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Article

Conceptualizing the Human Drivers of Low Tree Diversity in Planted Urban Landscapes

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Abstract: Despite the abundance of tree diversity in the natural world, and generally high tree species richness in urban areas, urban forests continue to be dominated by a limited number of species. As socio-ecological systems, urban forests are shaped by historical and current management efforts and decision-making of a wide range of human actors. Drawing on past research, we offer a conceptual framework for describing the complex interactions among tree producers and consumers as trees are selected, grown, specified, and planted in private and public urban areas. We illustrate how multiple layers of selection criteria filter down the entirety of potential local tree diversity to a handful of commonly used and accepted tree species. We detail the actors and decision makers who impact tree composition and diversity across several land types. Finally, we identify research, education and outreach needs as they relate to creating more diverse and resilient urban forest ecosystems.

Keywords: city trees; landscape design; landscape architecture; socio-ecological system; urban ecosystem; urban forest

1. Introduction

As urban areas expand in size and as human populations continue to concentrate within them (United Nations 2019; Seto et al. 2017), scholars are increasingly interested in how urban ecosystems develop and function (McPhearson et al. 2016; Pickett et al. 2020). Urban ecosystems, including urban forest systems, are shaped by current human actions, as well as the legacies of past decisions (Roman et al. 2018) and can be described as socio-ecological systems (Vogt 2020). To provide humans with ongoing ecosystem services, these dynamic urban landscapes must be resilient to biotic and abiotic stresses (McPhearson et al. 2015). Resilience is an ecosystem's ability to recover from or adjust to disturbances (Holling 1973), and biodiversity is often viewed as key requirement of resilience (Alvey 2006; Ordóñez and Duinker 2012; McPhearson et al. 2015; Steenberg et al. 2019; Huff et al. 2020).

When approaching urban forestry from a management perspective, as we do in this manuscript, it is useful to expand the conception of urban forests beyond trees to include "the associated biotic and abiotic components, including people, institutions, and infrastructure" as part of an integrated socio-ecological system (Steenberg et al. 2019; Vogt 2020). To develop management strategies to ensure the resilience of urban forest systems, research is needed on the relationships between humans and tree species (Loreau et al. 2001; Pickett et al. 2011; Pett et al. 2016). Specifically, there is a basic management need for information regarding the subset of tree species that are suitable for stressful urban growing conditions, produce maximal desired ecosystem services, limit disservices (Roman et al. 2020), and are compatible with changing climatic conditions in a given locale (Esperon-Rodriguez et al. 2022). Legacies of past monocultures have made urban forests vulnerable to tremendous losses from pests and pathogens (Campanella 2003; Poland and McCullogh 2006), yet urban forest managers continue to face challenges in bolstering diversification of planting palettes (Hilbert 2021). Although urban foresters have recognized for decades that taxonomic diversity of planted species boosts urban forest resilience (Santamour 1990; Ball and Tyo 2016), most urban communities rely on a relatively small number of species which dominate the total count of public trees (Lohr et al. 2016; Ma et al. 2020; Galle et al. 2021). With increasing attention on urban tree diversity and compositional patterns from both scholars and practitioners (e.g., Jenerette et al. 2016; Lohr et al. 2016; Nitoslawski et al. 2016; Steenberg et al. 2017; Ordóñez and Duinker 2013), there is a need to advance conceptual understandings of the actors and drivers shaping urban forests.

We draw on multidisciplinary sources to identify the key human actors whose decisions influence tree composition and diversity in planted urban landscapes. We present a conceptual framework to explain how these actors' tree selection decisions perpetuate low urban forest diversity.

2. The Problem of Low Urban Tree Diversity

Urban forests are comprised of all the publicly and privately owned trees within an urban area (Nowak et al. 2010) and are shaped by past and present biophysical and social processes (Roman et al. 2018; Vogt 2020). Tree species diversity includes the total amount of different tree species in an urban area (i.e., species richness) and the relative proportions of those different species (i.e., evenness). Composition (i.e., the identities of species and other taxa) is also important for resilience, particularly in light of pests and diseases impacting multiple hosts from unrelated taxa (Laçan and McBride 2008). Many urban areas have high tree species richness due to an abundance of non-native species (Aronson et al. 2015; Gillespie et al. 2017). This is demonstrated in studies comparing tree species diversity in city centers to adjacent peri-urban and rural areas (Kühn et al. 2004; Blood et al. 2016; Jha et al. 2019). However, the evenness of urban tree ecological communities is often low due to the dominance of a few species within a given city or neighborhood (Lohr et al. 2016; Wang and Zhang 2022)—this over-reliance on a few species is the problem of low urban tree diversity that we address in this paper. The overuse of planted tree species poses a management challenge to managers seeking to improve overall diversity and resilience of the urban forest.

