Urban Tree Mortality: What the Literature Shows Us

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Background

Urban tree death is a major consideration for anyone managing urban forests. Whether conserving canopy cover, planting new groups of trees, or protecting large, mature trees, urban forestry professionals often gauge the success of their projects by evaluating how many trees live or die. Tree death is also relevant in planning and budgeting for tree removal needs. There is a growing body of research on urban tree mortality—studies concerning tree deaths and removals in a given place and time. However, less is understood about tree mortality in built-up urban areas compared to tree mortality in natural forests (i.e., rural, wildland settings). A thorough, evidence-based understanding of what factors contribute to tree death and what rates of mortality can be expected for different species and situations can aid urban forest managers in increasing transplant survival, using resources efficiently, and assessing their projects' effectiveness (Roman 2014; Roman et al. 2016).

The process of urban tree mortality is complex and differs from trees in non-urban areas (Roman et al. 2016). Trees located in heavily built-up and landscaped urban areas—such as boulevards/parkways and lawns—experience very different growing conditions compared to trees growing in natural forests. For example, urban growing conditions can be more stressful due to factors like limited rooting area, degraded soils, and excessive heat, or they can be enhanced through practices like irrigation and fertilization (Urban 2008; Miller et al. 2015). Additionally, while mature trees in natural forests generally die from a slow accumulation of stressors (Das et al. 2007), urban trees can be removed by people while they are still alive. There are preemptive removals of stressed or vulnerable trees, where the removal is justified by tree risk management and health perceptions, as well as removals entirely unrelated to health and safety, such as a tree cut down due to human landscape preferences (Kirkpatrick et al. 2013; Koeser et al. 2015; Conway 2016).

These complexities reflect the idea that urban trees exist in an intricate socio-ecological system, a term used to describe the linked natural and human components in urban forests (Mincey et al. 2013; Vogt et al. 2015a). Urban tree deaths and removals are directly influenced by factors that are human-related, biophysical, or a combination of the two. Human factors include stewardship and maintenance actions (or lack thereof), construction and development, and land use (e.g., Hauer 1994; Nowak et al. 2004; Boyce 2010; Lawrence et al. 2012; Koeser et al. 2014; Roman et al. 2014a). Biophysical (ecological) factors include taxonomic groups like species, drought tolerance, tree size, or time since planting (e.g., Nowak et al. 2004; Koeser et al. 2014; Roman et al. 2014a; Roman et al. 2014b).

We investigated this complex issue as part of an ISA Science and Research Committee-sponsored literature review on urban tree mortality (Hilbert et al. 2019). Specifically, we collected and reviewed past research on urban tree mortality to: (1) summarize reported mortality and survival rates to determine what levels of mortality could be considered typical in urban forests, and (2) identify and categorize biophysical and human factors associated with urban tree mortality. 56 studies were included in the review. Of these, 41 studies were conducted in the United States, and nearly a third were from temperate areas. Studies were published between 1979 and 2017, with over half (31) published in the last decade. Urban tree mortality research is therefore a very active area of recent scholarship, but geographically limited in scope.

How Trees Die

While trees can die from acute (i.e., severe) threats like noxious invasive pests or extreme drought, mortality is often tied to several different compounding factors. Researchers have developed a conceptual model to explain this process in traditional forest settings called the disease decline spiral or the mortality spiral (Manion 1981; Franklin 1987). We drew on the literature and our own insights to modify the mortality spiral to apply it urban trees (Figure 1) and develop a framework for urban tree mortality (Box 1). This framework builds upon earlier research in the natural forest context by including human factors and additional biophysical factors associated with urban life.

