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The Fate and Persistence of Standing Dead Street Trees in Philadelphia, PA

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Abstract

Street trees are an integral component of urban forests. However, streetscapes are often challenging habitats, which lead to standing dead street trees persisting on these landscapes until their eventual removal. The management of dead street trees is entirely dependent upon human-driven cycles of replacement and removal. However, the fate and persistence of dead trees is not readily apparent during inventory and monitoring studies that capture tree mortality status at a single point in time, or only every few years. In this study, the fate of standing dead street trees were observed based on field remeasurements (2015 and 2021) and Google Street View (GSV) imagery of randomly-distributed plots within Philadelphia, PA. The total percent of standing dead street trees increased from 1.5% (2015) to 2.0% (2021), while the persistence on streetscapes prior to removal decreased from a median of 36-50 months (2015) to 24-38 months (2021). Additionally, the average diameter at breast height (DBH) of dead trees decreased from 15.3–30.4 cm (2015) to ≤7.6 cm (2021). The results demonstrate how current management practices are shifting to remove dead trees on streetscapes faster in order to compensate for the high rate of mortality, particularly in small, young trees. Future studies should investigate management practices that mitigate risk, promote preservation, and encourage stewardship to enable or hinder the removal of dead trees. Further investigation is also needed regarding how the persistence or removal of standing dead street trees alters the structure of urban forests over time.

Disciplines

Environmental Sciences | Physical Sciences and Mathematics

Comments

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ABSTRACT

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Street trees are an integral component of urban forests. However, streetscapes are often challenging habitats, which lead to standing dead street trees persisting on these landscapes until their eventual removal. The management of dead street trees is entirely dependent upon human-driven cycles of replacement and removal. However, the fate and persistence of dead trees is not readily apparent during inventory and monitoring studies that capture tree mortality status at a single point in time, or only every few years. In this study, the fate of standing dead street trees were observed based on field remeasurements (2015 and 2021) and Google Street View (GSV) imagery of randomly-distributed plots within Philadelphia, PA. The total percent of standing dead street trees increased from 1.5% (2015) to 2.0% (2021), while the persistence on streetscapes prior to removal decreased from a median of 36-50 months (2015) to 24-38 months (2021). Additionally, the average diameter at breast height (DBH) of dead trees decreased from 15.3–30.4 cm (2015) to ≤7.6 cm (2021). The results demonstrate how current management practices are shifting to remove dead trees on streetscapes faster in order to compensate for the high rate of mortality, particularly in small, young trees. Future studies should investigate management practices that mitigate risk, promote preservation, and encourage stewardship to enable or hinder the removal of dead trees. Further investigation is also needed regarding how the persistence or removal of standing dead street trees alters the structure of urban forests over time.

Introduction

Street trees are an integral component of urban forests, and healthy street trees provide various ecosystem services to urban communities. Street trees can reduce stormwater runoff, sequester carbon dioxide, shade buildings to reduce energy use, increase property values, increase walkability, and promote consumerism in business districts (Nowak et al., 2004; Pecenko & Brack, 2021; Roman et al., 2014; Thorn et al., 2020). Although trees can be found throughout the entire urban environment, such as in parks, cemeteries, and residential yards, street trees are often the primary focus of municipal arborists and tree planting campaigns. In cities and towns in the United States (US), street trees on average receive 62% of the urban forestry budget allotment (Hauer & Peterson, 2016). Arborists, other tree professionals, and residents have active roles in maintaining the structure of an urban forest through planting, maintenance, and removal (Conway, 2016; Mincey et al., 2013).

However, street trees face biophysical stressors and governance challenges. Streetscapes can often be more challenging than natural forested areas, with conditions such as compacted soils and low nutrient availability (Hilbert et al., 2019; Scharenbroch et al., 2017; Urban, 2008), although planted urban trees often receive beneficial interventions, such as irrigation and fertilizer, and may have more light availability compared to dense forested stands. Standing dead trees, although uncommon, can persist on streetscapes for years (Roman et al., 2014; Breger et al., 2019). For instance, in the West Oakland neighborhood of Oakland, California, standing dead street trees made up 1.7% of the street tree population, but 43.3% typically persisted from one year to the next (Roman et al., 2014). However, little is known about the temporal dynamics of standing dead trees and the transitions between the dead, removed, and replaced street trees in urban forests.

In natural forest settings, dead trees, also referred to as snags, contribute numerous ecological benefits that healthy trees cannot, such as promoting the diversity of fauna that rely on dead trees, influencing the behaviors of these animals, and playing a critical role in decay dynamics (Bovyn et al., 2019; Pecenko & Brack, 2021). In contrast, much of the literature on dead urban trees has focused primarily on identifying hazards and risk reduction (Pecenko & Brack, 2021). Indeed, dead urban trees are a source of ecosystem disservices, in that they pose dangers to built infrastructure and people, and can be perceived as aesthetically undesirable (Roman et al. 2021). Although dead trees act as a critical component in the ecology of natural forests, little is known about their role in street tree populations.

