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Selecting and Assessing Underutilized Trees for Diverse Urban Forests: A Participatory Research Approach

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Urban forests provide critical environmental benefits, but the resilience of these socio-ecological systems to stresses like pest and disease outbreaks relies on tree health and diversity. Despite this, low species diversity continues to be a challenge in urban forest management. Using a participatory research approach in central Florida (United States), we selected and tested underutilized native tree species (*Celtis laevigata* Willd., *Ilex vomitoria* Aiton, *Taxodium ascendens* Brongn., *Ulmus alata* Michx., and *Viburnum obovatum* Walter) in two urban settings (streetscape and park) in four communities (total *n* = 200). Our collaborative process was organized into five steps, including a 2-year monitoring period to assess mortality and health through establishment. At the end of the trial, 156 trees survived with annual mortality rates differing by species and plot type. *Taxodium ascendens* had the highest annual mortality of the five species trialed. Overall, *U. alata* and *V. obovatum* showed the greatest potential in central Florida urban settings. Our tree selection process can guide others who want to create forward-thinking and diverse planting lists. Furthermore, this project demonstrates that co-production of knowledge involving members of local municipalities, practitioners, and researchers can be an effective strategy for selecting and testing underutilized tree species.

Keywords: city trees, species diversity – woody plants, knowledge co-production, municipal forestry, transdisciplinary research, tree survival

INTRODUCTION

Urban forests serve many ecological functions (Ordóñez and Duinker, 2012), including regulation of hydrological cycles (Bartens et al., 2008; Livesley et al., 2016) and reduction of building energy-use (Ko, 2018). For urban forests to continue to provide such benefits, they must be resilient to disturbances like climate change, pests, and pathogens. Ecosystem resilience, the ability of a system to encounter a disturbance (and possibly change as a result) while maintaining its functions (Walker et al., 2004), relies on several factors, including species and genetic diversity, management history, the size of the forest, and the state of the surrounding landscape (Peterson et al., 1998; Thompson et al., 2009). While early resilience literature is generally focused on ecological components of natural systems, the resilience concept has expanded to address urban socio-ecological systems, including urban forests (Huff et al., 2020).

In Steenberg et al.'s (2017) framework on urban forest ecosystem vulnerability, the term "adaptive capacity" is used in place of resilience to describe the ability of a community to manage the functions of an urban forest in the face of stressors. Both socio-ecological resilience and adaptive capacity are useful terms when describing urban forests, in which tree systems are intimately connected to human actions such as planting, maintenance, and removal (Roman et al., 2020). For example, management strategies that promote species diversity to reduce vulnerability to pests, diseases, and droughts have been framed as building urban forest resilience (McPherson and Kotow, 2013; Fahey et al., 2013). The risk of having tree monocultures in cities has been demonstrated in the United States (US) and Canada through devastating outbreaks of the chestnut blight fungus [*Cryphonectria parasitica* (Murrill) Barr], Dutch elm disease [*Ophiostoma novo-ulmi* (Buisman) Melin and Nannf.], and more recently from the emerald ash borer (*Agrilus planipennis* Fairmaire) (Sinclair and Campana, 1978; Schlarbaum et al., 1997; Raupp et al., 2006). Emerald ash borer, which attacks trees in the *Fraxinus* genus, has spread to 35 states in the US (USDA and APHIS, 2020) and is estimated to have cost North American cities over 10 billion USD (2010 currency rate) to manage (Kovacs et al., 2010; McKenney et al., 2012). In response to such losses from invasive pests and pathogens, and the recognition among urban forestry professionals that there was a historical overreliance on a limited set of species, practitioners and researchers have supported species diversification since the 1970s (Morgenroth et al., 2016; Roman et al., 2018).

Despite these devastating outbreaks, the problem of low urban tree species diversity continues. For instance, *Tilia* species constitute between 13 and 46% of the total tree population in Nordic cities (Sjöman et al., 2012). In the temperate northeastern US, *Acer* species dominate the urban forest (Cowett and Bassuk, 2017), and recent plantings in this region continue to feature species in the genera *Quercus*, *Syringa*, and *Prunus* despite their current abundance (Doroski et al., 2020). Similarly, *Fraxinus pennsylvanica* Marshall comprised 35.3% of the total street tree population in communities in South Dakota – a state with a continental climate (Ball et al., 2007). In subtropical Tampa, Florida, only 10 of the 109 inventoried species made up 63% of Tampa's inland urban forest (Landry et al., 2018).

This overreliance on a handful of species undermines efforts to increase urban forest resilience in the face of inevitable stressors. Tree care practitioners often rely on a limited number of species that are readily available and sturdy enough to thrive in the built environment (Conway and Vander Vecht, 2015; Miller et al., 2015). Municipalities, non-governmental organizations, and other practitioners such as landscape architects do consider diversity when selecting trees, but these efforts to diversify are frequently limited by tree availability (Burcham and Lyons, 2013; Conway and Vander Vecht, 2015), site constraints, and local regulations (Miller et al., 2015). Growers face the additional challenge of operating within an unusually extended crop cycle in which they must plan for market demand 10–15 years out (Burcham and Lyons, 2013). These factors create a feedback loop that limits the variety of tree species that are produced, purchased, and planted. To address the diversity and resilience of urban forests, human decisions and management practices must be considered.

To mitigate the risk of catastrophic canopy loss associated with the loss of a dominant genus or species, it is essential to identify underutilized species that can be planted to diversify urban forests. The concept of underutilized species has been applied in agricultural and silvicultural systems, where scholars and policymakers have pursued neglected and underutilized species to address productivity, food security, malnutrition, and resilience to climate change (Youngs, 1989; Youngs and Hammett, 2001; Padulosi et al., 2013; Barbieri et al., 2014; Hunter et al., 2019). In the urban forestry context, we define underutilized tree species as those with the potential to thrive in the cultivated, human-dominated urban landscapes of a particular city or region, but which are rarely planted. As financial resources for tree planting and maintenance are often limiting (Hauer and Peterson, 2016), local practitioners typically require some assurance that investing in these lesser-used species will generate expected growth and benefit outcomes.