The challenge of low urban tree diversity due to an over-reliance on a few species threatens urban forests across the globe. In a global assessment of 108 urban tree inventories from around the world, on average, a single species made up 20% of a given city's tree population (Lohr et al. 2016). In Helsinki (Finland) and Bangkok (Thailand), 40% of the urban forest was represented by one tree species, common linden (*Tilia × europaea*) and angsana (*Pterocarpus indicus*), respectively (Lohr et al. 2016). Galle et al. (2021) noted that tree diversity appears to be the most limited near the most heavily developed cores of cities. In Amsterdam (The Netherlands) for example, elms (*Ulmus* spp.) accounted for nearly half of the trees (47%) in the city center, compared to 11% of the trees in more suburban quarters of the city (Galle et al. 2021). A similar association between diversity increasing with increasing distance from city center was found in Beijing (China; Jiao et al. 2021). While there are some instances of diversity increasing over time (Nitoslawski and Duinker 2016; Cowett and Bassuk 2021), it is also the case that some communities have experienced declining diversity (Sjöman et al. 2012a).

A limited number of tree species and genera dominate urban forests in the United States (US) and Canada, as well (Lohr et al. 2016; Cowett and Bassuk 2017; Ma et al. 2020;

Galle et al. 2021). Historically, uniform planting of a single species through entire urban neighborhoods was viewed as desirable both aesthetically and in terms of management convenience, with taxa such as American elm (*Ulmus americana*) and London planetree (*Platanus* × *hispanica*) dominant in street tree plantings in northeastern US cities (Dümpelmann 2019; Roman and Eisenman 2022). The legacies of past monocultures create time-lagged vulnerabilities to pest and disease outbreaks (Greene and Millward 2016).

Overall, low tree species evenness increases the potential for greater losses due to an over-reliance on a few taxa. Furthermore, species-level diversity assessment can be problematic. When species diversity is the primary metric of diversity and higher taxonomic relationships are not considered, or are considered to a lesser degree, this exacerbates the potential threats to the urban forest because many of the most damaging introduced pests and diseases impact plants at the genus or family level (Morgenroth et al. 2016). For example, emerald ash borer (*Agrilus planipennis*) typifies a genus-level threat. Following the widespread loss of American elm to Dutch elm disease (*Ophiostoma ulmi* and *Ophiostoma novo-ulmi*), ash trees (*Fraxinus* spp.) were planted throughout temperate urban landscapes in the US and Canada. Between 2009 and 2019, emerald ash borer affected an estimated 37.9 million ash trees in urban communities in the eastern US, with an estimated cost of US$10.7 billion in management expenses (Kovacs et al. 2010). Financial losses from emerald ash borer extended to nursery producers as well. In Michigan, nurseries experienced US$11.6 million in damages and restricted sales due to reduced demand for the trees as a result of the invasive pest (Herms et al. 2004). This is just one example of a contemporary pest disaster resulting from low urban forest diversity, and accompanying challenges for the nursery trade.

The Dutch elm disease crisis around the 1970s, which decimated American elm populations in cities throughout the US and Canada (Campanella 2003), actually spurred the development of the "urban forest" as a concept (Dean 2008; Roman et al. 2018), in that managing a collection of urban trees for pathogens required a system-wide consideration of the entire forest, as opposed to single-tree arboricultural treatments. Since the late 20th century, urban forest researchers and managers have proposed various guidelines for managing urban forest diversity. For instance, Santamour's (1990) oft-cited 10-20-30 rule suggests that if managers want to limit deforestation due to pests and disease, a given community of trees should be comprised of no more than 10% of a single species, 20% of a single genus, or 30% of a single family by stem count. Despite widespread recognition of the importance of diversity to forestalling major tree losses, a few species dominate the urban forests of many cities (Ma et al. 2020). For example, across 188 communities throughout the continental US, only six species accounted for the majority (61.5%) of a given city's street trees, and the single most common species in a given region had a mean abundance of 14% to 23% (Ma et al. 2020). These results mirror the findings of a study of 275 urban tree inventories in New York, Pennsylvania, and New Jersey, which found that Norway maple (*Acer platanoides*), a known invasive in this region, accounted for over 16% of street trees (Cowett and Bassuk 2017). Moreover, maples (*Acer* spp.) accounted for nearly 39% of the aggregated population across the tree inventories in those tree states (Cowett and Bassuk 2017). Maples also dominate in Toronto, Ontario, and other Canadian cities, due in part to political symbolism of maples in Canada (Vander Vecht and Conway 2015; Roman et al. 2018). With multi-host pests such as Asian long-horned beetle (*Anoplophora glabripennis*) and shothole borer (*Scolytus rugulosus*) threatening other regions of the US and Canada (Berland and Hopton 2016; Rabaglia et al. 2019), strategies to diversify at multiple taxonomic levels, and invest in underutilized species, have become even more important to reduce urban forest vulnerabilities (Laçan and McBride 2008, Hilbert et al. 2022).