In city landscapes, street trees experience a distinct mortality process. The management of street tree populations is dependent upon human-driven cycles of removal and replacement (Hilbert et al., 2019; Roman et al., 2014). Although biophysical factors may influence the removal or replacement of a tree, removal is ultimately reliant upon human decision-making. Street trees can have three types of mortality outcomes: death-in-place (standing dead), preemptive removal for tree and safety reasons, and removal unrelated to safety (Hilbert et al., 2019). In the latter two outcomes, healthy trees can be removed while still alive. For example, one street tree can be removed based upon risk concerns, while another tree can be removed while still alive purely due to aesthetic preferences. Among residents in Mississauga, Ontario (Canada), tree health concerns were the motivation for most residents' tree removal decisions (Conway, 2016). Negative perceptions of standing dead trees are often due to their perceived safety problems, particularly with respect to falling branches that may damage property or injure people (Wolf, 2003; Schroeder et al., 2006). However, during street tree monitoring, it is not always apparent whether a removed or replaced tree was originally healthy, unhealthy, or standing dead at the time of removal. In order to gain a more complete perspective of the state of an urban forest, one must understand the removal and replacement plantings that drive the changes in the structure of the community (van Doorn & McPherson, 2017).

Tracking the fates of standing dead street trees will allow a deeper understanding of how long dead trees linger in the landscape, as well as how often removals and replacements occur. Furthermore, understanding the fates of a street tree is crucial to improving management practices and projection models. In this study, we compared field-based street tree monitoring data between 2015 and 2021 from neighborhoods throughout Philadelphia, Pennsylvania, complemented by street-level imagery for longer temporal coverage. My research objectives were to: (1) track the fates of standing dead street trees; (2) assess the degree to which standing dead trees persist in streetscapes; and (3) determine how the standing dead tree population has changed over the study period.

Study Area and Methods

Approach

In this study, I used a mixed-methods approach, combining field-based street tree monitoring data collected in 2015 and 2021 in Philadelphia, Pennsylvania, complemented by street-level imagery for longer temporal coverage before and during that time interval. More specifically, this study is a part of a repeated-measures longitudinal study on street trees throughout Philadelphia, PA in partnership with the USDA Forest Service, the University of Connecticut, and The Nature Conservancy. I was an acting member of the 2021 field crew.

Study System

With a 2020 population of 1,603,797 (U.S. Census, 2020), Philadelphia is the largest city in Pennsylvania and currently the sixth-largest city in the US. Demographic information for Philadelphia is shown in Table 1. The city contains a mix of residential neighborhoods, industrial areas, historic centers, shopping complexes, and parks. Philadelphia's older residential neighborhoods contain rowhomes or other forms of attached housing with little to no yard space (Roman et al., 2021), making street trees a primary form of urban vegetation for such neighborhoods. The climate of Philadelphia is at the northern edge of humid subtropical (Köppen-Geiger Classification System subtype "Cfa") in which it experiences hot summers with high humidity and cold winters (Kottek et al., 2006). As a forested biome, emergent forests can occur on abandoned/vacant lands, leading to increased vegetative cover at the cost of depopulation and disinvestment (Berland et al., 2020; Roman et al., 2021; Zipperer, 2002). Natural regeneration of trees in sidewalks and medians is possible in this city, but new street trees emerge primarily from planting.

In Philadelphia, property owners formally own the street trees adjacent to their parcels, although the city maintains jurisdiction over street trees (City of Philadelphia, 2019). Specifically, Philadelphia Parks & Recreation (PPR) has formal oversight over all street trees and is responsible for planting, pruning, and removing street trees. However, PPR has long faced budgetary challenges limiting their capacity to maintain street trees (Roman et al., 2021). In 2016, PPR conducted a complete virtual inventory of the city's street trees using Cyclomedia, a GIS software that provides high-definition imagery and integrates with ArcGIS (Maldonado, 2016). This virtual street tree inventory enabled PPR to be proactive and remove dead trees before they fall (Birchmeier, 2016). PPR subsequently conducted a field inventory, noting the species and DBH of all street trees in the city, although that data has not yet been publicly released (E. Smith Fichman, pers. comm.). This field inventory represents the first comprehensive city-wide street tree assessment in a century.

Currently, the public can report standing dead trees in need of removal to PPR through the 311 contact center for non-emergency customer service or by calling PPR directly (City of Philadelphia, 2019). In addition to PPR, street trees are planted and cared for by a variety of organizations, including the Pennsylvania Horticultural Society (PHS), the Philadelphia Water Department (PWD), and numerous private landholders (Roman et al. 2018, PWD 2021).

Median Income	$47,474
Percent in Poverty	23.30%
Percent White	39.03%
Percent Black/African American	42.2%
Percent Native American	0.4%
Percent Asian	8.9%
Percent Hispanic (of any race)	9.3%

Table 1. Demographic information for Philadelphia County, Pennsylvania (U.S. Census, 2020).

Tree Data Collection

For this study, a plot is a 0.8 km stretch of road, with 103 plots randomly located throughout Philadelphia (Image 1). Plots turn randomly at corners so that each plot could include multiple city blocks. A baseline street tree inventory was conducted in 2015 and then remeasured in 2021.