To further complicate efforts to increase species diversity, trees have the potential to be long-lived organisms. As such, the species chosen for diversification must be suitable for a site's current and projected conditions (Richards, 1983; McPherson and Kotow, 2013). To address this concern, researchers have developed tools like the Climate-Species-Matrix (Roloff et al., 2009), which categorizes species and their usefulness based on predicted climate changes in Central Europe. The Citree database (Vogt et al., 2017) builds upon this research by providing a detailed list of nearly 400 species and a web-based app that allows for the selection of trees based on different design specifications. There is also the Pest Vulnerability Matrix (Laçan and McBride, 2008), which uses municipal tree inventories, combined with existing and potential pest and disease threats for those locales, to display tree species diversity and related susceptibility. These efforts provide tools for species selection decision-making by urban tree professionals—including municipal arborists, non-profit urban forestry staff, landscape arborists, and local tree commission members—to promote resilient urban forests, particularly in terms of pests, diseases, and climate change. Our paper goes a step beyond these tools, pairing them with a series of field trials of underutilized species, done in partnership with local practitioners. Our overarching goal is to demonstrate an approach that can be used to identify underutilized species and evaluate their performance potential.

Research Objectives

In the field of arboriculture, there is a long history of studies that test the performance of new cultivars for use in urban areas (Gerhold et al., 1994; Gerhold, 2007). However, the testing of species specifically for diversity and climate preparedness is a newer avenue of research, as is the inclusion of stakeholders through participatory research approaches. A long-term study of drought-tolerant trees is being conducted in northern California to assess the survival, growth, and climate vulnerability of six tree species (McPherson et al., 2017). A complementary study is underway in California that will help identify "climate ready trees" and outline the steps needed to test trees for their potential vulnerability to climate stressors (McPherson et al., 2018). Roman et al. (2015) studied the survival of less common, drought-adapted tree species planted in East Palo Alto, California, finding high survival rates and qualitative data that supports the importance of stewardship. Informal trial and error plantings and studies are equally important, such as the work done by an International Society of Arboriculture Board-Certified Master Arborist on uncommon oaks for use in California (Muffly, 2008). To conserve biodiversity and increase the adaptive capacity of communities, researchers must partner with stakeholders from the community (Torkar and McGregor, 2012). Without the knowledge these trials provide, both growers and buyers cannot be confident in trying out new trees and are likely to use ones that are consistently in demand.

In this paper, we outline a collaborative process for selecting and trialing underutilized species that can be adopted in other regions with different climates and available plant material. We begin with a general approach for selecting potential species to trial. We then offer a real-world demonstration of the application of this process and an associated monitoring study through the experiences of a regional working group of educators, government officials, practitioners, and researchers. In relating these ideas and experiences, our objectives are to: (1) present a participatory research approach for research-practice collaborations to address the common concern of low tree diversity, (2) offer our experiences in central Florida as evidence of the practical utility of this approach.

MATERIALS AND METHODS

Approach for Selecting Underutilized Tree Species

The number of potential tree species one could trial in a given area can be somewhat overwhelming, especially when considering the uncertainty around how lesser-known species will perform given the multitude of plant, design, and site factors one must consider when selecting urban trees. As such, the development of a tree planting list for the diversification of the urban forest benefits from a knowledge co-production approach that incorporates practitioner experiences and priorities as well as past research. **Figure 1** outlines the process we developed for this study.

The approach involves the following five steps:

1. **Classify underutilized tree species from the region:** Define a threshold for what constitutes an underutilized species based on urban forest risk or stakeholders' canopy loss tolerance. For example, this could be any species that currently makes up less than 10 percent of the urban tree population, if following the 10-20-30 rule which suggests an urban tree population should contain no more than 10 percent of any one species, 20 percent of any one genus, and 30 percent of any family (Santamour, 1990).
2. **Create a draft list of potential tree species to trial, based on these criteria for inclusion or exclusion:**

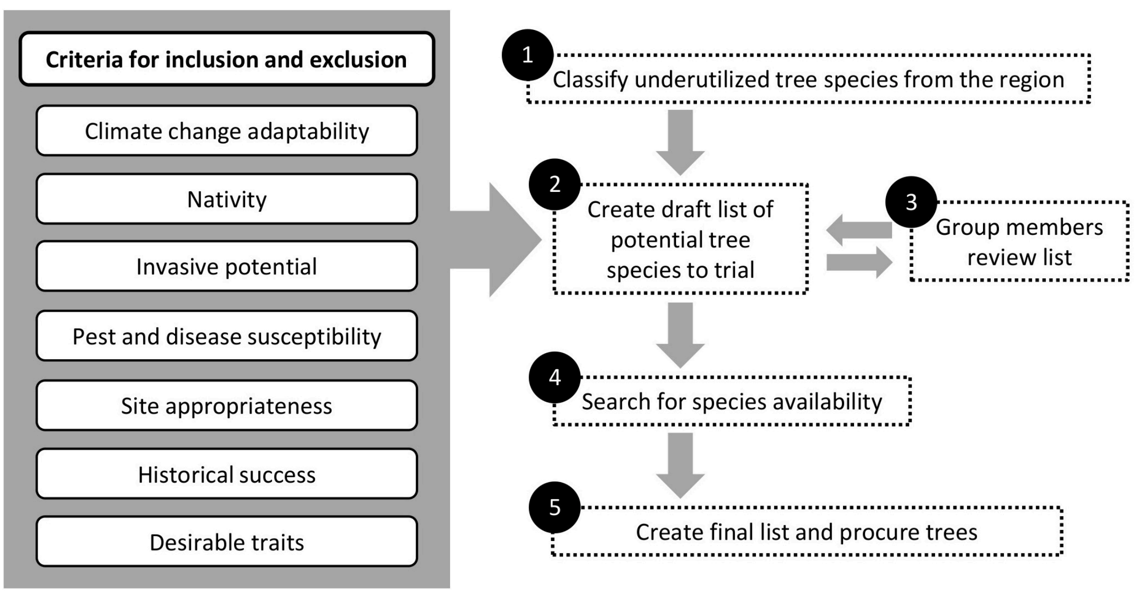

FIGURE 1 | An approach to select underutilized urban tree species for experimental trials through transdisciplinary collaboration. The **left panel** outlines the criteria a group may consider important for the inclusion or exclusion of particular species. The **right panel** outlines the process for developing the list of trees to trial. The process is not always linear, as draft lists are revised and reviewed several times during group discussions and emails. Species availability may also influence the final list.

