Choices Support a Diverse, Resilient Urban Forest?

Urban areas would benefit from increased diversification of their tree taxa. The benefits of increasing urban forest diversity include increased resilience to pest and disease outbreaks, heightened functional diversity, and more reliable provision of ecosystem services (Kendal, Dobbs, & Lohr, 2014). As mentioned earlier, the often quoted 10-20-30 “rule of thumb” states that no more than 10% of the urban forest should be any one species, no more than 20% any one genus, and no more than 30% any one family (Santamour, 1990). Some cities may choose to interpret these ratios as their diversity targets, and some may strive towards more ambitious goals.

In cities across North America, urban forest diversity is estimated at levels that fail to meet the 10-20-30 recommended thresholds. In an analysis of 1,696 North American urban forest inventory datasets, only 111 met the 10-20-30 guidelines in terms of number of stems and only 28 met the guidelines in terms of basal area; the majority of these failures were due to an overabundance of trees from the genera *Acer*, *Fraxinus*, or *Quercus* (Ambrose, 2018, Ambrose, 2018a). Another study of city tree inventories found that the relative abundance of the most common tree species in cities across North America averages 20%, or twice the recommended abundance. The most common genera comprised 30% on average, and the most common family comprised 32% on average (Lohr, Kendal, & Dobbs, 2016). These abundance levels are the cumulative result of planting decisions (as well as tree deaths and removals) made over decades of history. When we discuss the “palette” of tree species available to professionals, this is not synonymous with the current species make-up of the urban forest. The palette of tree species planted each year has the potential to slowly alter the overall diversity of the urban forest, and thus planting decisions must be made with current diversity ratios in mind. While survey results revealed many species that professionals encourage planting, in reality the palette of street trees available for planting each year is limited by significant barriers, as discussed above. The tree species that surveyed professionals encouraged planting are perhaps some of the species that they would ideally plant, absent consideration of constraints such as nursery availability or budget issues.

Professionals are highly aware of the benefits of diversity, with a primary focus on taxonomic diversity. Some also are aware of age class diversity. Ideally, urban forests should be taxonomically diverse across a well-distributed span of age classes: “I know that we want diversity of species and then the thing that is less talked about, is that all-important diversity of age…. I try to diversify these things across the campus as a whole but also within a locality, I try to diversify the species and the ages” (Associate Director of Grounds Operations, Temple University). The narrative of taxonomic diversity increasing resilience to pests is particularly common; professionals cite historical memory of Dutch elm disease (*Ophiostoma ulmi*) and discuss current and arriving pests such as the emerald ash borer (*Agrilus planipennis*). The discussion of these pests is usually coupled with a bemoaning of urban tree allées and monocultures:

> *So sure, that having a block lined with the same kind of tree does give that aesthetic, but then, we know that if that pest or disease comes through affecting that, then that whole block is toast! It's not going to have any trees. So you know when we have the chance to do, to have influence on that block level, we try to switch things up a bit, or you know, try to keep small clusterings of the same species. Still have diversity in what we are planting.*
>
> *Dana Dentice, Urban Forestry Program Manager,*
> *The Pennsylvania Horticultural Society*

> *…biodiversity would be the biggest thing that I would emphasize. We want to be resilient to pest and disease infestations so we want to have lots of different species and it would look different on every street and you wouldn't have a monoculture anywhere. You'd just have a lot of diversity.*
>
> *Anonymous Landscape Architect working with the City of Philadelphia*

> *I think very few people like to see all Oaks down Walnut street or all Tilias or something, and so I think the days of that monoculture kind of allée is hopefully gone, cause that really represented maybe a time when we didn't import diseases from everywhere.*
>
> *University of Pennsylvania Landscape Architect*

> *I think genetic diversity matters because… if you have street trees that are all genetically the same and one gets sick from a disease or borer, you know that when it goes through, those all will be affected.*
>
> *Amanda Wood, Urban Forestry Intern, The Morris Arboretum*

> *I mean if you go back a long time, certainly American elms were widely planted, they were easy to transplant, fast-growing, a flood-plain species, tolerant of over-drainage, beautiful arching form that people really enjoyed, and they were over planted, then along came the Dutch elm disease, wiped them all out.*
>
> *Paul Meyer, Executive Director, The Morris Arboretum*

> *What we have done since our department has been formed, April 18, 2005, is diversify our urban forest. We have gotten away from monoculturing and, I know it's looks pretty, oh you have a whole allée of cherry trees, and a whole allée of London planes, and it looks fine and dandy, but guess what, one pest comes in and takes it all out. And if you don't have the resources, whether it be knowledge, money, personnel, this and that, you can't combat those types of scenarios. So you have to be smart from conception of the project. Because that's where it starts.*
>
> *David Lewis Cupps, District Arborist Supervisor for the Street Tree Management Division of Philadelphia Parks and Recreation*

> *But it was in the 70s when that whole concept of urban forestry systems management really came into the fold, I mean with the DED crisis, with this idea of not just doing arboriculture or single-tree management or just a few trees on a block, but managing the whole system and thinking about diversity.*
>
> *Anonymous Researcher*

The disasters of the past combined with the threats of the present heavily inform modern discussions of urban tree diversity. Professionals clearly indicate their goals to diversify tree species composition on multiple scales in order to mitigate the risk of major simultaneous tree losses. However, these larger stated diversity goals professionals hope to meet by planting trees are (in some cases) not supported by the trees they plant: “I think this season we are slated to plant 30% *Prunus*, which is, it's really high” (Dana Dentice, Urban Forestry Program Manager, The Pennsylvania Horticultural Society). It is often difficult for even the most well-meaning professionals to affect taxonomic diversity ratios. The barriers discussed above are often relevant when professionals make species selection decisions that do not support their diversity goals. For example, poor site conditions may necessitate prioritizing tough trees over diverse selections, resident preferences may steer planting ratios towards an overemphasis on small flowering trees, and lack of inventory data impedes the identification of overplanted species. Often some of the most valuable, well-performing trees are planted in excess of diversity ratios. This was true of excellent trees like elms in advance of the Dutch elm disease crisis, and it is true of some excellent street trees today:

> *… take the London Plane tree: it's a tough tree. It survives and thrives in urban settings because of where it grew in nature. [It is] maybe construed as overused because of the diversity aspect, 10, 20, 30 guideline… Which is true, but these are excellent performing trees. Gleditsia, Thornless Honey Locust is probably another one. It's perhaps overused. And I use that word with caution ‘cause you have to balance performance with diversity.*
> *Jason Lubar, Associate Director of Urban Forestry, The Morris Arboretum*

For many of these commonly planted tree species, genetic diversity is further reduced by planting cultivars, or cloned trees with particularly desirable attributes. The use of clonal propagation in the nursery industry has reduced the genetic diversity of trees, with old historical tree specimens grown from seed exhibiting much greater genetic diversity than currently available tree stock (Morton & Gruszka, 2008). A survey of wholesale nurseries in Washington state, USA found that respondents were aware of risks due to low plant diversity, but more often based their decisions on customer demand rather than advocating for greater genetic diversity (Polakowski, Lohr, & Cerny-Koenig, 2011). For some professionals, the risk reduction provided by planting cultivars (a known entity) seems to often overshadow the concerns of lowered genetic diversity in the urban forest.

I like the use of cultivars, you know sometimes you hear people say, 'Oh, shouldn't plant cultivars, only species' and to me that's like saying we should only grow wild apples and not enjoy all the selections that people have made over millennia. I mean, as it is, trees are one of the few crops that we grow where there's in many cases no selection. But, so, I'm a proponent of cultivars, but I'm also a proponent of using very diverse cultivars and not always using cultivars. If I was going to plant a red maple in my backyard, I would want to make sure that red maple had good fall color, and I would never plant a seedling without knowing what it's gonna look like. But, on the other hand, everybody shouldn't be planting October Glory Red Maple, that's a good cultivar, we should be planting some of those, there are many many red maple cultivars out there and we should be using them all.

Paul Meyer, Executive Director, The Morris Arboretum

There is certainly a place for cultivars; they are extremely useful. However, it is also important to consider the role of genetic diversity within each species when forming diversity targets, above and beyond the 10-20-30 rule of thumb. Genetic diversity within a species may hold the key for resistance to future pests or diseases, whereas a narrowly structured cultivar population is more vulnerable to complete loss (Morton & Gruszka, 2008).

Nurseries play a crucial role in developing and advertising tree cultivars. Several interviewees cited the role of nursery availability in their cultivar selection process:

…we'll talk to the folks at the nursery and they'll show us things that are new or that are doing well, and it seems like there's always different cultivars that are helping to solve historic, maybe urban-related issues, like the tree was messy or the form wasn't great or different things like that so it seems like there's always new cultivars coming out. Yeah, or they're just attractive, nice leaf color, things like that, that help to make the urban environment a little more vibrant.

Anonymous Landscape Architect working with the City of Philadelphia

Genetic diversity in a species is also important as tree breeders seek to develop new useful cultivars for the urban environment. Breeding and trialing tree cultivars is an extremely slow process, compared to other plant crops, and can easily take years to decades. Genetic diversity within a species must be maintained in order to adapt tree populations to future climates and diseases. To reach this goal, professionals must actively work to reverse the trend of decreasing genetic diversity in urban tree species. Although many share the goal of planting a diversity of trees, continued efforts are needed to evaluate and improve current genetic diversity ratios.