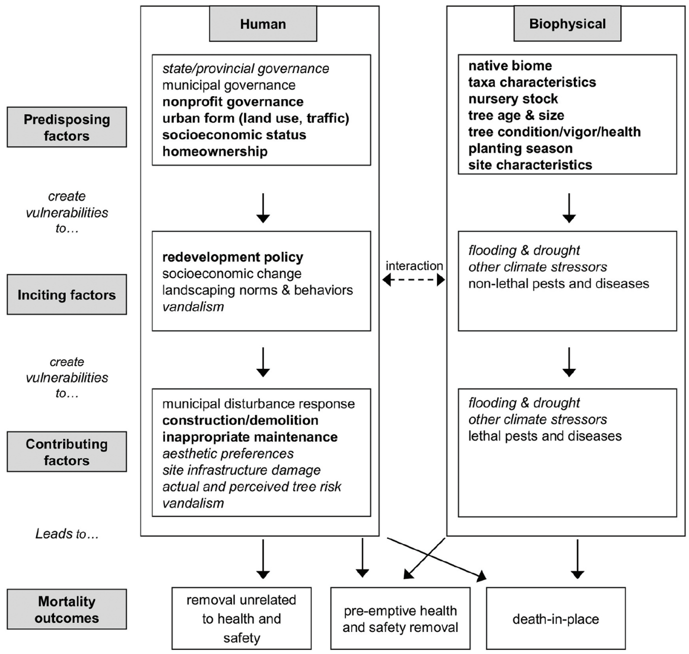
Trees are long-lived, resilient organisms that can persist for decades or centuries despite being unable to flee from threats or move towards more hospitable locales.

Box 1. The Urban Tree Mortality Framework: Predisposing, Inciting, and Contributing Factors

The urban tree mortality framework identifies predisposing, inciting, and contributing factors.

- **Predisposing factors**: the normal human and site-related conditions that a tree is exposed to in its environment.
- **Inciting factors:** short-term stressors that impact tree vigor.
- **Contributing factors:** the mechanisms that ultimately lead to tree death.

Predisposing and inciting factors work against the tree, setting the stage for the contributing factors to cause mortality (after Manion 1981). In the framework below, factors in each box are ordered from larger scales at the top (e.g., regional, municipal) to smaller scales (e.g., parcel, planting site). Factors found to be statistically significant in the studies reviewed are bolded, while those that were qualitatively important are italicized. (Hilbert et al. 2019)



They use their size to their advantage, shading out competition and storing the energy reserves needed to survive periods of hardship and fend off pests and disease. In explaining the deaths and removals of trees with a framework, the factors that work against trees can be categorized as predisposing, inciting, or contributing (Box 1).

For instance, look at the mortality spiral created by Franklin et al. (1987; Figure 1a) to examine the different layers of factors leading to a tree's demise. This diagram describes the life of a hypothetical Douglas-fir in a natural forest setting. The tree starts off at the top of the spiral as a healthy tree. It is in an already crowded stand, which predisposes it to more competition with neighboring trees. It begins to lose its needles, which leaves it weakened and susceptible to bark beetle infestation. These inciting factors in turn allow blue-stain fungus, the contributing factor, to infect and kill the tree. There are chances for the tree to exit the spiral, but it becomes more difficult as the stresses add up.

In Figure 1b, we reimagine the mortality spiral to describe a hypothetical urban tree. This red maple is planted in a