- *Climate change adaptability:* Assess whether the underutilized species is appropriate for both the current and projected climate, factoring in specific microclimate conditions that could facilitate and further limit the adoption of a species (Brandt et al., 2016; McPherson et al., 2017, 2018).
- *Species Nativity:* Determine the natural range of each species to be considered if plant selection group prioritizes native species and their associated ecological functions. Choosing native trees can support native animal diversity (Tallamy and Shropshire, 2009) and decrease the chances of introduced species escaping cultivation and becoming invasive in the ecosystem (Hulme et al., 2008). However, non-native tree species may be necessary when looking for underutilized urban trees, especially in regions with limited native tree diversity or urban conditions that differ greatly from local, non-urbanized habitats (Sjöman et al., 2016).
- *Invasive potential*: If non-native species are considered for inclusion, use regional invasive plant resources (e.g., USDA and National Invasive Species Information Center [NISIC], 2021) to assess the potential threat posed by each species (and any applicable restrictions), so that non-natives with invasive tendencies are not used in the trial.
- *Pest and disease susceptibility:* Use regionally appropriate references (e.g., state extension resources and regional horticultural guides) to determine if the underutilized species is susceptible to any pests or diseases that would limit their functional longevity (Laçan and McBride, 2008).
- *Site appropriateness:* Consider the likely planting sites and determine if there are any site-specific conditions (e.g., soil, hydrology, light availability) or regulations that would prevent planting or long-term success of the species (e.g., local ordinances and policies regarding permitted tree species for planting).
- *Historical success:* Draw on local practitioner knowledge of past planting efforts (Muffly, 2008) to determine if an underutilized species has an anecdotal history of failure despite its supposed appropriateness for the region and site. Consult local urban tree inventories to determine if mature, healthy specimens exist in the local urban forest, which in turn suggests that a given species has the potential to thrive.
- *Cultural Significance:* Work with local communities to identify species having a significant cultural value (e.g., as spiritual representations, food sources, medicinal sources, fiber/dye sources).
- *Avoid species with traits associated with nuisance disservices:* Traits like large or messy fruits, poor compartmentalization, thorns, frequent root sprouting, or human toxicity may limit the appropriateness of a species in certain locations (Roman et al., 2020). Discussions with local practitioners can shed light on underutilized species with reputations for nuisance complaints.

3. **Group members review list:** After working through the criteria above, engage the community of practice to identify which species they favor or wish to avoid, based on factors such as species traits, ecological functions, and cultural or personal connections. It is important to involve practitioners in the creation of the list and its revisions so that everyone supports the final plant selections and is invested in the planting trial and its outcomes.
4. **Search for species availability:** Determine what size or stock attributes (e.g., production method) are preferred or required. Assess nursery availability using local plant finders, wholesaler stock lists, or other resources. Species availability is frequently a limiting factor for those wanting to plant uncommon tree species (Burcham and Lyons, 2013; Conway and Vander Vecht, 2015). Species which are deemed appropriate after group review but are completely unavailable at regional nurseries are impractical for planting trials if the communities involved lack in-house production facilities.
5. **Create the final species list for trial and procure trees:** After the list of species for planting has been refined based on nursery availability, confirm this final list with the researchers and practitioners and procure the planting materials.

Practical Demonstration – Tree Selection and Establishment in Central Florida, United States

In this section, we demonstrate the practicality of our approach based on our experiences with the tree selection process (**Figure 1**) in central Florida (US) (**Figure 2**). The central Florida region has a warm temperate climate with hot summers (Beck et al., 2018). This region is a densely populated and rapidly urbanizing area along the Interstate-4 highway corridor. Florida is the third most populous state in the US, and 91.3% of its residents live in urban areas (Florida Department of Transportation, 2021). There are approximately 15.2 million publicly owned trees in the state of Florida, and urban forestry is a major industry, with an output of approximately USD $8.40 billion in 2017 (Hodges and Court, 2019).

The Central Florida Urban Forest Diversity Working Group—composed initially of local government (*n* = 7), extension/research (*n* = 6), nursery (*n* = 1), and state/federal forest service professionals (*n* = 2) from the region—is focused on creating strategies for urban forest diversity monitoring, policy, and adaptive management. The Working Group (hereafter "we") formed in 2016 and met sporadically through 2018 to discuss issues of low diversity. In December 2016, we met to discuss the possibility of testing underutilized tree species for use in the urban landscape. One of our members, an extension researcher from the University of Florida (Koeser), proposed having their new graduate student (Hilbert) lead the trial. The extension researcher was embedded in the working group (Campbell et al., 2016), having participated fully in the group since its inception. The graduate student joined the existing community of practice, created a list of underutilized trees, and ran the experimental trial.

FIGURE 2 | Map of central Florida, US, showing partnering communities where trees were planted (red dots) for the establishment trial. Moving left to right, planting trial locations were Pinellas County, Hillsborough County, the City of Lakeland, and the City of Orlando. Representatives from each of these communities were members of the Central Florida Urban Forest Diversity Working Group that developed the planting list.

Practical Demonstration – Underutilized Species Selection Approach

We met in February 2017 to discuss the planting trial as a critical step to address issues of low species diversity. In developing the potential underutilized tree species to test, many different factors had to be considered, and the species list underwent several iterations along the way (**Figure 1**). Below we show how our approach was used in central Florida to develop the final list of trees that would then be trialed. It is important to note that some of these steps were not linear but involved back-and-forth discussions with group members.

1. **Classify underutilized tree species from the region:** To classify underutilized tree species, we compiled public tree inventory data from seven municipalities around Florida (Coconut Creek, Green Cove Springs, Milton, Naples, Ocala, Orlando, and Tampa). These data sets included primarily trees along streets and in managed parks. Trees that made up 1% or less by count within any given municipality were designated as underutilized. We considered other threshold levels but opted for the more restrictive 1% to limit the number of species considered. The most common (and thus avoided) tree species in the dataset were *Quercus virginiana* Mill., *Lagerstroemia indica* L., *Quercus laurifolia* Michx., and *Sabal palmetto* (Walter) Lodd. We found 313 species that were 1% or less of the urban forest tree communities in the aforementioned municipalities.
2. **Create a draft list of potential tree species to trial, based on these criteria for inclusion or exclusion:**

