A Survey of Wounding Frequency among Trees found in Urban and Forest Environments

by

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Abstract

Trees are exposed to a variety of natural and/or anthropogenic factors that expose internal wood to the external environment, resulting in decay and tree failure. Urban trees are exposed to improper landscaping practices, pruning cuts, soil contamination, and even vandalism. Forest trees are less impacted by anthropogenic activities, but are still susceptible to weather-and pathogen-related damages. To compare these two environments, we measured eight types of common wounds in maple (*Acer* spp.), hackberry (*Celtis* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.), and elm (*Ulmus* spp.). Urban environments surveyed included college campuses and industrial plazas; forest environments included state parks. All five genera of trees surveyed in urban environments exhibited higher frequencies of wounding in the number of open wounds, small wounds $< 2\ cm^2$, girdling roots, open root wounds, and pruning cuts when compared to conspecifics in forest environments. We saw interspecific variation among eight surveyed metrics. Since wounded trees are more likely to fail, posing a risk to humans and property, a reevaluation of arboricultural management practices in urban environments is needed.

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I. Introduction

Trees are long-lived, photosynthetic organisms that play a vital role in shaping the environment. They are primary producers that fix carbon dioxide, synthesize sugars, and release oxygen gas. By removing carbon dioxide from the atmosphere, trees act as a carbon sink, reducing the effects of global warming (Pan *et al.* 2011). A recent *Nature* study estimated that there are more than 3 trillion trees inhabiting all 14 biomes found on the planet (Crowther *et al.* 2015). Trees provide a wealth of environmental, ecological, and economic benefits (Crowther *et al.* 2015) and provide habitats to a variety of species including insects, reptiles, birds, and mammals, while hosting lower organisms such as fungi, lichen, and mosses (Kohli *et al.* 2011).

Wood formation in trees is a very orderly process where horizontal growth is initiated via the vascular cambium (Plomion *et al.* 2001). The vascular cambium is vital in the translocation of water and nutrients throughout a tree. This lateral meristematic region performs active cell-division, cell elongation, and cell wall thickening, giving rise to annual xylem and phloem layers (*i.e.*, a growth ring). This lateral meristematic growth, along with apical meristematic growth, permits the perennial life and indeterminate growth of trees (Plomion *et al.* 2001). Living, dying, and dead cells all function together to generate wood, effectively increasing the mass of a tree over time (Shigo 1982). The role of wood cells within a tree differs according the age of each cell, and cell differentiation further defines the cell’s role as it ages. Sapwood (made up of living wood cells) transports mineral solutions, stores energy reserves, helps support the tree’s mass, and maintains the tree’s defense system (Shigo 1984). Heartwood (made up of dead wood cells) provides further mechanical support for the ever-growing mass of the tree while retaining some enzymatic activity for defense (Shigo 1984).

Trees are unable to move away from negative stimuli found within their environments, so they have developed adaptations allowing them to survive. Species will vary in their tolerance, susceptibility, and survivability to harsh environments. Lacking an immune system, trees instead rely on a variety of chemical and mechanical defenses to protect themselves (Gozzo 2003). An immediate, localized defense, known as the hypersensitive response (HR), occurs within hours after an injury, causing cell and tissue death at the site of a wound in an attempt to restrict the spread of pathogens (Gozzo 2003). Following the HR, systemic acquired resistance (SAR) produces signaling molecules that upregulate defenses throughout the tree, lasting for weeks, or even months (Gozzo 2003). Lastly, trees undergo compartmentalization, a slow process that encapsulates the wound by forming callus tissue around the site of the injury (Shigo 1985; Neely 1988). Combined, these processes have allowed trees to not only cope, but capitalize on environments which might otherwise be inhospitable.