The limited urban tree diversity revealed in the aforementioned studies is a worldwide problem and is the product of a long chain of ecological, social, and economic constraints associated with tree biology, nursery production, site-specific demands, and final adoption by end-users, that is, actors selecting trees for public spaces (Conway and Vander Vecht 2015; Kabrel 2016; Nitoslawski et al. 2016). To remain competitive, tree growers are constrained by biology; the realities of producing a quality, marketable product of slow-growing plants; and the complexities of consumer demand (Thompson et al. 2021; Hilbert 2021), which do not fully reflect the risks associated with continued reliance on over-used species in the planted landscape. High profitability and low economic risk motivate tree producers to favor fast-growing, easy-to-manage, and high-demand trees (Hilbert 2021). These business realities diminish the palette of available urban trees, resulting in production systems and landscapes that are less diverse and thus less resilient to pests and pathogens, as well as to abiotic pressures (e.g., climate change) (Lohr et al. 2016). As most trees require three to ten years to reach marketable size, this relatively long-term investment is a financial burden for many producers (Warren 1990; Burcham and Lyons 2013). Consequently, there exists little economic reward for experimenting with species perceived as less familiar, slower growing, or for which current market demand is low or questionable. At the end of the process, major purchasers of trees for urban tree planting (e.g., municipal arborists, landscape designers working with developers) are left with limited options that often do not reflect the diversity that is ecologically possible for a given region (Hilbert 2021).

3. The Planted Urban Landscape

Trees in the planted urban landscape (as opposed to trees in urban forest natural areas) are subject to intensive human control over species composition and community structure, with trees typically arising from planting decisions with minimal natural regeneration (Roman et al. 2014; Roman et al. 2022). The planted urban landscape includes trees along streets, in parking lots, and other hardscape settings, as well as trees in lawns and other manicured ground cover at neighborhood parks, institutional settings, and residential landscapes (van Doorn et al. 2020). The arboricultural best practices for planted tree care includes pruning, mulching, weeding, plant health care interventions, and planned removals. It can be particularly challenging to grow trees in highly developed landscapes because of conditions like altered soils, drought stress, pollutants, and disruptions to nutrient and water availability (Miller et al. 2015; Roloff 2016). In this article, we focus on planted landscapes that exist in many contexts along the urban-rural gradient (i.e., not just in downtown urban cores), which can be broken down into several different land types (Table 1). Specifically, we focused on the planted urban landscape in which tree selection and population demographics are anthropogenically-controlled (Roman et al. 2016), and we outline the human actors who participate in tree selection and procurement. We draw on multidisciplinary sources to propose a conceptual framework that demonstrates how human decisions and associated limitations influence tree composition and diversity in planted urban landscapes. Our discussion focuses primarily on the process of selecting trees through nursery production and eventual planting in the built landscape, but acknowledges the indirect effects some actors, such as urban planners, can have on the built landscape and resulting taxonomic composition.

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Table 1. Built-up urban land types on which trees are actively planted and managed (adapted from Nitoslawski et al. 2016). Based on urban forest systems in North America.