   - *Climate change adaptability:* Predicted climate trends in central Florida include an increase in days with temperatures over 26.7°C, decrease in wet season precipitation, and more extreme tropical storms (Florida Oceans and Coastal Council, 2010; U.S. Global Change Research Program, 2017). These changing climate conditions were compared to the species' tolerances to wind, flooding, drought, and heat stress based on the tree fact sheets from the University of Florida Environmental Horticulture Department, as well as other literature, when available (Dirr, 2002, 2011; University of Florida IFAS, 2021b). Natural habitat distributions and current hardiness zones for North American species were also examined (USDA Agricultural Research Service, 2012).
   - *Species nativity:* Our group favored native species for this project because Florida has a wide variety of native tree species (Nelson, 1994), and choosing native trees can support native animal diversity (Tallamy and Shropshire, 2009). Furthermore, prior introductions of non-native plants to the region have resulted in numerous species escaping cultivation to become major pest plants (Florida Invasive Species Council, 2021; University of Florida IFAS, 2021a). However, non-native species which were not considered invasive were not totally excluded from the selection process.
   - *No invasive potential*: When selecting non-native species, the researchers screened the tree species against two regional pest plant databases to ensure they were not documented as being invasive or potentially invasive to central or south Florida University of Florida (Florida Invasive Species Council, 2021; University of Florida IFAS, 2021a).
   - *Pest and disease susceptibility*: We also considered susceptibility to pests and diseases (including new and emerging ones) to be important because managing these stressors can require significant resources. Regional pest reports were referenced (Florida Department of Agriculture and Consumer Services, 2017; University of Florida IFAS, 2021c), as well as literature on pest vulnerability in urban forests (Laçan and McBride, 2008). Working Group members were also sources of anecdotal and experiential knowledge on this topic, having dealt with tree health issues in practice first-hand.
   - *Site appropriateness:* We discussed the likely growing conditions at the local test plots (street rights-of-ways and parks) and how they relate to tree planting success. The researchers decided to focus on trees that had short-term flood tolerance and long-term drought tolerance (Florida has both a dry and a rainy season), and an ability to tolerate a range of soil salinity and pH values. Several horticultural sources were referenced to determine the site needs and tolerances of each proposed species (Duryea et al., 1996, 2007; Watkins et al., 2005; Northrop et al., 2013; Buckley, 2015; Texas A&M University, 2017; University of Florida IFAS, 2021b).
   - *Historical success:* We discussed the proposed species' historic success given the experiences of the practitioners, including informal trials in their respective communities. The researchers also examined public tree inventory data (see step 1 above) to search for which underutilized

species were present at large diameter at breast height (DBH) sizes, indicating their ability to survive over time in urban environments and grow to maturity.
- *Avoid species with traits associated with nuisance disservices:* The practitioners in the working group voiced concerns about planting trees with messy fruits or thorns on public property along streets, so trees with these characteristics were removed from the final list. Their concern over the amount of time and resources spent on addressing tree nuisance complaints is shared by many other tree care practitioners (Roman et al., 2020).

3. **Group members review list:** We drafted a list of potential trees after the first meeting. The list was collaboratively annotated and added to by the members through email exchanges and during a second conference call, resulting in a revised list of 48 species. A spreadsheet matrix was created to organize the tree species characteristics and incorporate the criteria developed earlier in the process (**Supplementary Data**).
4. **Search for species availability:** Once the combined matrix of site appropriate species was constructed, we identified sources for the selected trees using nursery directories, an online database (PlantANT, 2017), and personal conversations with other Working Group members. Budget, tree size, tree quantity, and tree quality ultimately influenced the final tree trial species. For this project, we wanted trees in containers no smaller than 11.4 L that met the Florida No. 1 standard (e.g., only minor and correctable structural defects, minor or no trunk injuries, and no significant root defects) or could be pruned by the trial participants to meet that standard (Florida Department of Agriculture and Consumer Services, 2015).
5. **Create the final species list for trial and procure trees:** After calling 13 different wholesale nurseries and obtaining quotes from four nurseries, the final species were selected based on the steps taken above. The final list contained five species.

Practical Demonstration – Establishment Trial

The five species selected for the trial were *Celtis laevigata* Willd., *Ilex vomitoria* Aiton, *Taxodium ascendens* Brongn., *Ulmus alata* Michx., and *Viburnum obovatum* Walter (**Table 1**). Forty of each species were obtained for the trial, for a total of 200 trees. All trees came in 11.4 L containers. The planting plots were publicly owned street and park areas in Pinellas County, Hillsborough County, the City of Lakeland, and the City of Orlando (**Figure 2**). Within each of the four cities/counties, there were two planting plot types, one street and one park (**Figure 3**). In each plot, five of every species were planted. For example, Orlando had five of each species in the park plot and another five of each species in the street plot. Replicates were spatially independent at the plot level *via* randomization. A randomized complete block design was applied to the Hillsborough and Lakeland park plots since those plots had variation in drainage and soil quality.

All research plots were treated with similar irrigation methods and other forms of maintenance (e.g., bi-annual mulching, physical weed management). We followed the 6-month irrigation schedule outlined by Gilman and Sadowski (2017), which recommends watering approximately 3.8 L per tree daily for the first month, every other day for the next 2 months, and three times per week for the last 3 months. Irrigation was carried out by water trucks or bucket (i.e., not in-ground irrigation or water bags). Any deviations from the schedule were documented. The establishment phase, typically between the first 2 and 6 years of planting, is especially important since trees are vulnerable to drought stress during this time (Sherman et al., 2016). In Florida, a small, irrigated tree can be established in 2 years or less (University of Florida IFAS, 2015), so this trial lasted 2 years, summer 2017 through summer 2019.

Tree survival was assessed after the first and second years by noting if trees were alive or dead (i.e., standing dead, removed, or uprooted). Tree health condition was also assessed three times by scoring vitality and quality (Scharenbroch et al., 2017). Normalized health conditions were assigned to categories (i.e., dead, poor, fair, good, excellent) by using the modes of the original scores to normalize the data (Bond, 2012). Analyses were run using the normalized categorical designations. Site characteristics were measured as described in the Rapid Urban Site Index (RUSI) created by Scharenbroch et al. (2017): precipitation, growing degree-days, light exposure, traffic, proximity to infrastructure, surface covering (e.g., bare soil, vegetation, mulch), soil texture, soil structure, resistance to root penetration (as a proxy for bulk density), soil pH and EC, soil organic matter, estimated rooting area, a-horizon depth, and wet aggregate stability. All field measurements were collected by research staff/graduate students working with the Central Florida Urban Forest Diversity Working Group's university partner.

When calculating rates from cohort study data, annual mortality, q_{annual}, and cumulative survivorship, l_t, can be defined as:

$$q_{\text{annual}} = 1 - l_t^{(1/t)}$$

where t is the number of years since planting and l_t is the proportion of the population alive at time t to the original population (Roman and Scatena, 2011).

The cumulative RUSI score results were continuous data and were treated as such in analyses. Simple proportions tests were used to test for differences in the proportion of trees dead between species, site types, communities, and planting sites using the prop.test() function in R (R Core Team, 2018). A Bonferroni correction was used to adjust the p-vales to account for multiple comparisons using the p.adjust() function in R. To test for factors associated with differing urban tree health scores, an ordered logistic regression analysis with dummy variables was employed using the polr() function in R.