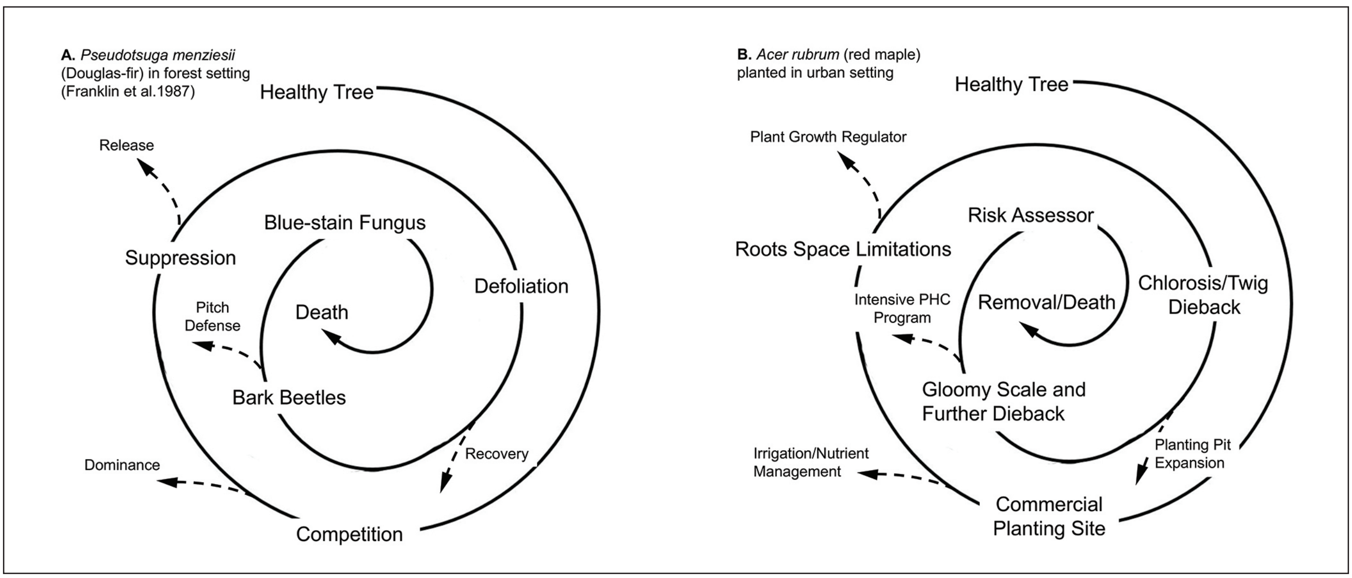


Figure 1. Tree mortality spirals depicting (A) an example tree in a natural forest (adapted from Franklin et al. 1987) and (B) an example planted urban tree (Hilbert et al. 2019).

commercial site with limited rooting space, which predisposes it to inciting factors like chlorosis, dieback, and gloomy scale. Along the way, managers can step in to improve the planting space or treat the tree. Without proper maintenance, however, the tree ultimately dies. As previously mentioned, unlike trees in natural forests, urban trees can be removed while still alive for health and safety or other reasons. This means the risk assessor making the removal decision is the final, contributing factor which causes tree mortality. Conceptualizing urban tree mortality this way can aid our understanding of the process of urban tree mortality and the role managers play in the cycle.

In our review of the past literature, the human factors that appeared the most were related to stewardship, maintenance, and vandalism (15 studies), with stewardship activities generally playing a positive role in tree survival. The most common tree and environmental factors in the literature were species (15), tree size or age (13), and site characteristics (12). Despite their potential importance, few studies examined topics like soil characteristics, microclimate, planting program characteristics, or resident behavior. We suspect that these factors are rarely included because they require more equipment, expertise, and time to measure. Indeed, many of the variables commonly included in tree mortality studies are relatively easily obtained from quick field observations or planting records. The urban tree mortality framework in Box 1 includes some of the factors that appeared to be important influencers of tree death.

Many studies analyzed tree mortality through statistical associations with various potential factors, generally involving field data collection, while some used surveys of residents about reasons for tree removal, and a few used municipal records of tree removal or construction. Future interdisciplinary research could apply mixed methods to unpack the tree mortality process in terms of predisposing, inciting, and contributing factors.

Mortality Rates

A useful way to think about patterns of tree death is to look at mortality rates, which are the proportions of trees in a particular group that have died or were removed during a specified time-frame. For example, urban forestry researchers and professionals could monitor mortality for all neighborhood street trees every five years, or track mortality two years after installation of a park planting project. If an urban forester has accurate mortality rates for different groups of trees over a long period of time, he or she might be able to see that trees are dying more frequently in a specific part of the city or during certain time periods. This information can help managers pinpoint causes of tree deaths and intervene to decrease mortality. Mortality rates are also used to project future canopy growth and associated environmental benefits. Roman et al. (2016) provide a useful overview of why and how to calculate different mortality and survival rates in urban forestry programs using the science of demography—the statistical study of populations.

We were able to calculate annual mortality rates for 33 articles. These were grouped by the following study types:

- *Repeated inventories of uneven-aged trees.* These studies monitored existing trees of different ages or planting times in a particular landscape, such as all street trees in a neighborhood.
- *Planting cohorts of relatively even-aged trees.* The word cohort refers to trees planted around the same time. These studies monitored trees of similar ages or time since planting, such as all trees from a particular year of a planting initiative.