4.5 Do Current Species Choices Support a Functional Urban Forest?

The choices required to diversify the urban forest discussed above (such as choosing uncommon species and genetically diverse/non-clonal nursery stock) may be viewed as at-odds with goals of optimizing the functionality and provision of ecosystem services of the urban forest. Uncommon species may be viewed as unproven and high-risk; if a tree does not perform well it would not contribute significant services, and thus professionals may lean towards proven selections even if they are not increasing urban forest diversity. Similarly, clonal tree specimens are not only highly available, but also highly in demand by planting professionals due to the dependability of a trialed and named cultivar juxtaposed with the unknown characteristics of a genetically diverse tree grown from seed. Thus issues of diversity and function may be negatively linked as professionals balance the risks of trying new species and genotypes with the goal of providing the greatest possible ecosystem services through their species choices. However, this trade-off is not so simple, due to the increased resilience to pests, disease, and climate change provided by a greater diversity of tree species. One interviewee spoke to this interplay between genetic diversity and resilience: “I think there could be more diversity. But it's costly and takes a lot of time to do because you have to get the seeds and grow it, versus just grafting it on and calling it a day. But it might help in the long run with pests and diseases, which climate change is bringing” (Amanda Wood, Urban Forestry Intern, The Morris Arboretum). Though costly and slow, increased trialing and monitoring of uncommon tree species would mitigate some of the risk of poor tree performance professionals encounter when choosing to diversify the palette of trees.

In general, professionals highly value the services that trees can provide (Figure 3). Interviewees in Philadelphia discussed the environmental, health, and social benefits of trees planted in urban spaces. Jim Kisker, Sales Manager at Schichtel's Nursery which provides street trees to Philadelphia, cited specific environmental benefits he hopes trees will provide the city: "…would love to see a lot of large trees, producing a very full canopy over a large portion of the city, which then provides more cooling effects, stormwater reduction, air pollutant reduction, pleasing environments for the residents of the city." Other interviewees mentioned additional environmental services, especially adaptive services in anticipation of climate change. Though large trees in good conditions can provide these environmental services, since street trees encounter tough sites and physical constraints, they provide perhaps a lower proportion of environmental services and a higher proportion of health and social services:

> *It probably comes down to what you consider ecosystem services. So they are definitely providing services, but they're providing lots of stuff it's maybe hard to measure. You know kind of like general social, neighborhood building, relationship building, stuff like that around tree planting or taking care of the shared resource, or any of the aesthetic stuff is really hard to measure, any of the human health stuff is hard to measure. So the stuff that we measure in iTree like carbon storage, or air pollution removal, avoided runoff, they don't perform as well in those categories as a tree in a natural forested park.*
>
> *Jason Henning, Research Urban Forester,*
> *The Davey Tree Expert Company, and USDA Forest Service*

Though many services trees provide seem intangible or difficult to measure, the environmental and social benefits of trees are most needed in urban environments without resources of plentiful green space. For some respondents, the services that trees can provide urban areas were the largest incentive for planting trees. The Program Coordinator of the West Philadelphia tree planting non-profit UC Green emphasized the importance of this functionality: "really what the best result is, is we can say in our messaging we have this much environmental impact, we make our community more beautiful. So however they want to pick species, as long as those two objectives are followed through, it's like whatever you want really." Although many professionals would like to plant trees that optimize for greatest environmental impact and greatest beautification, this pairing of criteria oftentimes represents another trade-off. Large tree species provide some of the highest levels of environmental services such as air filtration, carbon storage, shade, cooling, and stormwater reduction. However, fewer large tree species are able to survive the tough urban streetscape conditions, and professionals are limited in their choices of trees:

> *I wish I could make the same decision for street trees as I do for other locations. You know, like I wish I could put white oaks as street trees, but I just know that they're not gonna do well. So there's certain, I wish I could use the same list of like, well these trees are the longest-lived, tallest, widest, most shade producing, provide the most environmental benefits over like 100 years plus, and I wish I could just look to those trees and those qualities, and just pick from that list, put them all as street trees.*
>
> *Chloe Cerwinka, Landscape Planner, The University of Pennsylvania*

Not only are large trees more difficult to establish and fit into existing streetscapes, but also in many instances, urban residents aesthetically gravitate towards small flowering trees for their showy colors and also for the lower risk of damage they pose.

Though professionals hope to meet stated goals of providing environmental services by planting larger trees, these goals are often not supported by the tree species they plant. In recent years in Philadelphia, small flowering tree species such as the Japanese Tree Lilac, *Syringa reticulata*, have been planted at disproportionately high rates:

> *But sometimes, this year, they put in all these, what was it, it wasn't Redbud, it was, was it a Tree Lilac? Something, they put in just a ridiculous number of. And, and even called them on it, like should we really be having 20% of one species. But what people like, inevitably, they want a small flowering tree.*
>
> *Mindy Maslin, Tree Tenders Project Manager,*
> *The Pennsylvania Horticultural Society*

There are very few species of small flowering trees available for tough sites, so planting trends that emphasize small trees may have negative impacts on the current and future diversity of the urban forest. These small trees do not provide the same environmental services as large trees, yet many prefer them. Currently professionals often make the choice to plant a small flowering tree in response to local resident opinions, though this planting choice will have long-lasting implications:

> *… not only is it a bad choice of a tree but it's a choice that we're going to live with for 60, 70, 80 years. … here's this spot here that could potentially, if we don't plant now, maybe at some other point we could get the big tree that would provide all those environmental benefits. And if we just say, "Oh, ok they want to put a crabapple here," then we lose that opportunity. So that's something that many Tree Tenders are really passionate about and I'm glad. But it's like, how to get that across to the city, how to say that we should be making the cuts in the sidewalk as big as possible. And we should be planting the biggest tree possible. And that has to be the default. And if people want a tree and they're afraid of this big tree, well, you know, we just have to talk to them.*
>
> *Mindy Maslin, Tree Tenders Project Manager,*
> *The Pennsylvania Horticultural Society*

Professionals are often aware of this tension between small aesthetic trees and the provision of environmental services, and attempt to overcome the barriers that exist to planting large functional tree species. Professionals interviewed in Philadelphia were both attuned and responsive to the opinions of residents who prefer small flowering trees, and many emphasized the need to work with the public in a bottom-up way to increase green space equity and awareness of tree benefits.

4.6 Future prospects for urban forest diversity and function through species selection in the case study city of Philadelphia

Although interviewees in Philadelphia discussed in depth the barriers that they encounter as they strive to select and plant street trees, the interviews also revealed examples of the innovative spirit that is prevalent among tree professionals in the region. Though many choices are constrained by funding and other barriers, professionals in Philadelphia utilize many strategies to overcome these issues. Firstly, the professionals I interviewed typically have strong channels of communication with each other, meeting both formally and informally to share plans and information. Interviewees were typically very familiar with the details of tree planting activities other than their own and frequently referenced each others' work. Several programs and organizations were noted as sites of networking and coordination: the Southeast Pennsylvania Landscape Management Forum, Longwood Gardens education programs, the Temple University horticulture program, Pennsylvania Urban and Community Forestry Council, and the informal group "Philadelphia Tree Partners." Annual conferences hosted regionally such as the Woody Plant Conference at the Scott Arboretum of Swarthmore College and the Tree Canopy Conference organized by the Morris Arboretum of the University of Pennsylvania bring together many actors to network and help to spread the latest information on trees in the region.

> *[W]hen you look at the impact that those conferences have over a period of time, and how they bring new ideas to practitioners, whether they're community groups or professional landscape architects, or professional arborists, it's, we're really fortunate here in Philadelphia that we have so many public garden institutions and so many programs that it really raises the bar of presentation of trees in our communities.*
>
> *Paul Meyer, Executive Director, The Morris Arboretum*

The culture of horticulture and arboriculture in Philadelphia stems from a long history and remains vibrant to this day.

Beyond the good coordination and communication among interviewees, organizations and individuals in Philadelphia have worked together to start volunteer programs, source trees, plant trees, record data, and educate themselves and the public. Programs such as Tree Tenders are made possible through public-non-profit collaboration and the immense energy of staff and volunteers to green the city. The city has also long been recognized for its storm water management programs, which include major green infrastructure innovations (Mandarano, 2011). The tree-giveaway programs in Philadelphia engage and educate residents, while volunteer labor opens a wide range of possibilities that are otherwise restricted by lack of funding.

While Philadelphia is already succeeding in many ways despite major barriers, many under explored opportunities still exist. Philadelphia's current efforts to expand data collection, through the Tree Checkers citizen science program and through the PPR street tree inventory, will expand future opportunities for proactive management and maintenance of the urban forest. Many organizations in Philadelphia have unexplored opportunities to increase their level of communication and collaboration with tree nurseries. Opportunities also exist to partner with public gardens, research institutions, and other actors to trial new tree species on street and in other urban settings. The city currently lacks an explicit interpretive grove of street tree species; this would be a valuable and educational addition. Issues such as the lack of tree protection bylaws, the lack of funding, the financial burden of sidewalk repair that is placed on residents, constrained planting space, and the often poor sub-surface tree pit infrastructure may continue to be barriers for the foreseeable future in Philadelphia, yet working towards diminishing these barriers will open even greater opportunities for a diverse and functional urban forest.

4.7 Palettes, barriers, diversity, and function: Conclusion

Selecting street trees to increase biodiversity and improve urban ecosystem functions is a complex and difficult task. Based on survey results, professionals from different fields have access to palettes of trees with different levels of diversity and overlap. The fields of urban forestry and arboriculture encouraged the greatest diversity of trees for planting and their recommendations also shared the most overlap. Increasing communication with other fields whose recommendations did not overlap so closely may reveal new or underutilized urban trees and increase the level of familiarity that all professionals have with a wider palette of trees. When examining tree palettes utilized across climate regions, we find variation between the most extremely different climates, yet most species in use are found in the tree palettes of several large regions, indicating that urban tree palettes tend to be similar or homogeneous across much of the USA and Canada.

Although professionals may recommend a diverse variety of highly functional trees, under real-life conditions many barriers restrict the implementation of diverse and functional street tree palettes. These barriers include funding limitations, poor planting site conditions, restricted nursery availability, lack of forest inventory and data tools, poor public perception of some or all trees, and lack of research and/or information transfer on the qualities of new urban tree introductions. In order to move beyond these barriers and move towards meeting urban forestry goals of increased diversity and function, many proactive planning, communication, and management steps are necessary.