RESULTS

Of the 200 trees planted, 156 were alive after 2 years, resulting in an annual mortality rate of 11.7% for all trees. **Table 2** outlines mortality and survival rates for each species and city/county. Of the 44 dead trees, four were removed after dying, 26 were standing dead after showing past signs of biophysical stress (with

TABLE 1 | Final five species selected by the Central Florida Urban Forest Diversity Working Group to be trialed in central Florida.

Species	Common name	Mature spread (m)	Mature height (m)	Soil pH	Drought tolerance	Aerosol salt tolerance	Root salt tolerance	Wind resistance	Flood tolerance	Hardiness
Celtis laevigata	Sugarberry	15–21	15–21	Acidic, alkaline	H	M-H	L	L-M	Extended	5A-10B
Taxodium ascendens	Pondcypress	3–5	15–18	Acidic, slightly alkaline	H	M	None	H	Extended	5B-9B
Ulmus alata	Winged elm	9–12	14–21	Acidic, alkaline	M-H	M	None	M	Extended	6A-9B
Ilex vomitoria	Yaupon holly	5–6	5–8	Acidic, alkaline	H	H	H	H	Extended	7A-9B
Viburnum obovatum	Blackhaw, Walter's viburnum	2–3	2–8	Acidic, alkaline	H	n/a	L	n/a	Occasional	7-10

Tree tolerances to different environmental conditions are indicated by H (high), M (moderate), and L (low). Sources: Dirr, 2002, University of Florida IFAS, 2021a, USDA and NRCS, 2021.

FIGURE 3 | Example of **(A)** a street plot in Lakeland, FL, US and **(B)** a park plot in Hillsborough County, FL, US for the establishment trial.

no evidence of mowing damage or vandalism), six were removed for unknown reasons, and eight were killed by mower damage. The latter two sets of dead trees were left out of subsequent analyses because they were associated with human choices and inappropriate maintenance, and thus do not directly relate to our understanding of species suitability in the trial. The proportions tests provided evidence that mortality rates differed by species ($P < 0.0001$, adjusted $P < 0.0001$), plot type (park vs. road; $P = 0.0023$, adjusted $P = 0.0091$), and city or county location ($P = 0.0008$, adjusted $P = 0.0031$). After using a Bonferroni correction, the threshold for statistical significance was adjusted to $\alpha = 0.0166$.

The results of the health score analyses are summarized in **Figure 4** (where each category was compared against the best performer in that group). *Ilex vomitoria* and *T. ascendens* and *V. obovatum* (compared to *U. alata*), Lakeland and Orlando trees (compared to Pinellas), and park trees (compared to street trees) were all significant factors associated with health scores, based on *p*-values and the confidence intervals. By exponentiating the coefficient into an odds ratio then transforming any that were initially negative, the results were much more intuitive to interpret. For example, holding all other variables constant, a tree in Orlando was 5.8 times more likely to have a lower health rating than one in Pinellas. A tree in a park was 3.6 times more likely to have lower rating than one on a street. An *I. vomitoria* was 4.8 times more likely to have a lower rating than an *U. alata*.

DISCUSSION

Underutilized Species Selection Approach

The participatory research approach to creating the underutilized species list underscored the knowledge of the Working Group as a whole. Not only did we (i.e., the members of the Central Florida Tree Diversity Working Group) select species that met several environmental criteria for planting in urban areas, thus highlighting strong horticultural and arboricultural knowledge of these species, but our group also provided a range of perspectives regarding social criteria, such as common tree nuisance complaints, and practical criteria, such as availability at nurseries. This perspective can be overlooked by natural scientists who approach studies from a biodiversity-focused perspective (Lyytimäki et al., 2008). Trees which are potentially horticulturally suitable, but ultimately untenable due to nuisance disservices or lack of stock at nurseries, are inappropriate for planting trials that deeply value practitioner input and real-world

TABLE 2 | Overview of annual mortality and survival rates for the different establishment trial species.

Species	City/County	Number dead (annual mortality rate)	Number alive (annual survival rate)
Celtis laevigata	Hillsborough	4 (23%)	6 (77%)
	Lakeland	0 (0%)	10 (100%)
	Orlando	4 (23%)	6 (77%)
	Pinellas	0 (0%)	10 (100%)
	All sites combined	8 (11.0%)	32 (89%)
Ilex vomitoria	Hillsborough	0 (0%)	10 (100%)
	Lakeland	0 (0%)	10 (100%)
	Orlando	5 (29%)	5 (71%)
	Pinellas	0 (0%)	10 (100%)
	All sites combined	5 (6.5%)	32 (89%)
Taxodium ascendens	Hillsborough	2 (11%)	8 (89%)
	Lakeland	10 (100%)	0 (0%)
	Orlando	6 (37%)	4 (63%)
	Pinellas	3 (16%)	7 (84%)
	All sites combined	21 (31%)	19 (69%)
Ulmus alata	Hillsborough	1 (5%)	9 (95%)
	Lakeland	0 (0%)	10 (100%)
	Orlando	4 (23%)	6 (77%)
	Pinellas	1 (5%)	9 (95%)
	All sites combined	6 (7.8%)	34 (92%)
Viburnum obovatum	Hillsborough	0 (0%)	10 (100%)
	Lakeland	1 (5%)	9 (95%)
	Orlando	3 (16%)	7 (84%)
	Pinellas	0 (0%)	10 (100%)
	All sites combined	4 (5.1%)	36 (95%)

Annual mortality and survival rates were calculated for a 2-year period, and each species started with 40 trees at planting (n = 40). This dataset included tree deaths due to human-related causes.

constraints of urban forestry programs. Those seeking to develop tree-planting lists using this transdisciplinary method should involve a diversity of experts such as extension agents, certified arborists, landscape architects, and urban foresters for ideas on potential trees. A limitation to our group was that we did not have representation from consulting landscape architects or landscape contractors, whose input on tree traits and function in designed landscapes could be informative. Furthermore, nuisances like messy fruits can alternatively be viewed as benefits to individuals who value fruits for human sustenance or wildlife.

A growing number of urban ecologists and conservation experts have called for more transdisciplinary partnerships (Ludwig, 2001; Reyers et al., 2010; Torkar and McGregor, 2012; Angelstam et al., 2013; Muñoz-Erickson, 2014; Brandt et al., 2016; Pickett et al., 2016). Urban forestry is a prime example of a transdisciplinary field, which Vogt (2020) defines as combining "knowledge and methods from multiple academic disciplines and from research and practices and integrates both researchers as well as non-researcher stakeholders from across multiple actors." Transdisciplinary research in urban forestry allows for knowledge co-production between researchers and professionals (Campbell et al., 2016).