Land Type	Residential - existing	Residential - new or renovated	Institutional	Street and right-of-way	Manicured parks and gardens	Commercial/ industrial
Ownership	Private	Private	Public or private	Public (generally)	Public or Private	Private
Tree Site Types	Yards, patios, gardens	Yards, patios, gardens	Open space dominated by lawn or other planted ground cover	Sidewalk cut-outs, planting strips, road verge, medians	Open space dominated by lawn or other planted ground cover	Parking lot islands, courtyards
Tree Management	Landholder, tenant, landscape contractor	Landholder, tenant, real estate developer, landscape contractor	Private institutional landholder, public agency, landscape contractor	Municipality, business district, contractor, tenant, volunteer tree steward	Municipality or another public department, private garden landholder	Landholder, landscape contractor

4. Conceptual Framework: How Humans Produce Urban Tree Diversity

Humans act at several stages in the tree selection process. The incorporation of a tree species into a planted landscape is typically preceded by a long process that begins with local, regional, and global plant exploration and the testing of the viability of the species as a commercial product (Stage 1: Germplasm and Propagule Supply) (Sjöman et al. 2012b; Jones 2016), then leads to nursery production (Stage 2: Market Availability) (Avolio et al. 2018), inclusion in landscape design plans and specifications (Stage 3: Site Design) (Conway and Vander Vecht 2015; Thompson et al. 2021), and the eventual planting of the tree (Stage 4: Planted Trees) (Figure 1). The different stages in this process are driven by the decisions made by different actor groups, each limited to varying degrees by the decisions made by those in preceding stages (Figure 1, Table 2). Furthermore, there is a feedback loop that occurs when those who purchase and plant trees (Stage 4) send a consumer signal to the tree growers (Stage 2) who in turn base stock decisions on sales. Those at the end of the process are greatly limited by availability, and even if they want a diverse set of species to select from, their purchasing may be directed towards the available tree species, as opposed to the desired alternatives. "Stage 3: Site Design," refers not only to landscape architects/designers, but the planners and managers who are responsible for creating landscaping codes, developing planting lists, and making tree recommendations. Some actors in Stage 3 may also operate within Stage 4, and vice versa, but our conceptual framework organizes them based on the stages within which they predominately operate.