5. Conclusions

Selecting tree species to plant in the difficult conditions of an urban streetscape is an extremely complex decision on multiple scales. In this thesis, I explored the tree planting choices that professionals make and the selection criteria they use. This analysis led to the identification of knowledge gaps regarding the ecosystem services that different tree species provide, and on the performance and characteristics of rare or infrequently utilized trees. By analyzing the palettes of tree species that are recommended by various professional fields and in various climates, I identified the level of diversity of each palette as well as the overlap between palettes. I further examined the broader context of tree selection choices, including the many barriers that professionals encounter as they attempt to select trees to meet goals of urban forest diversity and function.

A first step to tree selection for a particular site is deciding which selection criteria are most valuable or important. This ranking of selection criteria may vary greatly from situation to situation, and I was unable to generate an ordered rank of the full list of potential selection criteria. The trade-offs and interconnections between many tree characteristics further complicate the task of creating a universal ranking of the importance of selection criteria. However, survey results did provide a clear summarized ranking of larger selection criteria themes. Professionals rank the value of selection criteria related to the stress tolerance of a tree highest, with the services that a (surviving) tree provides ranking second. Through interview and survey data, I found that the information available to professionals on ecosystem services is inadequate and not broken down by tree species, leading to uncertainty as professionals operationalize this important category of criteria. While professionals rated the disservices of trees as less important in their tree selection process, I found that disservices were in fact frequently mentioned as important factors when interviewees explained their opinions on trees they discouraged planting. The ecological origins of a tree were also rated as a less important tree selection criterion, which may signal a need for increased research and education on links between the provenance of trees and their success in urban environments.

I revealed that professionals are not in full agreement when they make species selection decisions; there are differences in the diversity of the tree palettes that various professional fields draw on and in the identity of the trees that various professional groups encourage and discourage. Urban forestry and arboriculture encouraged the greatest diversity of trees for planting, while landscape architecture discouraged the greatest diversity of trees. Respondents from the field of public horticulture encouraged the greatest percentage of rare tree species, indicating a potential role for public gardens in adding diversity to the urban forest via unusual species. Fields with strong professional linkages such as arboriculture and urban forestry recommend the most similar palettes of trees, while fields such as horticulture, ecology/conservation, and parks/rec/public works recommend trees that overlap less with the typical palette of trees. These results indicate that greater collaboration is needed between fields to share information on trees and expand the palette of trees that every professional is familiar with. This variation in tree palettes also exists across climate regions, as would be expected since trees tolerant of hot desert climates will not also tolerate cold and snowy conditions. However, several of the largest surveyed regions from temperate and snow climates shared comparatively similar tree palettes; future work should investigate the potential role of urban tree selection choices (including planting a diverse selection of non-native species) in the process of biotic homogenization across multiple climates in North America.

The sum total of many constricted species selection decisions for individual sites may not meet the ecosystem function and diversity goals of urban forest managers. Results from this thesis identified significant opportunities to diminish the effect of barriers, unlock more species selection choices, and share knowledge and successful strategies among actors. When making species selection decisions, a shift from reactive to proactive management is indicated, by increasing funding for planning and scheduled maintenance, remediating the underground structure of planting sites, engaging in planning dialogue with nurseries, harnessing the power of inventories to project taxonomic and age class diversity, and increasing the transfer of information among all actors including the public. Another arena of proactive management to support urban forest diversity and function is the intentional breeding and trialing of new urban trees. If public gardens can embrace equity and extend their efforts beyond their garden walls (Appendix 8), there is great potential for these organizations to serve in a revitalized role and make positive contributions to the urban forest.

One major limitation of this thesis is that I relied on very simplistic recommendations of trees that survey participants encouraged or discouraged. Future research should harness the power of existing street tree inventories and existing municipal recommended planting list documents to confirm patterns of urban tree diversity across North America and current trends in tree planting palettes. Additionally, future research should develop a clear quantitative method to calculate the ranking or weights of lists of selection criteria. Future research also should directly ask professionals how accessible information is on each selection criterion and what sources they utilize to describe the characteristics of trees. Finally, future work should update the fact sheets available for common species and create new fact sheets for rare species, including specific and standardized ratings of tree characteristics for the use of tree professionals as well as members of the public.

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Appendices

Appendix 1: The survey questionnaire text for this study, which was distributed online.

Welcome to the Urban Tree Species Selection survey!

Thank you for agreeing to take part in this survey regarding the priorities for tree species selection in cities across temperate North America.

Goal: Professionals from public gardens, urban forestry, landscape architecture, arboriculture, the nursery trade, non-profits, and academia may hold a variety of views and preferences about which tree species should be planted in cities. The goal of this research is to assess the current tree selection priorities of professionals and to inform future planting decisions.

Study team: This research is being conducted by graduate student Jehane Samaha and her supervisor Dr. Cecil Konijnendijk van den Bosch, through the University of British Columbia (UBC), Department of Forest Resources Management. If you have questions about this research in general, or about your role in the study, please feel free to contact either member of the study team using the e-mails listed below.

Your participation: We expect the survey to take 20-30 minutes. Your participation in the study is completely voluntary and you may exit the survey at any time. If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Confidentiality: Your personal information will remain strictly confidential and will not be linked with survey responses at any point. During the study, data will be safely stored on a password-protected computer and only the study team listed will have access to this information. This survey is conducted through Qualtrics, which is fully compliant with the BC Freedom of Information and Protection of Privacy Act (FIPPA).

Follow-up: Reports and publications associated with this research will be made publicly available via conference presentations, a thesis report, and peer-reviewed journal articles. At the end of the survey you may elect to be contacted for follow-up and/or to be notified of resulting publications.

We greatly value your time and appreciate your input.
Thank you!

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This survey is directed at professionals with knowledge of urban trees.

- What is your **primary job**?
  - ○ Arborist
  - ○ Horticulturist
  - ○ Urban forester
  - ○ Park manager
  - ○ Public garden manager
  - ○ Landscape architect

- Policy maker
- Researcher
- Educator
- Planner
- Civil engineer
- Other (please specify)

- In what **sector** is your profession?
  - Not-for-profit
  - Business or commercial
  - University
  - Other research and education
  - City or municipal government
  - State, provincial or regional government
  - National government
  - Other (please specify)

- Of those listed below, with which **field** do you most associate yourself?
  - Arboriculture
  - Architecture
  - Biology
  - Civil engineering
  - Ecology/conservation
  - Economics
  - Forestry
  - Landscape Architecture
  - Parks and recreation management
  - Permaculture
  - Planning
  - Public horticulture
  - Social sciences
  - Urban forestry
  - Other (please specify)

- In what **primary city** or town do you have knowledge of urban trees?
  - City/Town: ________________
  - State/Province: _____________
  - Country: _______________
  - ZIP/postal code: ___________

*For the remainder of the survey, please consider your experiences in the **primary city** you've indicated above when answering questions.*

*While trees are planted in many types of urban sites, for this survey please only consider **street tree sites** when formulating your answers. Some synonymous ways to describe a street tree site are: "Urban paved sites/environments," "sites where the surface is sealed with hard (impervious) materials such as concrete, asphalt, pavement, etc.," "down-town plantings," and "extreme urban environment" (Sjöman & Busse Nielsen, 2010).*

- *Name one tree species that you strongly **encourage** your city to plant in street tree sites:* _____________

- Why should this tree be planted?____
- *Name a different tree species that you strongly* ***discourage*** *your city to plant in street tree sites:* ________
  - *Why should this tree NOT be planted?* _______________________________________

Next, we'd like you to rank which criteria are most important **when choosing a tree species for a street tree site** in your city.
Please rank the criterion you believe is most important as #1, second most important as #2, and so on.
Drag your choices onto the numbered boxes on the left to rank each of the criteria below:

Importance of criteria:	Items:
#1: _________________________ #2: _________________________ #3: _________________________ #4: _________________________	• **Services** provided by the tree species • **Disservices** caused by the tree species • The tree species' **tolerance of urban stressors** • **Ecological origins** of the tree species

To what degree would you **encourage or discourage planting** the following trees in a street tree site in your city?

	strongly encourage planting	encourage planting	slightly encourage planting	neutral	slightly discourage planting	discourage planting	strongly discourage planting	don't know/no answer
Acer miyabei Miyabe maple	◎	◎	◎	◎	◎	◎	◎	◎
Ostrya virginiana American hop hornbeam	◎	◎	◎	◎	◎	◎	◎	◎
Quercus bicolor Swamp white oak	◎	◎	◎	◎	◎	◎	◎	◎
Gymnocladus dioica Kentucky coffeetree	◎	◎	◎	◎	◎	◎	◎	◎
Tilia tomentosa Silver linden	◎	◎	◎	◎	◎	◎	◎	◎
Amelanchier canadensis Shadblow serviceberry	◎	◎	◎	◎	◎	◎	◎	◎
Zelkova serrata Japanese zelkova	◎	◎	◎	◎	◎	◎	◎	◎
Ginkgo biloba Maidenhair tree	◎	◎	◎	◎	◎	◎	◎	◎
Acer saccharum Sugar maple	◎	◎	◎	◎	◎	◎	◎	◎

	strongly encourage planting	encourage planting	slightly encourage planting	neutral	slightly discourage planting	discourage planting	strongly discourage planting	don't know/no answer
Gleditsia triacanthos Honey locust	◎	◎	◎	◎	◎	◎	◎	◎
Acer platanoides Norway maple	◎	◎	◎	◎	◎	◎	◎	◎
Magnolia salicifolia Willow-leaved magnolia	◎	◎	◎	◎	◎	◎	◎	◎
Prunus sargentii Sargent cherry	◎	◎	◎	◎	◎	◎	◎	◎

These next questions ask you to rate the qualities of the tree you would discourage for planting: ((Discouraged Tree)). ((Survey coding: Fill in tree response from previous open response question.))
There are a number of contrasting phrases used to describe the tree. Mark the circle that is closest to the statement that describes **how you think about the tree, as it performs in YOUR CITY**.