The median annual mortality was 2.3 to 2.6% for repeated inventories of uneven-aged trees and 4.4 to 6.5% for planting cohorts (ranges reflect studies that reported a range for the time period or mortality rate). For planting cohorts, the median annual mortality was higher in the first five years after planting (6.6 to 7.0%), compared to the annual mortality for six years and beyond (2.8 to 3.8%). This supports the notion that the establishment phase is particularly challenging for urban trees (Harris and Day 2017).

We used the annual mortality rates from planting cohort studies to construct survivorship curves—these are graphs showing the percent of trees that survive over time, starting at 100% survivorship when trees are planted and declining as deaths and removals accumulate. Figure 2 shows survivorship curves representing better-than-normal, middle-of-the-road, and worse-than-normal survival. Urban forest managers can use this information to determine whether survivorship of their planting projects fits within typical ranges from the published literature.

In the future, standardizing definitions of mortality and survival and the procedures used to measure and calculate each could allow for more direct comparisons (Roman et al. 2016). Furthermore, well-organized monitoring data, including baseline records (i.e., the initial inventory or planting records), are essential to monitoring tree mortality (Vogt et al. 2015b). Studies about urban tree mortality also present an opportunity for collaboration across researchers and professionals, as both seek to understand how and why trees die in cities.

Summary

- There has been a dramatic increase in urban tree mortality studies in the past decade, with most studies in the United States.
- In order to understand urban tree mortality, it is useful to categorize factors as biophysical vs. human-related, and as predisposing, inciting, or contributing—building upon the disease-decline model of tree mortality from natural forests.
- Analyses of mortality rates associated with various factors can provide insight into how trees are dying and actions that can be taken to increase survival, but this requires well-organized monitoring data.
- Annual mortality for planting cohort studies tended to be higher during the first five years after planting, aligning with the establishment phase concept. The mortality rates reported in our literature review can be used to determine whether a given project fits within typical ranges.
- Future research could examine topics like microclimate, soil characteristics, planting program characteristics, household-level social factors, and resident behaviors. More studies are also needed in cities across varies climates and countries around the globe. Interdisciplinary research that blends different methods and research approaches will be essential to understanding tree mortality in the urban context, where human decision-making plays a central role in the mortality process.

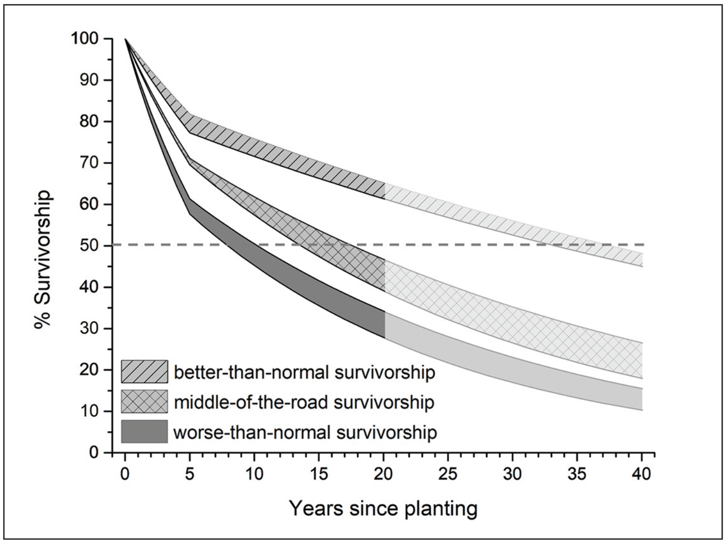


Figure 2. Survivorship curves based on quartiles of mortality rates in planting cohort studies. Better-than-normal survivorship reflects 1st quartile, middle-of-the-road reflects median, and worse-than-normal reflects 3rd quartile. The first five years used establishment mortality rates, while years 6+ used post-establishment rates. The dashed horizontal line shows 50% survivorship, also known as population half-life. After 20 years, the more transparent grey color reflects the fact that most published planting cohort studies were under 20 years post-planting, therefore post-20 years annual mortality rates are extrapolations (Hilbert et al. 2019).

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