Fieldwork for this study was first conducted June-August 2015 and then repeated June-August 2021. The 2015 field season determined the location, species, diameter at breast height (DBH), mortality status, and vigor class of street trees as a baseline for repeated studies. The 2021 field season revisited the 103 plots and recorded the mortality status of street trees, as well as any newly planted trees, including noting which were replacement trees for trees present in 2015 which had been removed. Information was recorded following the urban tree monitoring guides developed by USDA Forest Service researchers and colleagues (Roman et al 2020; van Doorn et al 2020). Mortality status in 2015 was recorded as either alive or standing dead. Mortality status in 2021 for trees already observed in 2015 was recorded as either alive, standing dead, removed, or stump; mortality status in 2021 for newly planted trees was either alive or standing dead. Standing dead trees had no signs of living leaves or buds. Stumps were cut down to 0.61m or less. For all alive and standing dead trees, DBH was taken at 1.37m from the ground (unless bark abnormalities or low-forking multi-stemmed trees required height adjustments, with diameter below fork used for multi-stemmed trees, Magarik et al. 2019, Roman et al. 2020).

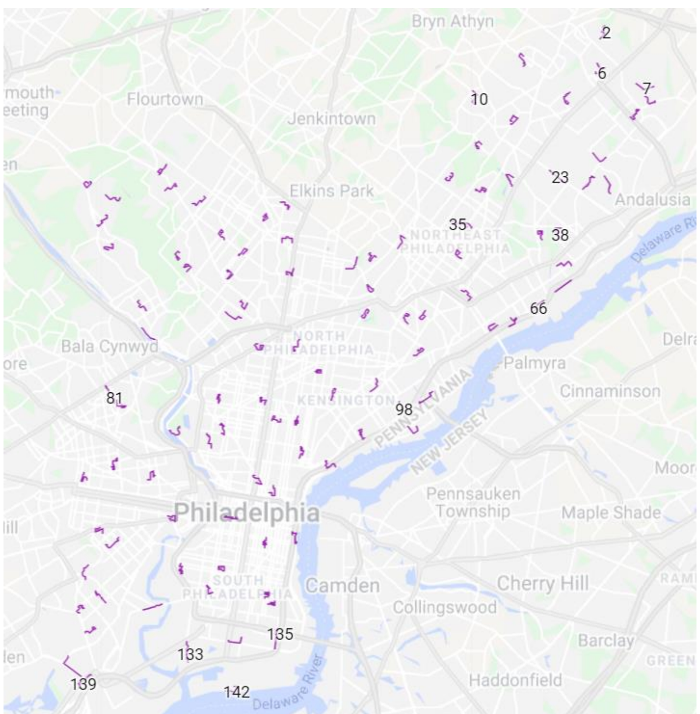

Image 1. The study plots (n=103) in Philadelphia, Pennsylvania via Google Maps.

GSV Tracking

To observe the fates of street trees throughout Philadelphia, Google Street View (GSV) was used to create a historical timeline of trees that were identified as standing dead in either the 2015 or 2021 field inventories, as well as trees all mortality cases between the two inventories (i.e., trees that existed in the 2015 inventory and were removed or stumps in 2021, in addition to the standing dead). The standing dead 2021 trees included both trees which existed in 2015 as well as new, recently planted trees observed in 2021 that died relatively young.

GSV has been shown to be useful in observing basic information about street trees, such as genus and mortality status (Berland & Lange, 2017; Berland et al., 2019), and can also be utilized for tracking street trees after planting (Berland and Roman 2020). Trees that have been identified as standing dead during the 2015 field season and as standing dead, removed, or a stump in the 2021 field season were first located by their address on GSV. By using the 'time travel' feature in GSV, which allows users to view historical imagery of a location following 2007, the fate of identified trees was recorded. Fates were recorded for every year between 2007 and 2021 for the 2015 inventory, and every year between 2015 and 2021 for the 2021 inventory. However, not all years had GSV imagery. If GSV images were unavailable for certain years, or if the tree was not yet planted, then no data was recorded. If GSV images were available, the fate of the tree was then recorded as either alive, standing dead, removed, replaced, or stump. If trees were found to be replaced, the first year that the replacement was observed in GSV was recorded and used as the year of removal for the original tree.

Comparison of 2015 and 2021 Data

I conducted a comparative analysis of standing dead street trees using a mixed-methods approach of fieldwork from 2015/2021 and GSV imagery. For each field season, the total percentage of standing dead street trees was calculated as the number of standing dead (SD) trees divided by the sum of standing dead and alive (A) trees:

$$\% \text{ SD} = \frac{\#SD}{\#SD + \#A}$$

To compare the fates of standing dead street trees, I noted the total amount of standing dead, removed, replaced trees, and stumps between both field seasons and whether their fates were observable in GSV. Bar graphs were made of each inventory year to reflect which fate standing dead trees experienced.

Similarly, the persistence of standing dead street trees was conducted by noting the shortest and longest amount of time that a tree could be standing dead in GSV. The true number of months that a standing dead tree persisted on the streetscape was unknowable without monthly imagery, so these shortest and longest numbers represent the range of persistence that was possible given the data available. The shortest amount of time was determined by the last month a tree was seen as standing dead, while the longest amount of time was determined by the last month a tree was seen alive. A box plot was created to display the range of shortest and longest persistence between both field inventories. It was also noted if they were observed standing dead in GSV. In addition to the box plot, a table was created to report the median, quartiles, range, outliers, and mean of each inventory.