There is no right or wrong answer. Please answer quickly and trust the first answer that comes to mind. (For example, if you really agree with the description on the left, mark the furthest left circle. If your agreement is a bit weaker than that, mark the next circle over, and so on.)

If you do not know what to answer, please leave that row blank.

*First, what do you think of the **aesthetic qualities** of ((Discouraged Tree))?*

Attractive in summer	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in summer
Attractive in fall	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in fall
Attractive in winter	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in winter
Attractive in spring	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in spring
Wide canopy form	◎ ◎ ◎ ◎ ◎ ◎ ◎	Narrow canopy form
Tall	◎ ◎ ◎ ◎ ◎ ◎ ◎	Short
Attractive smell	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive smell

*What about issues of **maintenance and stress tolerance** for ((Discouraged Tree))?*

Easy to establish	◎ ◎ ◎ ◎ ◎ ◎ ◎	Difficult to establish
Shade tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Shade intolerant
Air pollution tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Air pollution intolerant
Soil pollution tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Soil pollution intolerant
Soil compaction tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Soil compaction intolerant
De-icing salt tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	De-icing salt intolerant

Tolerant of a wide pH range	◎ ◎ ◎ ◎ ◎ ◎ ◎	Only grows at a specific pH
Heat tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Heat intolerant
Drought tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Drought intolerant
Freezing tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Freezing intolerant
Long life expectancy	◎ ◎ ◎ ◎ ◎ ◎ ◎	Short life expectancy
Produces allergenic pollen	◎ ◎ ◎ ◎ ◎ ◎ ◎	Does not produce allergenic pollen
Clean and tidy	◎ ◎ ◎ ◎ ◎ ◎ ◎	Major producer of debris
Fast growth rate	◎ ◎ ◎ ◎ ◎ ◎ ◎	Slow growth rate
Strong rooting system	◎ ◎ ◎ ◎ ◎ ◎ ◎	Weak rooting system
Resistant to pests & diseases	◎ ◎ ◎ ◎ ◎ ◎ ◎	Susceptible to pests & diseases
Good form without pruning	◎ ◎ ◎ ◎ ◎ ◎ ◎	Requires significant pruning
Never damages infrastructure	◎ ◎ ◎ ◎ ◎ ◎ ◎	Often damages infrastructure
Low risk of limb breakage	◎ ◎ ◎ ◎ ◎ ◎ ◎	High risk of limb breakage

How well does ((Discouraged Tree)) provide ***services and benefits****?*

Cools the urban environment more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Cools the urban environment less than other trees
Sequesters more CO2 than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Sequesters less CO2 than other trees
Controls erosion more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Controls erosion less than other trees
Filters air pollutants more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Filters air pollutants less than other trees
Mitigates storm water run-off more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Mitigates storm water run-off less than other trees
Promotes mental relaxation more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Promotes mental relaxation less than other trees
Reduces urban noise more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Reduces urban noise less than other trees
Provides more shade than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Provides less shade than other trees
Provides high-quality wildlife habitat	◎ ◎ ◎ ◎ ◎ ◎ ◎	Provides poor-quality wildlife habitat

Finally, how about these last questions on ((Discouraged Tree)) in regards to ***your city****?*

Easily available from nurseries	◎ ◎ ◎ ◎ ◎ ◎ ◎	Not available from nurseries
Affordable	◎ ◎ ◎ ◎ ◎ ◎ ◎	Expensive
Native to my region	◎ ◎ ◎ ◎ ◎ ◎ ◎	Exotic to my region

Common everywhere in my city	◎ ◎ ◎ ◎ ◎ ◎ ◎	Rare in my city
Highly invasive	◎ ◎ ◎ ◎ ◎ ◎ ◎	No potential to become invasive
The genetic origin (provenance) of this tree is appropriate for my city	◎ ◎ ◎ ◎ ◎ ◎ ◎	The genetic origin (provenance) of this tree is inappropriate for my city
Traditionally planted	◎ ◎ ◎ ◎ ◎ ◎ ◎	Not traditionally planted
Loved by local residents	◎ ◎ ◎ ◎ ◎ ◎ ◎	Hated by local residents

These next questions ask you to rate the qualities of the tree you would encourage for planting: ((Encouraged Tree)). ((Survey coding: Fill in tree response from previous open response question.))
There are a number of contrasting phrases used to describe the tree. Mark the circle that is closest to the statement that describes **how you think about the tree, as it performs in YOUR CITY**.

There is no right or wrong answer. Please answer quickly and trust the first answer that comes to mind. (For example, if you really agree with the description on the left, mark the furthest left circle. If your agreement is a bit weaker than that, mark the next circle over, and so on.)

If you do not know what to answer, please leave that row blank.

*First, what do you think of the **aesthetic qualities** of ((Encouraged Tree))?*

Attractive in summer	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in summer
Attractive in fall	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in fall
Attractive in winter	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in winter
Attractive in spring	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive in spring
Wide canopy form	◎ ◎ ◎ ◎ ◎ ◎ ◎	Narrow canopy form
Tall	◎ ◎ ◎ ◎ ◎ ◎ ◎	Short
Attractive smell	◎ ◎ ◎ ◎ ◎ ◎ ◎	Unattractive smell

*What about issues of **maintenance and stress tolerance** for ((Encouraged Tree))?*

Easy to establish	◎ ◎ ◎ ◎ ◎ ◎ ◎	Difficult to establish
Shade tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Shade intolerant
Air pollution tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Air pollution intolerant
Soil pollution tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Soil pollution intolerant
Soil compaction tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Soil compaction intolerant
De-icing salt tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	De-icing salt intolerant
Tolerant of a wide pH range	◎ ◎ ◎ ◎ ◎ ◎ ◎	Only grows at a specific pH
Heat tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Heat intolerant
Drought tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Drought intolerant
Freezing tolerant	◎ ◎ ◎ ◎ ◎ ◎ ◎	Freezing intolerant

Long life expectancy	◎ ◎ ◎ ◎ ◎ ◎ ◎	Short life expectancy
Produces allergenic pollen	◎ ◎ ◎ ◎ ◎ ◎ ◎	Does not produce allergenic pollen
Clean and tidy	◎ ◎ ◎ ◎ ◎ ◎ ◎	Major producer of debris
Fast growth rate	◎ ◎ ◎ ◎ ◎ ◎ ◎	Slow growth rate
Strong rooting system	◎ ◎ ◎ ◎ ◎ ◎ ◎	Weak rooting system
Resistant to pests & diseases	◎ ◎ ◎ ◎ ◎ ◎ ◎	Susceptible to pests & diseases
Good form without pruning	◎ ◎ ◎ ◎ ◎ ◎ ◎	Requires significant pruning
Never damages infrastructure	◎ ◎ ◎ ◎ ◎ ◎ ◎	Often damages infrastructure
Low risk of limb breakage	◎ ◎ ◎ ◎ ◎ ◎ ◎	High risk of limb breakage

How well does ((Encouraged Tree)) provide ***services and benefits****?*

Cools the urban environment more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Cools the urban environment less than other trees
Sequesters more CO2 than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Sequesters less CO2 than other trees
Controls erosion more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Controls erosion less than other trees
Filters air pollutants more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Filters air pollutants less than other trees
Mitigates storm water run-off more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Mitigates storm water run-off less than other trees
Promotes mental relaxation more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Promotes mental relaxation less than other trees
Reduces urban noise more than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Reduces urban noise less than other trees
Provides more shade than other trees	◎ ◎ ◎ ◎ ◎ ◎ ◎	Provides less shade than other trees
Provides high-quality wildlife habitat	◎ ◎ ◎ ◎ ◎ ◎ ◎	Provides poor-quality wildlife habitat

Finally, how about these last questions on ((Encouraged Tree)) in regards to ***your city****?*

Easily available from nurseries	◎ ◎ ◎ ◎ ◎ ◎ ◎	Not available from nurseries
Affordable	◎ ◎ ◎ ◎ ◎ ◎ ◎	Expensive
Native to my region	◎ ◎ ◎ ◎ ◎ ◎ ◎	Exotic to my region
Common everywhere in my city	◎ ◎ ◎ ◎ ◎ ◎ ◎	Rare in my city
Highly invasive	◎ ◎ ◎ ◎ ◎ ◎ ◎	No potential to become invasive
The genetic origin (provenance) of this tree is appropriate for my city	◎ ◎ ◎ ◎ ◎ ◎ ◎	The genetic origin (provenance) of this tree is inappropriate for my city
Traditionally planted	◎ ◎ ◎ ◎ ◎ ◎ ◎	Not traditionally planted

Loved by local residents	◎ ◎ ◎ ◎ ◎ ◎ ◎	Hated by local residents

Thank you! You made it through the longest part of the survey. We have just a few more questions to ask, you're almost done!

First, here are three optional questions, in case you would like to share additional thoughts with us:

- What **three** criteria do you believe are the most important to consider when selecting a street tree species?
  - #1:
  - #2:
  - #3:
- What role (if any) do you or your organization play in selecting or planting street trees?
- What else would you like to tell us, that we haven't asked about?