Knowledge co-production can take various forms, including participatory research and communities of practice (Campbell et al., 2016), both of which were used in our study. The participatory research approach is more "flexible and iterative" than conventional scientific studies (Cornwall and Jewkes, 1995) and includes local people in the research process at varying degrees of involvement (Balazs and Morello-Frosch, 2013). The participatory research project outlined by Campbell et al. (2016) involved a narrow research project taking place in one locality, namely, the establishment survival of trees in a program in Sacramento, CA, United States (Roman et al., 2014a). Likewise, the tree establishment trial detailed in this paper is an example of participatory research. The community of practice example from Campbell et al. (2016) was a network of researchers and practitioners with a focused topic and agenda: the Urban Tree Growth and Longevity Working Group, a voluntary and free organization of researchers and practitioners interested in the study and application of urban tree growth and mortality information (van Doorn et al., 2020). In this paper, we describe our partnership with the Central Florida Urban Forest Diversity Working Group, an existing community of practice, in order to select underutilized tree species for potential use in the urban landscape and to test the establishment success of the species.

By being embedded in and trusted by the existing community of practice, the researchers were able to access municipal tree inventory data from multiple communities and identify trends in diversity that helped create the thresholds used to classify species as underutilized. Other localities should consider examining their own tree inventory data for a quantitative understanding of their forest's diversity and collaborate as needed with extension agents and researchers to interpret diversity findings. While 1% was used as a threshold in our research, this was a somewhat arbitrary value, and can be adjusted to increase or decrease the number of species initially investigated. The term underutilized species has been used in other applied science fields, including traditional forestry (Youngs, 1989; Youngs and Hammett, 2001) and agriculture (Padulosi et al., 2013; Barbieri et al., 2014; Hunter et al., 2019). In this paper we provided a definition of underutilized trees in the urban forestry context, but future work should elucidate best practices for developing thresholds for classifying urban tree species as underutilized.

This project combined the experience and knowledge of practitioners and researchers with empirical data and climate change projections. While we started with a large initial list of prospective species, many underutilized trees were excluded given their ecological suitability to Florida's current and future conditions. For example, inventory data may include more tropical trees that were planted between occasional winter freezing events. Similarly, temperate species currently at the southern extremes of their range may not have been recognized as good candidates for a hotter future Florida. Tree selection and performance testing must incorporate climate change considerations to ensure individual trees will survive into maturity and selected species remain viable choices in the future (Roloff et al., 2009; Brandt et al., 2016; McPherson et al., 2017, 2018).

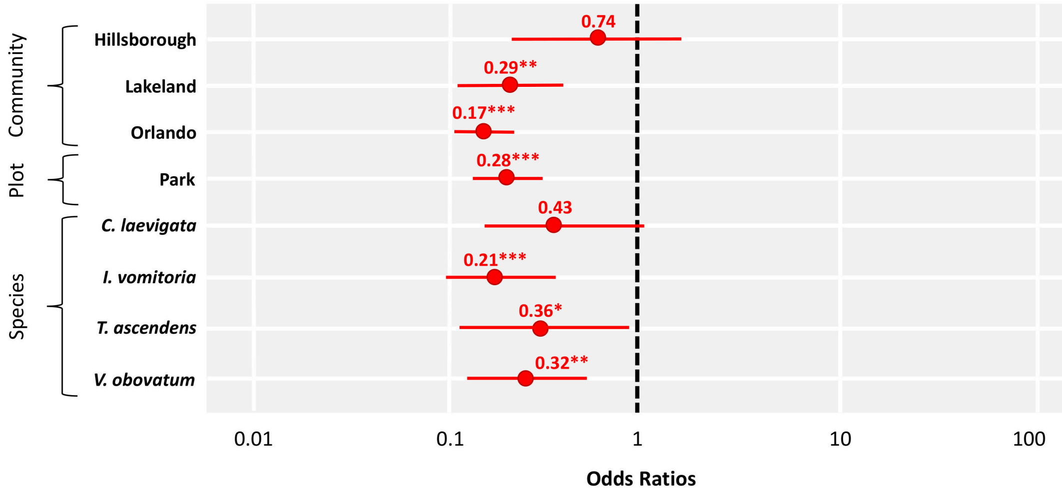

FIGURE 4 | Forest plot for the ordinal logistic regression, comparing against best performers in each category from the establishment trial. Scores from the cities/counties were compared against Pinellas County, trees in parks compared against trees along streets, and species against *U. alata*. The red dots represent the resulting odds ratios. The associated bars represent the corresponding 95% confidence intervals. An "*" marks statistically significant variables (*$P < 0.05$; **$P < 0.01$, ***$P < 0.001$). This analysis excludes trees that died by human-related causes.

Different priorities for species selection could lead to different choices for planting trials in our study region or others. The 48 species that made up the matrix (**Supplementary Data**) for our practical demonstration had a variety of mature tree heights and canopy widths. Fourteen of the species had maximum mature heights under 7.6 m, 14 between 7.6 and 15.2 m, and 20 over 15.2 m tall. Those creating lists for diversification could also consider other urban forest goals when prioritizing species. For example, increasing canopy cover is a goal for many communities (Hauer and Peterson, 2016), so prioritizing a search for large-stature underutilized trees could help address this secondary goal and help maximize ecosystem services provided by urban trees (McPherson et al., 2005). On the other hand, highly urbanized planting spaces under public management, such as sidewalk tree pits or planting sites under utility lines, can have restricted room for tree growth (Watson et al., 2014; Nguyen et al., 2017), and requiring small-stature species (Magarik et al., 2020). In this case, it may be more favorable to search for underutilized small-stature trees. When deciding on which trees to include, it could be useful to consider which ecosystem disservices urban forestry professionals want to avoid. Characteristics like showy fruits may add seasonal attractiveness and foster native birds and wildlife. However, these same fruits are considered a disservice if trees are planted near sidewalks in public spaces (Lyytimäki et al., 2008; Roman et al., 2020). Plant selection guides can help identify species with traits that are subjectively viewed as desirable or undesirable. If planted in a heavily trafficked area, another ecosystem disservice could be the presence of flowers, which while attractive and fragrant, attract pollinators such as bees and wasps that pose a threat to allergic individuals (Lyytimäki and Sipilä, 2009). In general, it is critical to acknowledge that the selection of species for trials is inherently subjective and based on the perspectives and professional judgment of local urban foresters.