To compare the changes in the standing dead community, I counted the total number of standing dead street tree species in each field inventory. Bar graphs were created in order to reflect the total number of standing dead species in 2015 and 2021. The diameter at breast height (DBH) for dead trees were then sorted into 7 DBH size classes: 1 (≤7.6 cm), 2 (7.7–15.2 cm), 3 (15.3–30.4 cm), 4 (30.5–45.6 cm), 5 (45.7–60.8 cm), 6 (60.9–76 cm), and 7 (>76 cm). These classes are a modified version of the 7.6 cm (3 in) classes, in which all classes following Class 2 are 15.2 cm classes (Morgenroth et al., 2020). This was done in order to accommodate small, newly-planted street trees, which experience the highest rate of mortality (Roman et al., 2014). Scatterplots of each inventory year were made to show the trend of DBH classes in standing dead trees.

Results

The Total Percentage of Standing Dead Street Trees

In 2015, 1.5% of street trees were found standing dead out of a total of 2,746 alive and standing trees. Comparatively, in 2021, 2.0% of street trees were found standing dead out of a total of 2,600 alive and standing dead trees.

The Fates of Standing Dead Street Trees

As previously mentioned, the fates of standing dead street trees were recorded from GSV if trees were standing dead in either the 2015 or 2021 inventory as either an existing or new tree, and if they were removed or a stump in the 2021 inventory. 40 records in 2015 and 552 records in 2021 met these criteria. 7 trees from the 2021 field season did not have GSV imaging and were therefore excluded from this study. The 40 trees from the 2015 field season and the remaining 545 trees from the 2021 field season had their fates recorded. For the remainder of the results, findings are discussed in terms of trees that were part of this study due to their mortality status in 2015 vs. 2021.

2015 Standing Dead Trees. All of the street trees that were observed as standing dead in 2015 (40 trees) were removed by the 2021 field season. Of these 40 trees, 26 trees were found as standing dead in GSV images prior to their removal in 2021 (Fig 1). In addition, 8 standing dead trees were found as replaced by other trees in GSV between 2015-2021.

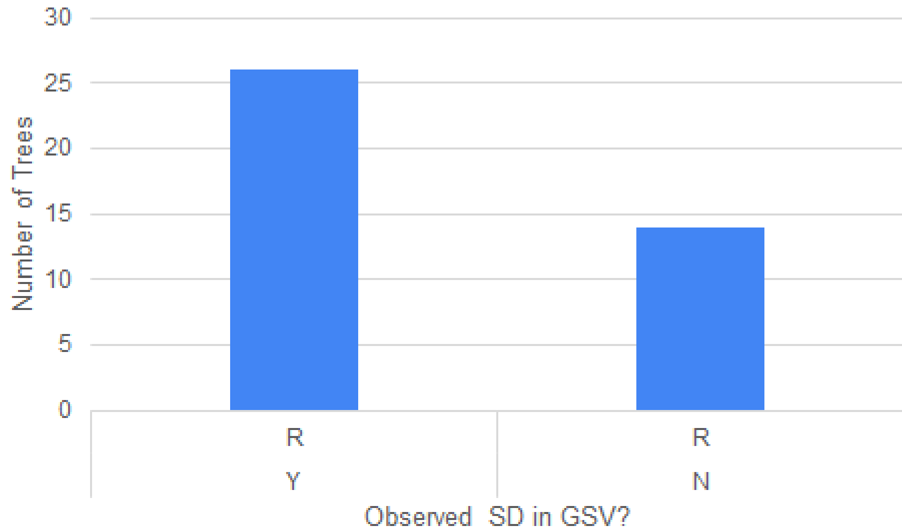

Fig 1. The fate of standing dead street trees from the 2015 inventory. The fates are removed (R), stump (S), or standing dead (SD).

2021 Standing Dead Trees. Out of the 545 street trees that were originally alive in 2015, and subsequently died or got cut down by the 2021 field season, 441 were removed, 53 were found as stumps, and 51 were found standing dead in the 2021 field season (Fig 2). Of these 545 trees, 31 street trees were not observed as standing dead in GSV but were ultimately found standing dead by field technicians in 2021. Street trees that were observed as standing dead in GSV imagery were either removed (38 trees), remained standing dead (20 trees), or found as stumps (5 trees). 59 street trees were found as replaced by other trees in GSV between 2015-2021.