In the last part of this survey, please answer a few questions about yourself:

- About how often do you influence choices about which street tree species are planted in your city?
  - Very frequently (nearly every day)
  - Frequently (about 1-4 times per week)
  - Occasionally (about 1-3 times per month)
  - Rarely (about 2-6 times per year)
  - Very rarely (Once or less per year)
  - Never

- How knowledgeable are you about urban trees?
  - Very knowledgeable
  - Somewhat knowledgeable
  - Average
  - Not very knowledgeable
  - Not at all knowledgeable

- How confident are you in giving advice regarding the selection of street tree species for your city?
  - Very confident
  - Somewhat confident
  - Average
  - Not very confident
  - Not at all confident

- Are you (or have you ever been) an ISA certified arborist?
  - Yes
  - No

- How many years have you been involved with activities (such as work, education, or volunteerism) related to urban trees?
  - Less than 1 year
  - 1-3 years
  - 4-6 years
  - 7-10 years
  - 11-20 years
  - 21+ years

- How do you identify your gender?
    - Male
    - Female
    - Transgender, transitioning
    - Other:
    - Prefer not to say

- In what year were you born?
    - Year of birth: __________
    - Prefer not to say

- What is the highest level of education you have completed?
    - Doctorate (PhD, EdD) or Professional (MD, JD, DVM, DDS)
    - Masters (MA, MS, MBA, Med)
    - Bachelors (BA, BS, AB)
    - Associates (2 year degree)
    - Trade/technical/vocational degree or certificate
    - Some college, no degree
    - High school diploma or GED
    - 9th - 12th grade, no diploma
    - 8th grade or less
    - Prefer not to say

- Where would you place yourself on the following political scale?
    - Very liberal
    - Liberal
    - Middle of the road
    - Conservative
    - Very conservative
    - Prefer not to say

- What is your race or ethnic background? Do you consider yourself:
    - White
    - Hispanic
    - Black
    - Asian
    - First Nations, Métis, Inuit, or American Indian
    - Multiracial or multi-ethnic
    - Other
    - Prefer not to say

- For employment, are you currently:
    - Working for pay
    - On vacation, sabbatical, parental leave, or sick leave from regular job
    - A homemaker
    - A student
    - Looking for work
    - Unable to work, disabled
    - Retired

- Other
- Prefer not to say

Thank you so much for completing this survey! Your responses are valuable contributions to this research on urban tree species selection.

Appendix 2: Names, titles, and organizational affiliations of interviewed participants in the Philadelphia, PA, USA case study.

Name	Title	Organization
Anonymous	Arborist Sales Manager	For-profit arborist sector
Anonymous	Associate Director of Grounds Operations	Temple University
Anonymous	Landscape Architect	Consultant for the City of Philadelphia
Anonymous	Program Coordinator	UC Green
Anonymous	Researcher	Anonymous
Anonymous	University Landscape Architect	The University of Pennsylvania
Amanda Wood	Urban Forestry Intern	The Morris Arboretum of the University of Pennsylvania
Anthony Aiello	Director of Horticulture and Curator	The Morris Arboretum of the University of Pennsylvania
Chloe Cerwinka	Landscape Planner	The University of Pennsylvania
Dana Dentice	Urban Forestry Program Manager	The Pennsylvania Horticultural Society
David Lewis Cupps	District Arborist Supervisor	Street Tree Management Division of Philadelphia Parks & Recreation
Erica Smith Fichman	TreePhilly Program Manager	Philadelphia Parks & Recreation
Hasan Malik	Founder and Owner	Tree Authority LLC
Jason Henning	Research Urban Forester	The Davey Tree Expert Company, and USDA Forest Service
Jason Lubar	Associate Director of	The Morris Arboretum of the University of

Name	Title	Organization
	Urban Forestry	Pennsylvania
Jim Kisker	Sales Manager	Schichtel's Nursery, Inc
Lori Hayes	Director of Urban Forestry	Philadelphia Parks & Recreation
Mindy Maslin	Tree Tenders Project Manager	The Pennsylvania Horticultural Society
Paul Meyer	Executive Director	The Morris Arboretum of the University of Pennsylvania
Trish Kemper	Urban Forestry Assistant	The Morris Arboretum of the University of Pennsylvania and The University of Pennsylvania

Appendix 3: Significant Kruskall-Wallis test results (p≤0.01) examining correlations between response and explanatory variables.

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
13 species ratings variables		
Likert.Acer.miyabei	Field	0.002
Likert.Acer.miyabei	Köppen climate region	0
Likert.Acer.platanoides	Köppen climate region	0
Likert.Acer.platanoides	Political inclination	0
Likert.Acer.saccharum	Country	0
Likert.Acer.saccharum	employment	0.005
Likert.Acer.saccharum	Köppen climate region	0
Likert.Amelanchier.canadensis	Köppen climate region	0
Likert.Amelanchier.canadensis	Years of experience	0
Likert.Ginkgo.biloba	Field	0.002
Likert.Ginkgo.biloba	Köppen climate region	0
Likert.Gleditsia.triacanthos	Country	0.002

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Likert.Gleditsia.triacanthos	Köppen climate region	0
Likert.Gymnocladus.dioica	Certified.arborist	0.009
Likert.Gymnocladus.dioica	Köppen climate region	0
Likert.Magnolia.salicifolia	Köppen climate region	0
Likert.Ostrya.virginiana	Köppen climate region	0
Likert.Prunus.sargentii	Köppen climate region	0
Likert.Quercus.bicolor	Certified.arborist	0.009
Likert.Quercus.bicolor	Country	0
Likert.Quercus.bicolor	Field	0
Likert.Quercus.bicolor	Köppen climate region	0
Likert.Tilia.tomentosa	Country	0.005
Likert.Tilia.tomentosa	Köppen climate region	0
Likert.Zelkova.serrata	Köppen climate region	0
43 selection criteria		
Discourage.air.filtration	Certified arborist	0.008
Discourage.air.filtration	Gender	0.002
Discourage.air.filtration	Köppen climate region	0.003
Discourage.air.filtration	Professional Field	0.004
Discourage.breakage	Country	0
Discourage.breakage	Frequency of planting influence	0.004
Discourage.breakage	Köppen climate region	0.004
Discourage.canopy	Country	0.001
Discourage.canopy	Frequency of planting influence	0.003
Discourage.canopy	Köppen climate region	0.006

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Discourage.canopy	Political inclination	0.008
Discourage.co2	Gender	0.009
Discourage.co2	Köppen climate region	0.001
Discourage.co2	Political inclination	0.001
Discourage.cooling	Gender	0.01
Discourage.cooling	Knowledge	0.004
Discourage.cooling	Köppen climate region	0
Discourage.cooling	Professional Field	0.006
Discourage.erosion	Gender	0
Discourage.erosion	Köppen climate region	0.005
Discourage.fall	Country	0.003
Discourage.freezing	Frequency of planting influence	0.009
Discourage.freezing	Köppen climate region	0.001
Discourage.habitat	Gender	0.001
Discourage.habitat	Köppen climate region	0.001
Discourage.habitat	Political inclination	0
Discourage.habitat	Professional Field	0
Discourage.height	Köppen climate region	0
Discourage.infrastructure	Certified arborist	0
Discourage.infrastructure	Frequency of planting influence	0.003
Discourage.infrastructure	Köppen climate region	0.001
Discourage.invasiveness	Köppen climate region	0.001
Discourage.nativity	Knowledge	0.002
Discourage.nativity	Köppen climate region	0.004

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Discourage.nativity	Political inclination	0
Discourage.noise	Gender	0.003
Discourage.pruning	Certified arborist	0
Discourage.pruning	Frequency of planting influence	0
Discourage.pruning	Knowledge	0.007
Discourage.pruning	Professional Field	0.005
Discourage.pruning	Tree advice confidence	0.002
Discourage.residents	Country	0.005
Discourage.root	Köppen climate region	0.001
Discourage.runoff	Gender	0.002
Discourage.runoff	Köppen climate region	0.001
Discourage.salt	Köppen climate region	0.002
Discourage.shade	Köppen climate region	0
Discourage.shade	Professional Field	0.001
Discourage.smell	Country	0.008
Discourage.smell	Knowledge	0.006
Discourage.smell	Köppen climate region	0
Discourage.spring	Köppen climate region	0.001
Encourage.air.filtration	Country	0.006
Encourage.air.filtration	Years of experience	0.008
Encourage.breakage	Years of experience	0.001
Encourage.canopy	Country	0.002
Encourage.co2	Professional Field	0.01
Encourage.compaction	Country	0.008

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Encourage.cooling	Country	0.001
Encourage.cooling	Years of experience	0.007
Encourage.disease	Tree advice confidence	0.001
Encourage.drought	Country	0.009
Encourage.drought	Köppen climate region	0.008
Encourage.drought	Professional Field	0.008
Encourage.erosion	Country	0.005
Encourage.fall	Gender	0
Encourage.freezing	Köppen climate region	0.003
Encourage.growth.rate	Tree advice confidence	0.009
Encourage.habitat	Gender	0.009
Encourage.habitat	Professional Field	0.002
Encourage.heat	Country	0
Encourage.heat	Köppen climate region	0
Encourage.height	Country	0.01
Encourage.height	Köppen climate region	0.001
Encourage.invasiveness	Education	0.002
Encourage.invasiveness	Köppen climate region	0.003
Encourage.invasiveness	Political inclination	0.001
Encourage.life.expectancy	Country	0
Encourage.life.expectancy	Köppen climate region	0
Encourage.nativity	Köppen climate region	0
Encourage.noise	Country	0.002
Encourage.noise	Years of experience	0.001

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Encourage.pollen	Köppen climate region	0.01
Encourage.provenance	Education	0.001
Encourage.provenance	Köppen climate region	0
Encourage.rarity	Köppen climate region	0.001
Encourage.rarity	Professional Field	0.003
Encourage.residents	Certified arborist	0.007
Encourage.root	Country	0.001
Encourage.root	Knowledge	0.003
Encourage.root	Köppen climate region	0.004
Encourage.root	Tree advice confidence	0.001
Encourage.runoff	Country	0
Encourage.salt	Köppen climate region	0
Encourage.salt	Professional Field	0.003
Encourage.shade	Country	0.001
Encourage.summer	Employment	0.006
Encourage.summer	Gender	0
Encourage.traditionally.planted	Köppen climate region	0.002
Encourage.winter	Country	0
Encourage.winter	Gender	0.002
4 main/short selection criteria rankings		
Short.Rank.Disservices	Köppen climate region	0
Short.Rank.Origins	Certified arborist	0.008
Short.Rank.Origins	Köppen climate region	0
Short.Rank.Origins	Professional Field	0.003

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Short.Rank.Tolerance	Köppen climate region	0.001
Short.Rank.Tolerance	Professional Field	0.001
Encouraged and discouraged tree choices		
Discourage.tree	Country	0.002
Discourage.tree	Köppen climate region	0
Encourage.tree	Country	0
Encourage.tree	Frequency of planting influence	0.005
Encourage.tree	Köppen climate region	0.001
Encourage.tree	Years of experience	0.002
Self-reported knowledge metrics		
Frequency of planting influence	Certified arborist	0
Frequency of planting influence	Education	0.003
Frequency of planting influence	Employment	0.004
Frequency of planting influence	Knowledge	0
Frequency of planting influence	Political inclination	0
Frequency of planting influence	Professional Field	0
Frequency of planting influence	Tree advice confidence	0
Frequency of planting influence	Years of experience	0
Knowledge	Certified arborist	0
Knowledge	Country	0.007
Knowledge	Frequency of planting influence	0
Knowledge	Professional Field	0.001
Knowledge	Tree advice confidence	0

Response Variable	Explanatory Variable	Kruskal-Wallis test p-value
Knowledge	Years of experience	0
Tree advice confidence	Certified arborist	0
Tree advice confidence	Frequency of planting influence	0
Tree advice confidence	Gender	0.004
Tree advice confidence	Knowledge	0
Tree advice confidence	Professional Field	0
Tree advice confidence	Years of experience	0

Appendix 4: Interview schedule, including the basic structure of questions each respondent was ideally asked.