Of the 48 species in the matrix, seven were not native to Florida. Native vegetation can support native animal biodiversity, regulate native tree gene pools, and keep invasive species in check (McKinney, 2002; Alvey, 2006). However, non-invasive exotic species have shown to be successful in urban areas that are different from their pre-development state and may be used to maximize ecosystem services in urban forests (Ordóñez and Duinker, 2012; Sjöman et al., 2016). In Florida, there is a large diversity of native tree species to pick from when screening for urban tolerant species (Wunderlin et al., 2020), but other regions may not possess the same bank of native tree diversity and might have to rely on non-native trees in efforts to diversify their forests (McBride and Douhovnikoff, 2012). The initial decision by the Working Group to focus on native species reflects the specific values of the group, and different groups of individuals may choose differently based on values and priorities. While native trees were prioritized in our study given their perceived adaptability to local conditions, we did not directly address issues related to intra-species genetics in this trial.

The matrix-style spreadsheet we created for this project was an organized method of comparing species and can serve as a reference for future regional trials of underutilized species. Practitioners and researchers in other regions can create a similar spreadsheet that list suitable trees to their specific region and its unique physical and climatic conditions. The document could outline typical characteristics and site requirements (e.g., mature height, flood tolerance, minimum distance from paved surface) for each tree. Indeed, many cities in the United States use such matrixes or planting lists to guide species selection. This study's matrix was modeled after the Tampa Tree Matrix (Northrop et al., 2013), which also served as a resource for identifying potential species that were underutilized in the study region. New York City Department of Parks and Recreation has an "Approved

Species List" that includes characteristics like form, growth rate, fall color, and tolerances (New York City Parks, 2021). There is also a statewide "Street Tree Factsheets" booklet for the state of Pennsylvania, United States (Gerhold et al., 1993). While urban planting lists can be a tool for increasing diversity, they can also hinder experimentation if too restrictive. Permitting a broad array of species or simply specifying what species/traits are not acceptable will allow nursery growers and designers to experiment with new species while maintaining some local control over the composition of trees planted.

Many of the species initially identified as candidates did not make it to the establishment trial because of limited availability from nurseries (**Supplementary Data**). There were several factors that played into a tree's availability for this study and will likely be important considerations for others following our approach. First, budget must be considered, especially if the list is being created for use in a planting trial like the study we outlined in this paper. A scarcity of a species in the desired size or grade could increase the price of that species. Similarly, underutilized trees may have slower growth rates (a significant cost determinant) than the more commonly produced species as growers favor species with shorter production times. Second, personal experiences of practitioners may preclude the inclusion of some species. For instance, members of the working group in this study were willing to try out small-stature species, but we prioritized trialing species capable of growing to large stature because members of the working group had concerns about small-stature trees, namely, that such smaller species require more training (i.e., formative pruning) and may be more vulnerable to vandalism. Third, tree quality preferences might affect overall availability. Like the limitations on plant size, there may be limitations regarding the quality of plants available if only produced by a few growers. While minor issues can be corrected with post-planting care and structural pruning, not every tree is salvageable (Gilman and Bisson, 2007). Tree quality preference was especially prevalent in this study because the communities in which we were planting the trial trees had existing rules on the quality of trees that could be planted on public property, specifying trees graded Florida No. 1 or Florida Fancy (e.g., a single-leader tree free of structural defects, missing or irregular foliage, trunk wounds, and root defects) based on the Florida Grades and Standards for Nursery Plants (Florida Department of Agriculture and Consumer Services, 2015). This leads to a fifth consideration, which is local policies may restrict what species might be considered for planting trials in other cities.

Limited nursery availability has been cited as a barrier to incorporating underutilized trees (Conway and Vander Vecht, 2015). For harder-to-source species, flexibility in accepting smaller size nursery material may be necessary, as it was for this project. Alternatively, municipalities could enter contracts with growers, encouraging suppliers to provide new trees. New York City utilizes tree procurement contracts to secure the types, quality, and quantity of trees they need for street tree plantings (Stephens, 2010). In the Chicago metropolitan area, consortiums of smaller communities have formed to increase buying leverage and even extend the length of time municipalities can enter into contracts with commercial nurseries (Miller et al., 2015). Alternatively, municipalities with a strict commitment to diverse plantings can grow their own trees in municipal nurseries (Miller et al., 2015).

Establishment Trial

Establishment trial results show annual mortality rates for trees in Orlando (25%), Lakeland (12%), all park plots (17%), and *T. ascendens* (31%) were higher than annual mortality rate ranges for establishment from existing literature (see **Table 3**). Trees in street plots had significantly lower mortality rates compared against those in park plots, which may seem counterintuitive. However, a recent study in Holyoke, MA, United States, found a similar result (Breger et al., 2019) and linked this difference to stewardship regimes, namely, that street trees received regular watering. There may be a similar reason for the discrepancies in our two plot types. The irrigation in all but one plot (Hillsborough park) was conducted by watering trucks, making the street trees far more accessible for tree crews than the park trees. In fact, early in the study a water truck in Orlando was stuck in the sandy soil at the park plot while attempting to water the trees. Furthermore, communications with our partner in Orlando revealed that immediately following Hurricane Irma (which hit Orlando on September 10th – 11th, 2017), tree crews had to prioritize post-storm cleanup over watering the trial trees. In Hillsborough County, the adjacent recreation center's "green team" of students watered the Hillsborough park plot by hand. The Pinellas park plot was on dredge and fill material dominated by calcium carbonate shell fragments and sand, potentially making this park plot, like the previously mentioned ones, challenging for tree establishment. Meanwhile, the Lakeland park plot was situated on land that was formerly a phosphate mine and was surrounded by bodies of water, which might explain why this park plot had similar mortality rates to the street plots in Lakeland. The Hillsborough street plot was in a median adjacent to a forest fragment, and partners in the public works building across the street said this piece of land was consistently moist. This could explain the comparatively lower rates of mortality at this street plot.

Furthermore, different weather patterns across our study municipalities may have impacted our findings. Pinellas County had more rainfall in the first 3 months after planting than the other three communities, with a total of 4.5 cm (WeatherSTEM, 2020) versus 2.5 cm in Hillsborough, 1.7 cm in Lakeland, and 2.8 cm in Orlando (University of Florida IFAS and Florida Automated Weather Network [FAWN], 2020). This might have contributed to Pinellas trees having a lower mortality rate compared to the trees in the other three communities.