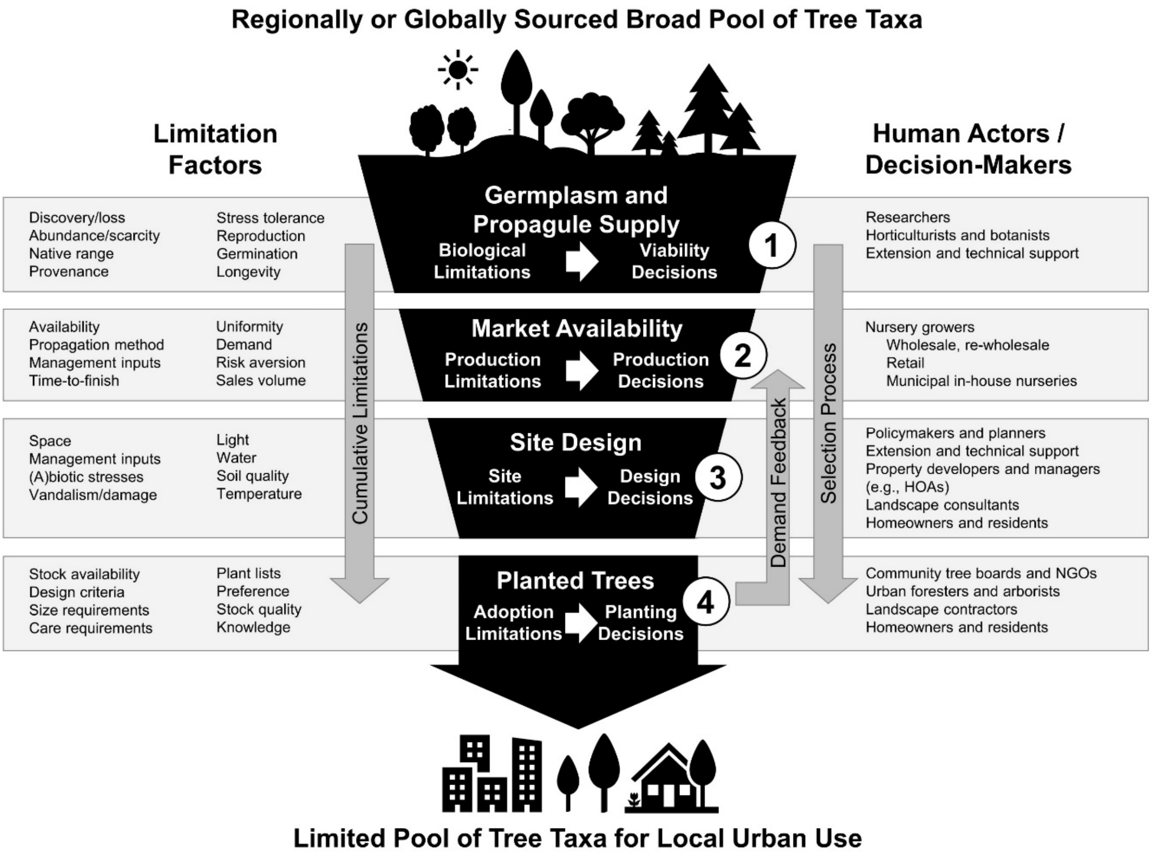

Figure 1. The selection funnel demonstrating how cumulative limitation factors and decisions by human actor groups at each stage in the tree supply chain (Stages 1-4) reduce the diversity of trees that are perceived as suitable for urban areas from a broader pool of possible locally or globally sourced tree taxa (adapted from Krabel 2016). Furthermore, a consumer demand feedback loop occurs when tree purchasers (Stage 4) select from the available stock, signaling growers (Stage 2) to continue to produce that subset of tree species that sell well.

Table 2. Key human actors whose decisions impact tree selection and resulting urban forest species diversity. The stages correspond to the planted tree diversity conceptual framework (Figure 1). Spatial scale refers to the scale at which the actors predominately operate.

Actor	Description and role in selection process	Stage in selection process	Spatial scale	Selected sources
Researchers	Scientists who investigate the viability of new species for commercial and urban use through breeding trials; may work for public or private research institutions	1	Regional	Sæbø et al. 2005; McPherson et al. 2018; Sjöman et al. 2012b
Horticulturists	Professionals or hobbyists who investigate the viability of new species for ornamental, commercial and urban use through breeding trials (formal or informal); may work for public or private institutions (e.g., botanic gardens)	1	Regional	Cavender and Donnelley 2019; Hirons et al. 2021
Extension and technical support	Science technology transfer professionals; typically work for public research and education institutions (e.g., state university extension or USDA Forest Service)	1, 3	Regional; municipal	Gilman 2015; McPherson et al. 2018; Hilbert et al. 2020
Nursery growers	Tree growers who cultivate at the propagation, wholesale, or retail levels	2	Regional	Polakowski et al. 2011; Lohr 2013; Conway and Vander Vecht 2015; Whittet et al. 2016; Avolio et al. 2018; Hilbert et al. in review
Policymakers and planners	Public policy and decision makers who create laws that influence the urban forest; may include politicians, urban planners, city sustainability directors, etc.	3	Regional; municipal; neighborhood	Northrop et al. 2013; Nitoslawski and Duinker 2016; Ordóñez 2019
Property developers	Real estate developers who purchase land and build or oversee building on it; may have their own landscape management team or may hire contractors	3	Neighborhood; household	Nitoslawski et al. 2016; Thompson et al. 2021; Roman and Eisenman 2022
Property managers (e.g., HOAs)	Official organizations of property managers beyond single property owners (e.g., homeowners associations); typically have landscaping rules and hire landscape maintenance contractors	3	Neighborhood	Lerman et al. 2012; Schmitt-Harsh and Mincey 2020
Landscape consultants (e.g., landscape architects, engineers)	Professional landscape designers; may work for public institution or private company to create site plans that specify trees	3, 4	Neighborhood; household	Conway and Vander Vecht 2015; Thompson et al. 2021; Hilbert et al. in review
Community tree boards and NGOs	Organizations of individuals invested in tree planting/and or stewardship; may include voluntary municipal tree boards or non-governmental organizations like urban greening groups	3, 4	Regional; municipal; neighborhood	Greene et al. 2011; Conway and Vander Vecht 2015; Roman et al. 2015; Sax et al. 2020
Urban foresters	Tree professional focused on large-scale management of the urban forest; may work for city or as a private consultant	3, 4	Regional; municipal	Sydnor et al. 2010; Conway and Vander Vecht 2015; Petter et al. 2020a, 2020b
Arborists	Tree professional focused on individual tree care; may work for city, as private consultants, or for utility districts	3, 4	Regional; municipal; household	Sydnor et al. 2010; Burcham and Lyons 2013; Petter et al. 2020a, 2020b

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Landscape contractors	Landscape maintenance professionals; typically hired by property owners or municipalities for planting and care	3, 4	Neighborhood; household	Miller et al. 2015; Nitoslawski et al. 2016
Landholders, tenants	Owners or occupants of residences	4	Household	Loram et al. 2011; Kendal et al. 2012; Plant and Kendal 2019; Avolio et al. 2020; Cubino et al. 2020.