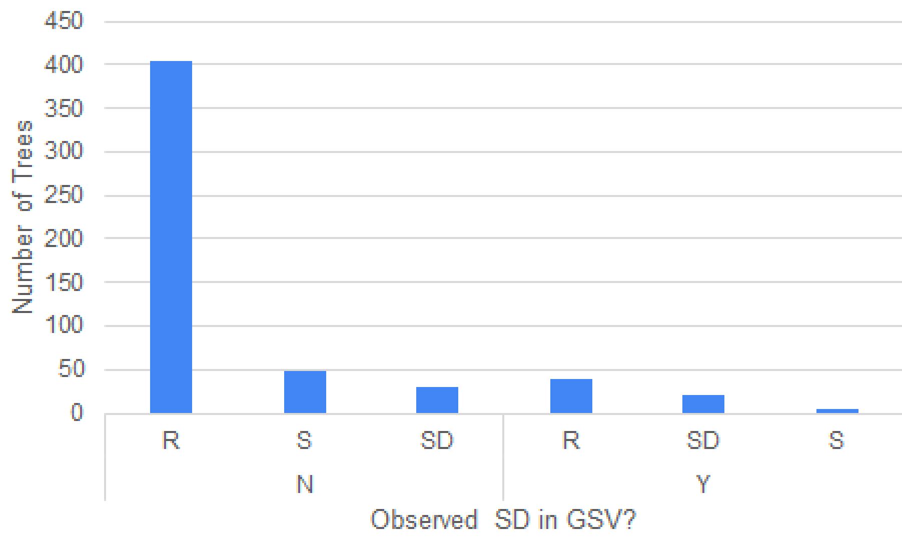

Fig 2. The fates of standing dead street trees from the 2021 inventory. The fates are removed (R), stump (S), or standing dead (SD).

Persistence of Standing Dead Street Trees

2015 Standing Dead Trees. The persistence of street trees found standing dead is a median of 36 to 50 months (Fig 3). The minimum length of persistence is 10 to 19 months, and the maximum amount of time persisting is 95 to 144 months (Table 2). Street trees that were not observed as standing dead in GSV images but were ultimately found standing dead by field technicians in 2015 persisted on streetscapes for a median of 15 to 48 months, with the shortest and longest amount of time being 10 months and 74 months, respectively. For street trees that were observed as standing dead in GSV imagery, they persisted on streetscapes for a median of 38 to 56 months, with the shortest amount of time being 10 months and the longest amount of time being 144 months.

2021 Standing Dead Trees. The persistence of street trees found standing dead is a median of 24 to 38 months (Fig 3). The minimum length of persistence is 2 to 8 months and the maximum amount of time persisting is 72 to 73 months (Table 2). Street trees that were not observed as standing dead in GSV images but were ultimately found standing dead by field technicians in 2021 persisted on streetscapes for a median of 23 to 26 months, with the shortest amount of time being 8 months and the longest being 26 months. For street trees that were observed as standing dead in GSV images persisted on streetscapes for a range of 24 to 38 months, with the shortest and longest amount of time being 2 months and 72 months, respectively.

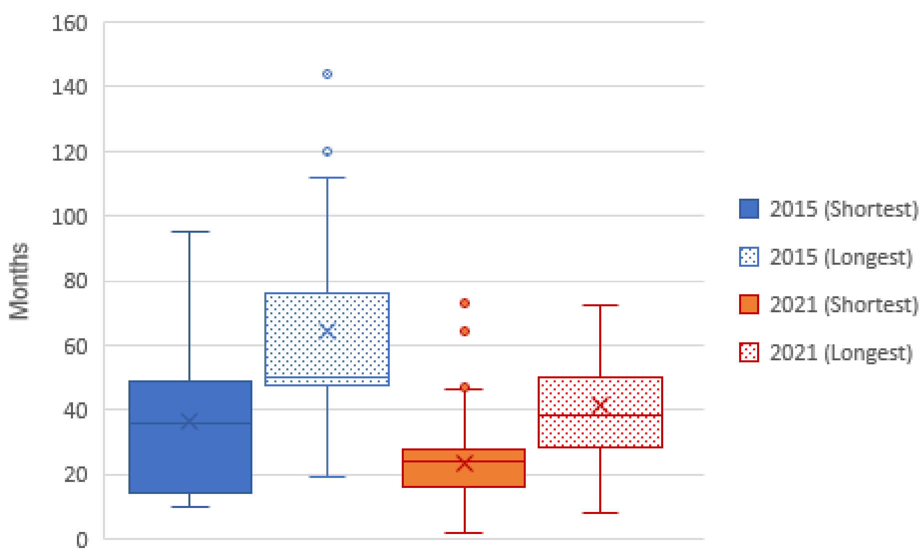

Fig 3. The shortest and longest amount of time (months) street trees from the 2015 and 2021 field seasons were found standing dead on streetscapes. The ‘x’ in each boxplot indicates the mean and the line through each boxplot indicates the median. Whiskers represent first and third quartiles, and dots represent outliers.

	Minimum	Q1	Median	Q3	Maximum	Range	Outliers
2015 (Shortest)	10	14	36	49	95	85	n/a
2015 (Longest)	19	47	50	76	144	125	120, 144
2021 (Shortest)	2	16	24	28	73	71	47, 64, 73
2021 (Longest)	8	29	38	50	72	64	n/a

Table 2. The summary statistics representing the boxplots (Fig 3) of the shortest and longest amount of time (months) standing dead street trees persisted on streetscapes.

Changes in the Standing Dead Street Tree Community

2015 Standing Dead Trees. The most common standing dead street tree species were unable to be identified (9 trees), followed by *Acer sp.* (5 trees), *Gingko biloba* (4 trees), and *Zelkova serrata* (4 trees) (Fig 4). For DBH size classes, 3 standing dead trees were not included as they did not have a DBH recorded at their time of observation during inventory. The average DBH of the 2015 standing dead trees was 24.8 cm (min=2.8 cm, max=67.3 cm). The DBH class with the highest number of dead trees is Class 3 (10 trees, 15.3–30.4 cm), followed by Class 2 (8 trees, 7.7–15.2 cm) (Fig 5).