In comparing species establishment, the statistical significance detected appeared to be driven by the higher mortality observed in the *T. ascendens*. Therefore, we would not recommend planting these trees on street or park sites if regular watering is not available. While generally considered a hardy genus once established, other studies in Florida have led to similar findings with the closely related (and more commonly planted) *T. distichum* L. Specifically, Blair et al. (2019) noted that *T. distichum* transplants had lower vitality compared to *Pinus*

TABLE 3 | Range of annual mortality for cohort studies of trees in highly managed urban landscapes.

Sources	City	Time period	Tree location	Species	Range of annual mortality (%)
Boyce, 2010	New York City, NY, United States	≤4	Street	Not specified	1.25–4.17
Gates and Lubar, 2007	Philadelphia, PA, United States	1–2	Mixed	Not specified	3.92–7.68
Koeser et al., 2014	Florida (several counties)	2–5	Mixed	Not specified	1.32–3.26
Struve et al., 1995	Cleveland; Pickerington; Powell; Upper Arlington; Worthington, OH, United States	2–3	Mixed	*Quercus rubra*; *Q. coccinea*; *Liquidambar styraciflua*; *Acer rubrum*	7.17–10.56
Vogt et al., 2015	Indianapolis, IN, United States	2–6	Street	21 families	1.85–5.45
Widney et al., 2016	Philadelphia, PA, United States	3–5	Street	Not specified	13

These studies were conducted in the United States in areas with a Cfa climate categorization (Kottek et al., 2006). Mortality values reflect ranges in the reported findings from each study (Hilbert et al., 2019).

elliottii Engelm. planted at the same time along highway rights-of-way. Similarly, Koeser et al. (2014) noted that while *T. distichum* planted on irrigated sites had similar levels of transplant success as other species, survival decreased significantly on sites lacking a dedicated water source.

Monitoring tree health is useful since health can be a predictor of future condition and overall survival (Hickman et al., 1995; Nowak et al., 2004; Koeser et al., 2013; Roman et al., 2014b, 2016). A tree's health is also linked to its ability to provide ecosystem services and benefits (e.g., rainfall interception, shading, aesthetic value), so it is important to consider not only survival, but also overall health (McPherson et al., 2011; Mullaney et al., 2015; Martin et al., 2016). Health scores were significantly lower for *I. vomitoria* and *T. ascendens* (compared to *U. alata*), Orlando trees (compared to Pinellas), and park trees (compared to street trees). The lower health scores for *T. ascendens* are in line with the similarly low survival rates for *T. ascendens* in this trial. *I. vomitoria* did not have very low survival, but did experience several cases of mowing equipment damage, which could have contributed to lower health scores. It could be insightful to continue monitoring the trees to determine if the *I. vomitoria* with lower health scores recover or die post-establishment. Lower health scores for Orlando trees are likely explained by the reasons proposed earlier, particularly the less consistent irrigation in Orlando following Hurricane Irma. Park trees were more likely to die, as well as to have lower health scores, again, probably due to site conditions and inconsistent irrigation. When survival and health were all considered, *U. alata* and *V. obovatum* were the most successful species in the planting trial and would be recommended for future plantings in the central Florida region. Based on follow-up conversations between the researchers and city/county partners, managers from three of the four communities are interested in continuing to use these suggested species.

Sample size for each location was limited due mainly to restrictions in available planting space and resources. However, there is a precedence of other *in situ* arboricultural and horticultural trials being conducted with similar sample sizes (e.g., Gerhold, 1999, 2007). Managers can consider the two species that performed well in our trials as strong candidates for moderate increases in local planting programs in Central Florida. Due to our limited sample size and geographic range, caution is warranted in expanding too quickly, and practitioners may want to track performance if they try planting these underutilized species.

Finally, while this study focused primarily on genetic diversity as it related to species, genus, and family, there are other aspects of diversity that should be considered. Diversity related to tree age class and typical species longevity can help stagger maintenance and removal demands placed on a community and ensure large swathes of urban forest do not decline at the same time. Additionally, there are recent efforts to bring the concept of functional diversity from traditional forest ecology into urban forest management (Núñez-Florez et al., 2019; Paquette et al., 2021). Maintaining functional diversity can increase the range of ecological services urban vegetation provides within the surrounding landscape. Researchers have classified urban trees based on their ability to sequester carbon or provide food and habitat for urban fauna in order to facilitate planning efforts (Núñez-Florez et al., 2019). Creating diversity thresholds based "functional groups" rather than taxonomy can help reduce potential losses of ecological function in the face of unknown threats (Paquette et al., 2021).

CONCLUSION

The selection process carried out in this study (**Figure 1**) can serve as a model for others wanting to identify potential underutilized tree species to include in planting lists or trials. The participatory research approach to the practical demonstration not only results in a more informed list, but discussing underutilized trees with communities of practice, whether they existed before or were created for a specific project, can encourage networking and ongoing discussions of the diversification of the urban forest (Campbell et al., 2016). Such transdisciplinary partnerships are critical to advancing the diversification of urban forests, which researchers and practitioners have recognized as a priority for management (Brandt et al., 2016; Morgenroth et al., 2016; Pickett et al., 2016).

It is important to conduct more studies like the practical demonstration presented in this paper to further our understanding of underutilized trees' survival and health in different regions and planting conditions. The final selection of trees in the practical demonstration was greatly limited by availability from growers, but conversations with growers revealed a shared interest in trying new and underutilized trees. In fact, carrying out this process and finding a limited availability for selected species could serve as the basis and justification of more formalized contract growing agreements for communities that are committed to diversifying their plantings. Increasing tree species diversity is an undertaking that will need to be addressed on all ends of the planting process, from consumer demand to production. Therefore, solutions are most likely to be found through strong transdisciplinary partnerships and participatory research approaches. While efforts to diversify publicly managed trees may seem limited given privately owned trees often make up the majority of urban forests (Nguyen et al., 2017), these efforts can have a ripple effect serving real-world arboreta which expose homeowners and others to species they may not have encountered before. Future work should investigate ways to increase diversity on private property (which despite increased richness, is often also subject to the overreliance on limited species) to enact the greatest change to urban forest compositions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

DH, AK, and RN: conceptualization. DH, AK, RN, LR, and MA: methodology. DH: validation, formal analysis, data curation, writing – original draft, and supervision. DH and AK: investigation and funding acquisition. DH, AK, LR, MA, GH, MT, and RN: writing – review and editing. DH and LR: visualization. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.759693/full#supplementary-material

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Conflict of Interest: DH is employed by Many Trees Consulting, LLC.

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