Hi! Thanks so much for taking the time to talk with me. And thanks for signing the consent form—is it okay that I'm recording? Today, I'm hoping we can talk about urban trees in Philadelphia. I'm especially interested in the way that tree planting decisions are made—which species go where, and why? I'm hoping that you can tell me a bit about your own experience in relation to urban trees: which characteristics of trees are important, which species work well, and about the process of choosing trees for urban environments.
First of all, could you give me a bit of background about yourself? What work do you do for your organization? (What brought you to this field/position?)
What are some of the specific challenges in Philadelphia that street trees face? (Challenges in specific neighborhoods?) (How is street tree survival in your city?) (How are those challenges overcome, if they are?)
Are you involved in any tree evaluation/selection/planting? (Or do you witness others doing that work?) (Where, geographically?)
Who chooses which street trees are planted in Philadelphia? (Are there other groups or individuals that choose which street trees are planted?)
How do they choose which street trees are planted? (What does the decision process look like?) What characteristics of trees do you, personally, think are most important? (Which are least important?) (Why?)
Are there barriers to choosing the optimal trees to plant in Philadelphia? (What are those barriers? How are they dealt with?)

Which selection criteria are theoretically important? Which are used on a practical day-to-day basis? Are there tree species that are overused in Philadelphia's urban forest, that you would like to see phased out? (What are the sub-optimal characteristics of that tree?) (Do you know when/why that tree species was commonly planted?)
Are there other promising tree species that you would like to see take a more prominent role in Philadelphia's urban forest? (Has that tree been planted/trialled at all in the city/region?) (What are the good characteristics of that tree?) (Are there any drawbacks to planting that tree?)
One other aspect of my project is looking at interactions between public gardens and the city urban forestry groups. Since Philadelphia is the "garden capital of the USA," I'm curious about whether there's any opportunity for collaboration between public garden people and urban forestry people in looking at new potential urban tree species. Are you part of (or do you know of) any collaborations between urban foresters and public gardens in the Philadelphia area? Have you been to conferences or other gatherings where professionals from each group is present? (where? When?) Do you know anyone who has worked in one of these fields, and then switched to the other? (If you have done that, what was that career shift like?)
Questions specifically for urban forestry professionals: Are there public garden people in your professional network who you can reach out to, formally or informally? (Who? What is their role? What types of things would you reach out to them about?) Have you ever used information from public gardens in deciding which trees to plant? (When? What information?) (What type of information would you *want* to receive from a public garden?)
Questions specifically for public garden professionals: Are there urban forestry people in your professional network who you can reach out to, formally or informally? (Who? What is their role? What types of things would you reach out to them about?) Have you ever provided information to urban foresters about which tree species to plant in Philadelphia? (When? What information?) (What type of information do you think public gardens *could* provide?)
In your best fantasy, what would Philadelphia's urban forest be like in the future? (What would it look like? Feel like? Smell like? Sound like? What would it do for the city and the people?)
Are there any questions you wished I had asked, or is there anything else you'd like to tell me?

Appendix 5: T-Test comparisons between mean discouraged tree ratings (disc. mean) and mean encouraged tree ratings (enc. mean) for 43 selection criteria. The difference between the means is calculated as the absolute value of the mean discouraged tree rating minus the mean encouraged tree rating. Ratings for each criteria are on a unique semantic differential scale from 1 to 7.

Criteria	Disc. mean	Enc. mean	Abs(disc. - enc.)	p_value	Value of “1” rating		Value of “7” rating
summer	3.12	1.69	1.43	<0.001	Attractive in summer	. . .	Unattractive in summer

Criteria	Disc. mean	Enc. mean	Abs(disc. - enc.)	p_value	Value of "1" rating		Value of "7" rating
fall	2.95	1.91	1.04	<0.001	Attractive in fall	. . .	Unattractive in fall
winter	4.23	2.48	1.75	<0.001	Attractive in winter	. . .	Unattractive in winter
spring	3.10	2.18	0.92	<0.001	Attractive in spring	. . .	Unattractive in spring
canopy	3.41	2.57	0.83	<0.001	Wide canopy form	. . .	Narrow canopy form
height	3.35	2.40	0.95	<0.001	Tall	. . .	Short
smell	4.54	3.72	0.82	<0.001	Attractive smell	. . .	Unattractive smell
establishment	2.39	2.29	0.11	0.1555	Easy to establish	. . .	Difficult to establish
shadetol	3.76	3.54	0.22	0.0084	Shade tolerant	. . .	Shade intolerant
air.pollution	2.85	2.24	0.61	<0.001	Air pollution tolerant	. . .	Air pollution intolerant
soil.pollution	3.20	2.38	0.82	<0.001	Soil pollution tolerant	. . .	Soil pollution intolerant
compaction	3.35	2.47	0.88	<0.001	Compaction tolerant	. . .	Compaction intolerant
salt	3.79	3.00	0.79	<0.001	De-icing salt tolerant	. . .	De-icing salt intolerant
ph	3.35	2.60	0.76	<0.001	Tolerant of a wide pH range	. . .	Only grows at a specific pH
heat	3.12	2.12	1.00	<0.001	Heat tolerant	. . .	Heat intolerant
drought	3.45	2.26	1.18	<0.001	Drought tolerant	. . .	Drought intolerant
freezing	3.33	2.36	0.97	<0.001	Freezing tolerant	. . .	Freezing intolerant
life.expectancy	4.56	1.95	2.61	<0.001	Long life expectancy	. . .	Short life expectancy
pollen	4.00	4.21	0.21	0.0153	Produces allergenic pollen	. . .	Does not produce allergenic pollen

Criteria	Disc. mean	Enc. mean	Abs(disc. - enc.)	p_value	Value of “1” rating		Value of “7” rating
debris	4.74	3.15	1.59	<0.001	Clean and tidy	. . .	Major producer of debris
growth.rate	2.66	3.16	0.50	<0.001	Fast growth rate	. . .	Slow growth rate
root	3.40	2.27	1.13	<0.001	Strong rooting system	. . .	Weak rooting system
disease	4.42	2.27	2.14	<0.001	Resistant to pests & diseases	. . .	Susceptible to pests & diseases
pruning	4.57	2.39	2.18	<0.001	Good form without pruning	. . .	Requires significant pruning
infrastructure	5.04	3.31	1.73	<0.001	Never damages infrastructure	. . .	Often damages infrastructure
breakage	5.18	2.54	2.64	<0.001	Low risk of limb breakage	. . .	High risk of limb breakage
cooling	3.88	2.85	1.03	<0.001	Cools the urban environment more than other trees	. . .	Cools the urban environment less than other trees
CO_2	3.97	3.08	0.89	<0.001	Sequesters more CO_2 than other trees	. . .	Sequesters less CO_2 than other trees
erosion	4.05	3.08	0.98	<0.001	Controls erosion more than other trees	. . .	Controls erosion less than other trees
air.filtration	3.96	3.08	0.88	<0.001	Filters air pollutants more than other trees	. . .	Filters air pollutants less than other trees
runoff	4.00	3.04	0.96	<0.001	Mitigates storm water run-off more than other trees	. . .	Mitigates storm water run-off less than other trees
relaxation	4.02	2.76	1.27	<0.001	Promotes mental relaxation more than other trees	. . .	Promotes mental relaxation less than other trees
noise	4.08	3.23	0.85	<0.001	Reduces urban	. . .	Reduces urban noise

Criteria	Disc. mean	Enc. mean	Abs(disc. - enc.)	p_value	Value of “1” rating		Value of “7” rating
					noise more than other trees		less than other trees
shade	3.88	2.96	0.91	<0.001	Provides more shade than other trees	. . .	Provides less shade than other trees
habitat	4.55	2.80	1.75	<0.001	Provides high-quality wildlife habitat	. . .	Provides poor-quality wildlife habitat
nursery	2.37	2.37	0.00	0.9730	Easily available from nurseries	. . .	Not available from nurseries
expense	2.24	2.47	0.24	<0.001	Affordable	. . .	Expensive
nativity	4.88	3.42	1.46	<0.001	Native to my region	. . .	Exotic to my region
rarity	2.21	3.58	1.37	<0.001	Common everywhere in my city	. . .	Rare in my city
invasiveness	3.77	6.22	2.45	<0.001	Highly Invasive	. . .	No potential to become Invasive
provenance	4.25	2.30	1.95	<0.001	Provenance appropriate for my city	. . .	Provenance inappropriate for my city
traditionally.planted	2.66	3.52	0.86	<0.001	Traditionally planted	. . .	Not traditionally planted
residents	3.35	2.78	0.57	<0.001	Loved by local residents	. . .	Hated by local residents

Appendix 6: Survey respondents were encouraged to leave any of the 43 selection criteria semantic differential questions blank if they were unsure, rather than guessing. This table summarizes the total count of NAs for each criteria, broken down by discouraged and encouraged tree, indicating the number of respondents who left the question blank. The table is sorted by the sum of these counts, with the criteria that the most respondents were unsure about at the top.