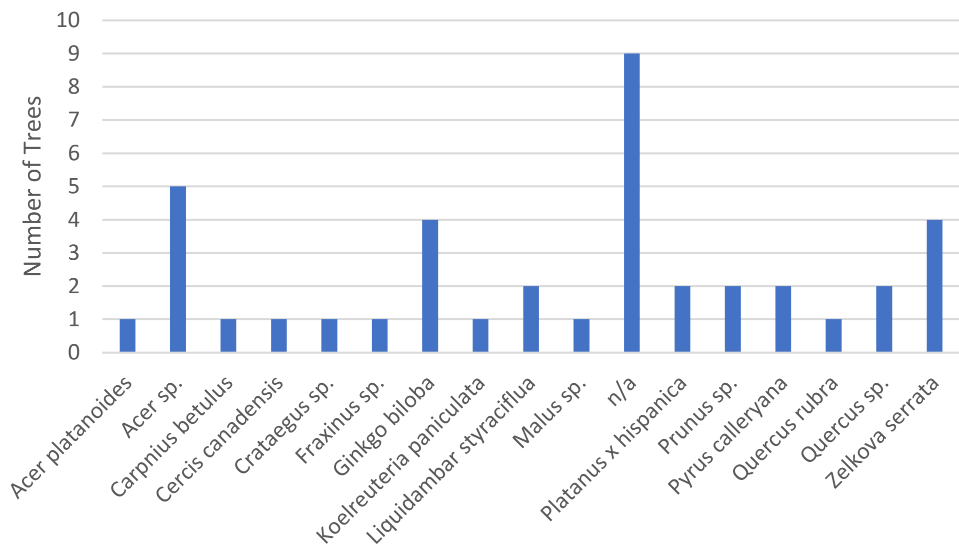

Fig 4. The total amount of standing dead street tree species from the 2015 inventory.

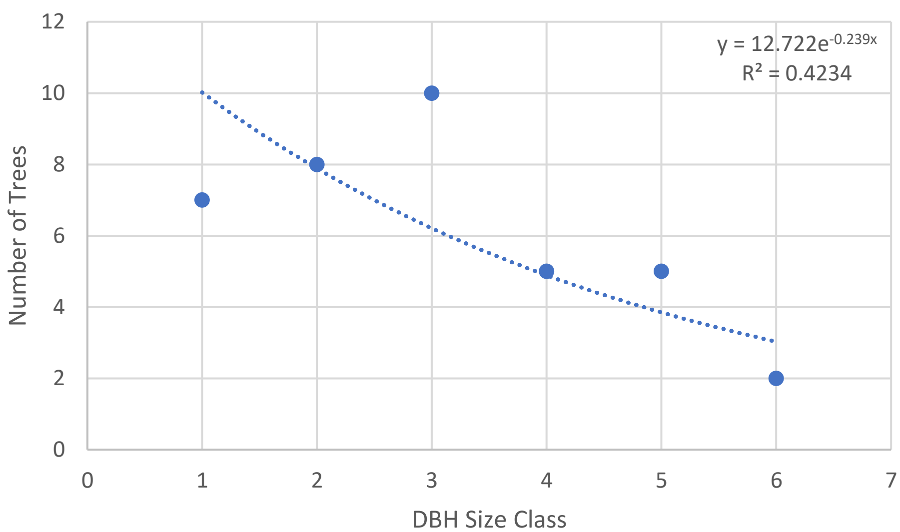

Fig 5. The diameter at breast height (DBH) of standing dead street trees from the 2015 inventory that fall within the following 7 DBH classes: 1 (≤7.6 cm), 2 (7.7–15.2 cm), 3 (15.3–30.4 cm), 4 (30.5–45.6 cm), 5 (45.7–60.8 cm), 6 (60.9–76 cm), and 7 (>76 cm).

2021 Standing Dead Trees. The most common standing dead street tree species were *Prunus sp.* (16 trees), *Acer platanoides* (8 trees), *Acer sp.* (4 trees), and *Platanus x hispanica* (4 trees) (Fig 6). For DBH size classes, 3 trees were excluded as they did not have a DBH recorded at their time of observation during inventory. Trees that were observed standing dead in the 2021 inventory had an average DBH of 25.2 cm (min=2.5 cm, max=61.2 cm). The DBH size class with the highest number of dead trees is Class 1 (16 trees, ≤7.6 cm), followed by Class 4 (11 trees, 30.5–45.6 cm) (Fig 7).