Key actors' decisions also affect tree diversity at different spatial scales in the urban landscape (Thompson et al. 2003; Cook et al. 2012; Shakeel and Conway 2014; Steenberg et al. 2015; Yang et al. 2015; Thompson et al. 2021). As outlined in Table 2, this can include household, neighborhood, municipal, and regional levels (Table 2). In addition to acting on different stages in the selection process and different spatial scales, human decision-makers also impact different built-up land types—either directly, indirectly, or both, depending on their role in the actual selection, procurement, or installation of trees (Table 3). Those at the beginning of the process tend to have indirect effects on the resulting tree species diversity within all the land types, since they are farther removed from the actual decision of "what tree gets planted here". Those involved with landscape design and the creation of tree planting lists and recommendations can have more complex relationships with the diversity of land types since their species recommendations may or may not be implemented in the landscape when the time to plant comes (i.e., what was planted was not what was recommended, or recommended lists were not used). Arborists, landscape contractors, urban foresters, and homeowners active in tree procurement and planting have the most direct interactions with the resulting observed tree species diversity.

Table 3. Different built-up urban land types and the human actors whose decisions impact tree selection and resulting urban forest species diversity.

	Residential – existing	**Residential – new or renovated**	**Institutional**	**Street and right-of-way**	**Manicured parks and gardens**	**Commercial/ industrial**
Researchers	○	○	○	○	○	○
Horticulturists/botanists	○	○	○	○	○	○
Extension and technical support	○	○	○	○	◐	○
Nursery growers	○	○	○	○	○	○
Policymakers and planners	○	○	○	○	○	○
Property developers	○	◐	◐	◐	◐	◐
Property managers (e.g., HOAs)	◐	◐	◐	◐	◐	-
Landscape consultants (e.g., landscape architects)	◐	◐	◐	◐	◐	◐
Community tree boards and NGOs	○	○	◐	◐	◐	○
Urban foresters	◐	◐	◐	●	●	●
Arborists	●	●	●	●	●	●
Landscape contractors	●	●	●	●	●	●
Landholders, tenants	●	●	●	◐	○	-

Legend: ● = direct role in tree selection, ○ = indirect role in tree selection; ◐ = either direct or indirect role depending on situation; - = no role.

5. Summary

The focus of this framework was on the actors involved in tree selection, procurement, and planting, and on the limitations and decision-making processes connected to the various actors. As demonstrated by the conceptual framework and our summary of the supporting literature, urban forest diversity is undermined by the established system of tree production and procurement. This is concerning given that diversity is a key facet of resiliency in the face of threats from introduced pests and climate change (Berland and Elliot 2014; Brandt et al. 2016). By focusing on the highly managed landscape—where new trees are by and large the result of human planting decisions—we created a focused framework that can guide future research and transdisciplinary collaborations regarding urban tree diversity in a particularly challenging landscape for trees. We suggest the following future research topics to address the different stages within the framework:

- Stage 1 – Germplasm and Propagule Supply: Discovery and trialing of underutilized species for urban use, particularly with respect to climate change (e.g., McPherson et al. 2018; Hilbert et al. 2022).
- Stage 2 – Market Availability: Nursery production studies to bring underutilized species to market; economic policy studies on incentives that reduce the risks growers face in introducing new stock; case studies of successful procurement arrangements (e.g., Stephens 2010).
- Stage 3 – Site Design: Social studies on the knowledge, priorities and concerns of the different actor groups in relation to tree selection and urban tree diversity; development of urban landscape management interventions that reduce site limitations and positively influence tree survival and health.
- Stage 4 – Planted Trees: Social studies on the knowledge, priorities and concerns of the different actor groups in relation to tree selection and urban tree diversity (e.g., Cubino et al. 2020).

Conceptual frameworks are meant to be revised and expanded upon as new knowledge and scenarios are discovered (Jabareen 2009). Our framework is largely drawn from the context of the continental US, although past literature clearly shows that tree diversity challenges exist in cities throughout the globe. As such, this framework should guide future work by researchers examining different ecological, economic, and governance contexts to bring more understanding to why we have low urban tree diversity in planted landscapes and what managers can do to intervene and maximize the ecosystem services trees provide to the growing number of urbanites worldwide.

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