Criteria	Count of NAs for Discouraged trees	Count of NAs for Encouraged trees	Sum of NAs
pollen	59	49	108
salt	46	55	101
CO_2	49	44	93
air.filtration	45	38	83
ph	45	34	79
runoff	42	30	72
noise	38	33	71
freezing	46	24	70
erosion	34	34	68
smell	31	31	62
relaxation	35	26	61
infrastructure	28	30	58
soil.pollution	33	24	57
provenance	33	24	57
expense	34	23	57
air.pollution	31	24	55
habitat	32	22	54
heat	33	20	53
root	33	19	52
breakage	28	22	50
compaction	27	22	49
shade	32	17	49
life.expectancy	28	19	47
cooling	28	19	47
shadetol	31	16	47

Criteria	Count of NAs for Discouraged trees	Count of NAs for Encouraged trees	Sum of NAs
drought	27	19	46
nativity	24	21	45
growth.rate	29	16	45
disease	25	19	44
invasiveness	27	17	44
debris	28	14	42
traditionally.planted	25	16	41
pruning	25	15	40
nursery	27	13	40
residents	22	17	39
winter	16	15	31
establishment	19	12	31
rarity	19	12	31
spring	14	16	30
height	15	15	30
canopy	17	13	30
fall	12	13	25
summer	11	13	24

Appendix 7: Mean rarity ratings of rare trees (score higher than 4) across all fields (including public horticulture), and for the subset of public horticulture respondents. Trees that were only encouraged by respondents from the field of public horticulture are marked with an asterisk (*).

Species	Rarity ratings from all fields combined	Rarity ratings from the field of public horticulture
Acer cappadocicum	7.00	NA
*Acer triflorum**	7.00	7.00

Species	Rarity ratings from all fields combined	Rarity ratings from the field of public horticulture
Carpinus betulus 'Franz Fontaine'	7.00	NA
*Carya cordiformis**	7.00	7.00
Covillea sp.	7.00	NA
Cupressus guadalupensis	7.00	NA
Fraxinus pennsylvanica	7.00	NA
*Maackia amurensis**	7.00	7.00
Ostrya sp.	7.00	NA
Phellodendron lavallei	7.00	NA
Pinus strobus	7.00	NA
*Styphnolobium japonicum**	7.00	7.00
Metasequoia glyptostroboides	6.50	NA
Eucommia ulmoides	6.33	NA
Corylus colurna	6.25	NA
Acer miyabei	6.00	NA
*Aesculus flava**	6.00	6.00
Aesculus glabra	6.00	NA
Celtis reticulata	6.00	NA
Ostrya virginiana	6.00	NA
Pinus elliottii var. *densa**	6.00	6.00
Quercus ellipsoidalis	6.00	NA
Ulmus alata	6.00	NA
Vitex sp.	6.00	NA
Liquidambar styraciflua	5.40	5.00

Species	Rarity ratings from all fields combined	Rarity ratings from the field of public horticulture
Maclura pomifera	5.40	5.00
Quercus muehlenbergii	5.27	5.00
Catalpa speciosa	5.25	NA
Carya illinoinensis	5.00	NA
Quercus stellata	5.00	NA
Quercus suber	5.00	NA
Quercus velutina	5.00	NA
Syringa reticulata	4.75	NA
Nyssa sylvatica	4.59	NA
Taxodium distichum	4.52	5.60
Acacia salicina	4.50	NA
Acer grandidentatum	4.50	5.00
Cercidiphyllum japonicum	4.33	NA
Quercus alba	4.33	5.00
Liriodendron tulipifera	4.29	NA
Gymnocladus dioica	4.20	4.33
Acer griseum	3.50	5.00
Pistacia chinensis	3.50	5.00
Quercus phellos	2.90	5.00
Tilia cordata	2.75	5.00

Appendix 8: The potential role of public gardens in urban tree species selection.

I originally hypothesized that increased partnerships between urban foresters and public gardens/arboreta would benefit the process of urban tree selection. Since historic and current partnerships exist, there are clear models of collaborations for the testing of potential urban tree species and the education of the public and professionals through plant display and active outreach. While my results provide supportive evidence for this hypothesis, I also revealed important caveats and areas of caution.

Opportunities for collaboration

Public gardens (including arboreta and botanical gardens) are often already involved in "the search for the perfect tree." Many public gardens display trees from around the world with a wide variety of traits and tolerances. The majority of public gardens globally are situated in or near cities, and are the most biodiverse areas in cities (Cavender et al., 2019). Historically, public gardens have served as a gateway for the introduction of tree species into cultivation in North America (Rehder, 1991). Currently, many North American public gardens participate in plant exploration to study and collect woody plants from around the world through consortia such as the North American Consortium for Plant Exploration in China (NACPEC) and the Plant Collecting Collaborative (PCC) ("Plant Exploration," n.d.). Since it is generally accepted that non-native trees will play a significant role in the urban canopy due to the novel and stressful environmental conditions of the city (Sjöman, et al., 2016), public gardens with plant collection programs can serve as a pre-existing conduit for the introduction of new urban trees. Increased communication between such public gardens and urban forestry programs is necessary, so that plant explorers fully understand the selection criteria that are most valuable for urban trees and so that the professionals planting urban trees are informed about the qualities of new tree choices.

In Philadelphia, the Morris Arboretum both participates in plant exploration efforts and also houses a for-profit urban forestry consulting group, creating great potential for the identification of potential urban tree species: “We can be expert advisors, you know, go out, do the research, identify the trees, identify where they grow, get the seeds, start growing them and then putting them, either in a nursery to grow and put out on the street, or directly on the street. We can also use our spaces to trial some of these trees” (Jason Lubar). Although the Morris Arboretum does not focus collection or evaluation efforts on trees with urban potential, employees there are informally keeping an eye on some new Ash tree species for this purpose: “it's not necessarily applicable to sort of urban forestry as it were. Other than, in a very passive way, we've added a few, a handful of Asian *Fraxinus* species that we’ve never had here, that are hardly in cultivation in the United States at all. So that will be, again not a formal evaluation, the more passive thing to see how they perform here, and when the waves of EAB comes through, we will see if they survive” (Anthony Aiello, Director of Horticulture and Curator, The Morris Arboretum). Employees of public gardens often take an interest in urban forestry, and may have anecdotal observations to share on the qualities of the trees they interact with in their collections. Survey results showed that respondents from the field of public horticulture were significantly more likely to encourage trees they rated as rare than other respondents ($p=0.003$) (Figure 10). This may indicate that public garden employees place a higher value on planting rare species, and/or that they are familiar with a variety of rare species. In either case, sharing reliable information on rare species with other professionals may decrease the risk associated with planting a new tree and diversify the palette of available urban tree choices.

One major risk of planting a new tree is the risk of starting a new plant invasion. Public gardens, nurseries, and individuals have historically introduced the majority of invasive plants (Reichard & White, 2001). Codes of conduct exist for public gardens and other horticultural organizations to preventatively minimize the risk of invasive plant introduction (Reichard, 2004). Modern introductions of trees should undergo extensive evaluation, especially to predict the invasive potential of trees in North American ecosystems using information on the geographic origin of the species, whether it invades elsewhere, and reproductive traits (Reichard & Hamilton, 1997). Since plant species can be invasive in some regions but not in others (Reichard, 2004), potential urban tree species should be evaluated in or near each city or localized climate region; the collections of public gardens may be the perfect network of sites for such an evaluation program. Evaluating tree species, especially for invasive traits, is a slow process; trees must reach sexual maturity before their seeding behavior can be observed, which can take from a few years to a few decades, and there is often a lag time before invasive behavior is observed (Reichard & Hamilton, 1997). Therefore, instead of simply waiting for recently collected trees to mature, the powerful diversity of the existing mature collections in public gardens should be examined closely for potential new urban trees. Although garden conditions may not mimic the rigors of street sites, public gardens may be a useful environment to compare the characteristics of trees, evaluate trees for invasive potential, and identify species with similar tolerances to currently useful urban tree species.

One historical pathway for public gardens to collaborate on issues of urban trees was the Metropolitan Tree Improvement Alliance (METRIA). METRIA was active from the mid-1970s until approximately the early 1990s, with their final symposium “Trees for the Nineties: Landscape Tree Selection, Testing, Evaluation, and Introduction” held in 1990 (Metropolitan Tree Improvement Alliance Conference, 1990). The organization still exists though is mostly dormant. The stated purpose of METRIA was “to provide opportunities for collaboration among members in developing better trees for metropolitan landscapes” (Gerhold, 1978). The specific objectives of the alliance were:

A. To provide information that will enable wiser choices of species or cultivars for

> *particular urban environments and uses; and information about managerial techniques that will lead to healthier, more beautiful trees.*
> *B. To create tree cultivars having improved characteristics through breeding, selection, and propagation; and preserve valuable germplasm.*
> *C. To promote the utilization of improved cultivars and better cultural techniques.*
> *(Gerhold, 1978)*

The cooperation facilitated by METRIA included collaborations between arboreta, universities, the Agricultural Research Service, commercial and state nurseries, the U.S. Forest Service, municipalities, and highway agencies. Future collaborations could likely be modeled in part on this organizational structure.

While past tree collecting efforts have focused on searching out new tree species and past breeding efforts have focused on developing new cultivars, these activities result in a limited expression of the full genetic diversity available for planting in urban sites. Since urban forests are experiencing a loss of genetic diversity due to the prevalence of cultivars (Morton & Gruszka, 2008), efforts should focus on collecting and breeding the widest possible genetic diversity of urban trees. Additionally, since the original habitat type of a tree can determine its tolerance of urban stressors (Sjöman & Busse Nielsen, 2010), tree collection and breeding efforts should collect the same species from multiple provenances, to both increase genetic diversity and the chance of finding trees that will tolerate a variety of urban conditions.