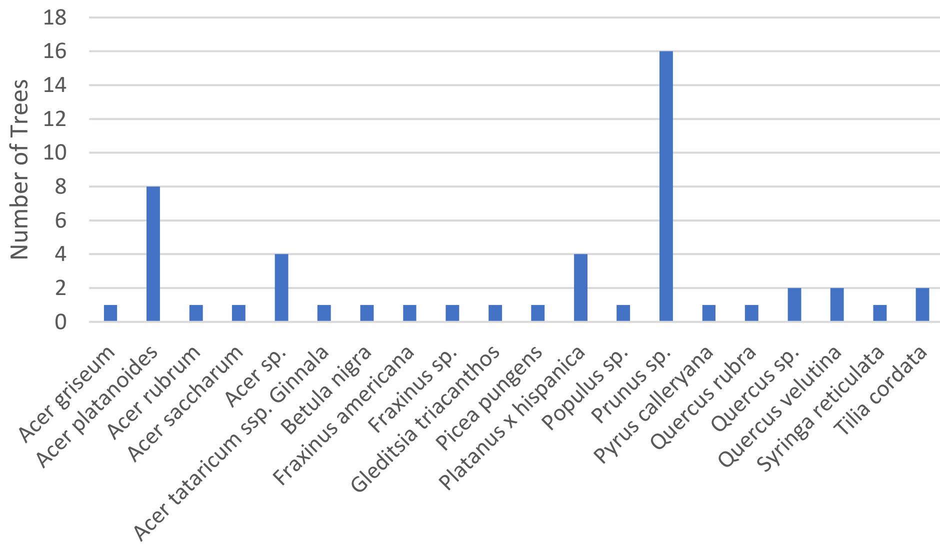

Fig 6. The total amount of standing dead street trees species from the 2021 inventory.

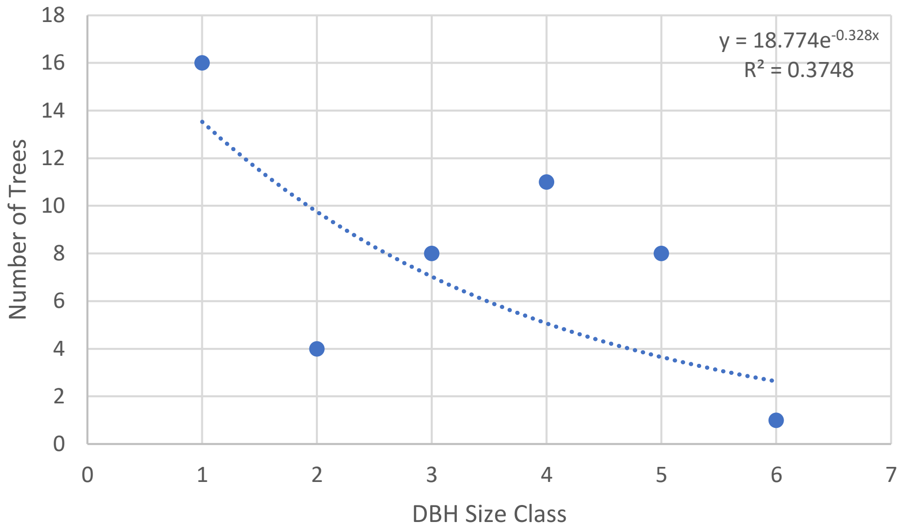

Fig 7. The diameter at breast height (DBH) of standing dead street trees from the 2021 inventory that fall within the following 7 DBH classes: 1 (≤7.6 cm), 2 (7.7–15.2 cm), 3 (15.3–30.4 cm), 4 (30.5–45.6 cm), 5 (45.7–60.8 cm), 6 (60.9–76 cm), and 7 (>76 cm).

Discussion

Analysis of the total amount of standing dead within the street tree community in each inventory shows a proportion of 1.5% (2015) and 2.0% (2021). This suggests that the standing dead population in Philadelphia is broadly similar to other urban forests, although the 2021 percent standing dead was a bit higher than other cities. In the West Oakland neighborhood of Oakland, California, a 5-year annual monitoring project reported that standing dead street trees made up 1.7% of the street tree community (Roman, 2014). In a municipal forest analysis in New York City, standing dead street trees made up 1.4% of the street tree community (Peper et al., 2007). However, the increased proportion of standing dead trees in the 2021 inventory could be a result of increased newly planted street trees. For instance, *Prunus sp.* had the highest amount of standing dead trees in 2021 with a total 16 trees (Fig 6). 8 of these 16 trees were newly planted trees that did not exist in the 2015 inventory. This supports the rate of high mortality observed in young, recently street trees (Roman et al., 2014, Roman et al. 2018). For urban trees, new plantings often have a relatively higher mortality rate during the establishment period—the first few years after planting—when they are vulnerable to transplant stress and require substantial maintenance effort to survive (Hilbert et al. 2019). One of the functions of the Pennsylvania Horticultural Society (PHS) Tree Checkers program is to find young, dead street trees that were planted through the program and to get them quickly replaced (Roman et al., 2018). However, the program only focuses on the replacement of trees during the first summer after planting. Additionally, any street trees that were planted by other stakeholders may receive varying degrees of monitoring in order to ensure prompt removal.

Standing dead trees persist on the streetscapes for many years. Based on my analysis, dead street trees typically persist for a median of 24 to 50 months (i.e., 2 to 4 years) prior to removal (Table 2). The longest length of time that a standing dead tree was observed persisting was 144 months (12 years). This is contrary to best practices in arboriculture and urban forestry, which call for dead trees to be removed to mitigate risk and eliminate disservices caused by unattractive and/or dangerous dead trees (Pecenko & Brack, 2021; Roman et al. 2021). Additionally, the generally long time that dead trees persist in streetscapes in Philadelphia aligns with anecdotal evidence from field crews: during the 2021 field season, field crew members were sometimes approached by residents while taking tree measurements, in hopes that the crew members were city arborists there to perform tree removals. After explaining the nature of the study to residents, many claimed that they have been trying to get the city to remove their standing dead street tree for months or years. When urged to contact PPR for tree removal, many residents stated that they had already contacted PPR. The challenge of managing dead street trees—and especially the need to promptly remove them—is well-known to PPR staff, who are currently undertaking a strategic planning process for Philadelphia's urban forest (Kummer, 2021). During the public outreach for that plan, many residents expressed concerns about the length of time for removals to occur (E. Smith Fichman, pers. comm.).