One modern collaborative North American urban plant breeding program is the Chicagoland Grows partnership between the Chicago Botanic Garden, The Morton Arboretum, and the Ornamental Grower's Association of Northern Illinois (Cavender et al., 2019). This partnership breeds and introduces regionally adapted plants, including urban trees. The Morton Arboretum in particular provides significant leadership in the realm of urban forestry and recently released a paper detailing a wide range of "suggested contributions of botanical gardens to improve urban forests" (Cavender &

Donnelly, 2019). This publication may signal a renewed call to action for public gardens to utilize their knowledge and public reach to benefit the trees and people beyond their garden walls.

Beyond the potential collaborative role of public gardens in the processes of tree collection, breeding, and evaluation, public gardens are also well situated to communicate information to both professionals and the public. This communication can occur in a variety of settings and be integrated into existing garden programs, as detailed by interviewees from the Morris Arboretum:

> *I think probably education both formal education and informal education. I think just a trip to the Morris helps open people's eyes to the world of trees that helps them see trees better. But also, whether it's a class for preschool kids that come to the arboretum and begin to open their eyes to the natural world, or internship programs, or continuing adult education, and particularly professional education. I think all of those things contribute to those lofty goals of the ideal urban forest.*
>
> *Paul Meyer, Executive Director, The Morris Arboretum*
>
> *One, we can display a diversity of species here so people can see what they do, not necessarily in an urban forestry setting, but certainly be exposed to a variety of different things. So that's one thing. I think, you know, demonstrating best management practices for trees is another way we can show people how to care for trees… the next step is the outreach, of being involved with…Tree Tenders, and PHS, and tree planting programs, and sort of taking what we know outside the gates here. So I think there's a whole spectrum of things we can do, both passively in terms of demonstrating trees, and then more actively, both education and outreach.*
>
> *Anthony Aiello, Director of Horticulture and Curator, The Morris Arboretum*

At a basic level, public gardens are well-equipped to demonstrate potential trees in local climates and interpret the characteristics of those trees in regionally meaningful terms. Public gardens can share information on the native environments of the trees in their collections and how those trees are well adapted for urban sites. Public gardens may be able to provide education on trees to the public in order to improve perception of tree species that provide more ecosystem services, thus decreasing one barrier to planting certain species. There is ample room for public gardens to collaborate in educating the public and professionals, and sharing information through display and outreach.

Cautions and caveats

When considering the role of public gardens in urban forestry, many skeptical questions arise. Public gardens are often extremely different environments, both physically and socially, from nearby or surrounding urban areas. They are an environment often built for pampered trees as well as for socio-economically elite visitors. On a physical level, the well-maintained conditions in public gardens may have little relevance to the tough conditions a tree experiences on a city street, diminishing the urban relevance of tree trials in the garden setting. On a metaphysical level, public gardens in many ways represent a long history of colonial exploitation of the world's plants and people. A large global network of botanical gardens was established in tandem with the British Empire (McCracken, 1997). While the global trade of plant species among networks of public gardens conserves and displays biodiversity (Cavender et al., 2019), it also has historically contributed to colonial notions of planting design, 'civilized' street spaces, and the ease of white settlement (Frawley, 2009). Many public gardens are challenging the disconnect between their spaces and surrounding urban communities, as evidenced by numerous contributions to the 2019 American Public Gardens Association conference in Washington D.C. that was themed around issues of inclusion, diversity, equity, and accessibility.

Gardens are attempting to reach diverse audiences through programming and outreach, while grappling with "a shortage of staff and leadership that reflects this diversity" (Qiu, 2017). Breaking down the cultural, racial, and economic barriers that have long excluded many people from public gardens is a long and difficult process requiring significant institutional changes, and even perhaps a re-imagining of a garden's mission. Many public gardens may not view outreach programs or urban forestry as part of their stated missions.

…you know, how well an urban tree initiative fits in with their mission. Because, for display gardens, why is that, why are we even talking about that? We're a display garden, or a pleasure garden. So really we're mission driven and the [Morris] Arboretum does have connecting people and plants as part of their mission… So, with any non-profit, you know, these initiatives have to be in line with their mission or else they're not going to, probably not going to do it, even if there is money.
Jason Lubar, Associate Director of Urban Forestry, The Morris Arboretum

In my interviews, respondents from outside public gardens mostly viewed public gardens as uninvolved in more urban landscapes and as distant from issues of equity in urban green spaces. When asked directly whether there is a potential role for partnerships with public gardens, one respondent alluded to the disconnect between the advice public gardens can provide and the social goals of tree planting programming:

I want to say that they've got very specific ideas of what kinds of plants they want to put in and it might be a match, but, really, our goal for the Tree Tender program, I think that's why I'm falling over myself, but the goal is really to work with community groups and preferably low-income, high-need neighborhoods.
Mindy Maslin, Tree Tenders Project Manager,
The Pennsylvania Horticultural Society

Many interviewees in Philadelphia spontaneously brought up issues of equity in urban forestry, and several additionally emphasized the need for bottom-up approaches when partnering with communities rather than the top-down dictation of information and planting choices.

So I would not want to see any kind of projects to, whether it's restore old buildings that have gotten run down, or take better care of the parks system, or put more streets trees in, I would not want to see that happening in any way that would disenfranchise residents that are already struggling. And I know the partners from PHS to PPR to everybody else, they're all very committed to equity.

Anonymous Researcher

But we just want them to have trees, because that makes for healthier neighborhoods. A lot of people just aren't aware of the tree benefits, or sometimes, you know that's not their priority, they have other problems that they need to tackle, and they don't have time to think about trees. But I think that a lot more of it is just education, like if they knew there was the ability to get trees. But that also has to come from the community itself, like we don't like to be, we don't like that top-down approach, telling people what they need? And trying to like force that on them? Because ultimately, for the urban forest to do well, you need the community to take ownership of it. So they need to champion the desire to have trees in their community from the get-go. So there's this, I don't know it's kind of a balance between not imposing your thoughts on what the community needs and more of actually listening to them.

Dana Dentice, Urban Forestry Program Manager,
The Pennsylvania Horticultural Society

Urban forestry partnerships that bring community stakeholders in from the beginning are more likely to address the needs of existing residents while avoiding negative gentrification effects: planners and local stakeholders should work together to “design green space projects that are explicitly shaped by community concerns, needs, and desires rather than either conventional urban design formulae or ecological restoration approaches” (Wolch, Byrne, & Newell, 2014). Since public gardens serve as expert consultants in many partnerships, and have a history of reinforcing inequity, they should form equitable partnerships with city organizations and local community groups, and not be satisfied with delivering information from the top-down. The goal is to provide resources while making space for communities to own their urban forestry decisions. While public gardens have much to contribute through the development of urban forestry programs, these gardens must concurrently accept criticism and direction from the communities they intend to serve. Extending the role of a public garden beyond its walls may require breaking down those same walls.

Appendix 9: Recommendations for additions to information in the Philadelphia Parks and Recreation street tree guide.

Many cities develop their own planting lists to recommend or restrict the planting of particular species. These overarching guidelines are commonly used by professionals, but actual decisions are made mostly on an individual scale. The Philadelphia Parks and Recreation's approved street tree list (*Approved Street Trees*, 2017) is also available in an expanded book form (*Philadelphia Street Trees*, n.d.). This book is a "color guide with the profile of each of the trees, that's mostly for our contractors and our staff, so they can reference things, and they can do some community interaction when needed, show them pictures of things" (Erica Smith Fichman). The guide is organized first by tree size, indicating which sites are appropriate for each tree based on its mature height and spread. Eight characteristics are described for each tree: height, spread, habit, sun requirements, growth rate, flowers, leaves, and fruits. The frequency with which each tree should be planted is categorized as "sparingly," "moderately," or "frequently" based on existing diversity ratios in Philadelphia. An "other" section for each tree includes special notes especially regarding tolerance of pests, diseases, and other stressors.

Approximately half of each page is devoted to photographs of each tree's form, flowers, leaves, bark, and fruits. Including several color photos of each tree in the guide makes it a good communication tool for professionals as they describe a potential tree option to a resident. However, the guide is not made directly available to residents, especially since residents are not able to choose what tree the city will plant, although they may make requests:

> *[W]e really don't allow citizens to dictate the tree they want. So you may do your homework, and research specimens, species. No telling if you're going to get that tree. Some of them, depending, again it's contractual, it's limited to get trees, so it's good to offer suggestions, but in no way, if you call and say you want a White Oak, that that's guaranteed.*
>
> *Lori Hayes, Director of Urban Forestry, Philadelphia Parks & Recreation*

Since the guide is mostly used by professionals as a reference, I recommend that additional information on each tree choice should be added and standardized, and that the space allotted to photos emphasizing the aesthetic qualities of each tree should be reduced. Alternatively, the written descriptions of flowers, leaves, and fruits could be removed or de-emphasized, since this information is visually apparent in the color photos. The guide's over-reliance on aesthetic characteristics does not match the planting priorities for Philadelphia (as stated by many interviewees) that de-emphasize the importance of aesthetics in comparison to diversity and function. In particular, information on stress tolerances should be more consistently included, and ecosystem services other than aesthetic interest should be added. Since the street tree inventory for Philadelphia will be completed in the next several years, it should also be possible to update the recommendations for frequency of planting. Including the actual current diversity ratios for each tree may be useful, or at the least defining what percentage of a planting list is meant by "sparingly, moderately, or frequently." Multiple interviewees outside PPR mentioned using the PPR list of recommended trees as a baseline, although they using a simple list rather than the full color guide. Once the guide is updated, it could be distributed to partner organizations and professionals to set the standards tree selection as high as possible across Philadelphia. The addition of this crucial information will increase the usefulness of the guide to city arborists and also make clear the planting goals and priorities of the city.