The persistence of standing dead street trees in Philadelphia decreased between field seasons (Fig 3). Standing dead trees identified through the 2021 inventory persisted on streetscapes for shorter lengths of time compared to dead trees from the 2015 field season. This could be due, in part, to the 2016 virtual inventory of city trees that PPR conducted, because locating and removing dead trees throughout the city was one of their top priorities. Out of all the removals related to both the 2015 and 2021 inventories, the most common year for removals was 2018—only 2 years after the PPR inventory was performed. This suggests that PPR became more vigilant in identifying, assessing, and removing street trees following the virtual inventory. In terms of calculating persistence through observations on GSV, the average year for removals being in 2018 could be a result of a lack of imagery in GSV. Between 2015 and 2021, the years with the most available GSV imagery were 2018 and 2019; the amount of 2018/2019 imagery could skew the average year of removal. My persistence calculations depended on the years that were available for their location. In determining the longest and shortest months of time found standing dead, the absence of GSV years could have provided an overestimation in their length of persistence. It is possible that a particular tree was removed years prior to their first instance of removal on GSV—but without additional years of imagery, determining the exact year, let alone the month, is difficult to estimate. The range of persistence values was implemented in order to accommodate the uncertainty inherent in the data sources.

In urban forests, the proactive removal of dead street trees can be a form of stewardship. For large, old trees, this type of stewardship is rooted primarily in risk management in order to mitigate the possibility of injuring residents, property, and infrastructure that may result in death, power outages, or liability (Hilbert et al., 2019; Klein et al., 2019). In Holyoke, Massachusetts, resident interviews showed that large, mature trees are viewed as a threat to utilities and sidewalks, leading arborists to focus on removing trees rather than planting new trees (Breger et al., 2019). In that same study, planted trees which did not have dedicated crews maintaining them tended to have higher mortality, including more standing dead trees (Breger et al. 2019). In the case of standing dead street trees, this type of proactive stewardship would encompass removal before risk. For young and newly planted street trees that are standing dead, these trees do not pose a safety risk, but they can be an eyesore, and they are easier and cheaper to remove than mature trees (Roman et al., 2014). Indeed, aesthetics can play a major role in the removal and planting decisions of street trees. For planted trees in Los Angeles, California, and New Haven, Connecticut, residents' preferred traits for trees were size, ease of maintenance, and aesthetics (Pataki et al., 2013; Locke et al. 2015). The DBH classes with the highest number of dead trees were Class 3 (2015, 15.3–30.4 cm) and Class 1 (2021, ≤7.6 cm) (Fig 5 and Fig 7). In 2015, the high amount of mature standing dead trees that are removed by the 2021 inventory supports the idea that large, mature trees were removed as a form of risk management. The higher percent of small standing dead trees in 2021 may be due to the proliferation of street tree planting programs from various stakeholders, and the higher mortality often seen with young trees (Hilbert et al. 2019). It is also important to note that the second-highest number of dead trees in 2021 is Class 4 (15.3–30.4 cm) (Fig 7), which suggests that mature trees are indeed still present in Philadelphia's streetscapes, and in need of removal to mitigate risk.

Observing the fates of standing dead street trees can provide urban foresters and arborists with a better understanding of the temporal dynamics of an urban forest. By understanding the proportion of standing dead trees, as well as removal and persistence trends, foresters and arborists can develop management practices to maximize tree standing life. Particularly, they should focus on the stewardship of large, mature trees that provide ecological benefits to their surrounding urban habitat (Le Roux et al., 2014). Although the current perception of these trees is risk mitigation, future research should aim to investigate alternative management scenarios that balance mitigation and management in order to preserve mature standing dead trees. However, it is important to note that even with continual management, pedestrian and vehicular traffic would make the maintenance of mature dead street trees difficult and impractical. Therefore, tracking the persistence of standing dead trees can help foresters and arborists make faster, well-informed management decisions. Although GSV is shown to be a useful tool for tracking the fate of standing dead trees, its lack of imagery can best be supplemented by using other sources in order to fill the gaps in time. The addition of street-level imagery has great potential for practical management (Berland et al., 2019; Berland & Roman, 2020). Future studies observing the persistence of standing dead street trees through street-level imagery should incorporate the use of multiple sources in order to gain a clearer understanding of persistence.

Conclusion

In this study, the fate and persistence of standing dead street trees were observed in-field and through street-level imagery. Through conventional field data and GSV imagery, it is apparent that dead trees can persist on streetscapes for years prior to their removal. The body of literature regarding urban tree mortality is growing; however, little is known about the role of standing dead trees in urban forests as a whole, or street tree systems in particular. The persistence of dead trees suggests a need for improved management practices to mitigate risk and ameliorate aesthetic problems of dead street trees. Future research could also compare dead tree dynamics in cities with varying levels of proactive and reactive management, and varying degrees of active inventory and monitoring programs to manage removal decisions.

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