Trees have an evolutionary history dating back some 360 – 290 million years and have expanded into some of the oldest, longest-lived, most massive organisms on the face of the planet (Kohli *et al.* 2011; Shigo 1985; Stephenson 2000). *General Sherman*, a gigantic living sequoia tree (*Sequoiadendron giganteum*), which resides in Sequoia National Park, California, holds the record as the largest known single stem tree by volume at 1,487 m^3 with an estimated age between 1790 and 2500 years (Stephenson 2000). *Hyperion*, a coast redwood (*Sequoia sempervirens*) resides in an undisclosed location in Northern California, and currently holds the title of the world's tallest tree, measuring 115.85 m (conifers.org 2015). While both record holders are gymnosperms, angiosperms (flowering plants) have diversified into the largest catalog of land plants. Consisting of more than 250,000 species across more than 13,000 genera (Gorelick 2001; Thorne 2002), angiosperms have a remarkable history of co-evolution alongside insect pollinators (Cappellari *et al.* 2013), although there is controversy shifting these ideas (Gorelick 2001)

Primary growth forest ecosystems are some of the planet's most biologically diverse habitats, containing a dense network of trees, plants, mosses, fungi, and microbes (Crowther *et al*. 2015). Four major forest classifications have been identified by the Food and Agriculture Organization (FAO): primary forests, naturally regenerated forests, planted forests, and mangroves (FAO 2015). For the purposes of this study, the term *woodland forest* will refer to the FAO's definition of a naturally regenerated forest—one with noticeable human activities (FAO 2015). The term *urban forest* will refer to trees found growing in urban and metropolitan sites. Urban forests now constitute some 78.2 billion trees found throughout the United States (Dwyer *et al. 2*003). This displays the phenomenal growth of our urban forests, as only 3.5% of the United States is classified as urban area (Dwyer *et al*. 2003). As the human population rises, urban areas will continue to increase in size, reducing woodland forest tree populations. Currently, they are decreasing at an estimated 15 billion trees $year^{-1}$ (Crowther *et al.* 2015), thus increasing our interaction with urban forests.

Well-maintained urban forests can be as diverse and functionally advantageous as their woodland counterparts (Nowak *et al.* 2007). In New York City alone, an estimated 5.2 million urban trees cover 20.9% of the city. Valued at more than $5.2 billion, these urban trees remove air pollutants at a rate of 2,202 tons year^{-1} while lowering air temperatures, reducing rainwater runoff, improving water quality, and providing habitats for many species in the community. In addition to these ecological benefits, they also provide many sociological benefits. New York City's urban trees reduce building energy costs by $11.2 million year^{-1}; they sequester 42,300 tons of carbon year^{-1}, reduce noise, and increase property values by providing aesthetically-pleasing landscapes (Nowak *et al.* 2007).

There is also a positive link between arboriculture and healthier sociological ecosystems (Kuo 2003). Communities with well-maintained green spaces exhibited encouraging patterns of more children playing, reduced crime rates, and a greater sense of safety due to social connectedness (Kuo 2003). Residents were also more likely to spend time outside and take ownership of these green spaces, thereby creating healthier social bonds.

While urban forests provide many of the same positive benefits as their woodland counterparts, they must also cope with many consequences unseen in woodland forests. Urban trees are surrounded by volatile air pollutants such as ozone (O_3) and sulfur dioxide (SO_2; Gregg *et al.* 2003). Ozone leads to visible damages in trees, exhibited as chlorosis (leaf yellowing), and physiological damage by reducing photosynthetic rates, leading to decreased growth (Felzer *et al.* 2007). Sulfur dioxide affects plants twofold; sudden, high concentrations lead to leaf necrosis (premature death of living cells in leaf tissues), but more often, sulfur dioxide affects plants through an accumulative process, slowing growth and increasing senescence (World Health Organization 2000). Invariably, these conditions lead to stress and deter plant growth. In a separate study, significant interspecific differences in physiological effects caused by ozone and sulfur dioxide arose between *Fraxinus americana* and *F. pennsylvanica*. *F. americana* demonstrated a greater tolerance to injuries caused by ozone, but was substantially more affected by sulfur dioxide; while *F. pennsylvanica* showed less tolerance to ozone, but tolerated higher levels of sulfur dioxide (Karnosky and Steiner 1980). This demonstrates difference in tolerance, susceptibility, and survivability among species.

Trees in urban environments are also exposed to a variety of anthropogenic wounding occurrences that expose internal wood to the external environment. Such wounds can lead to decay and resulting tree failure. Trees found in urban environments are more routinely subjected to adverse growing conditions such as air pollutants, compacted soils, improper landscaping and construction practices, and even vandalism. Urban trees also receive benefits such as supplemental water, increased fertilizer regimens, warmer temperatures, and increased carbon dioxide concentrations—factors which enhance plant growth (Gregg *et al*. 1997). Thus, urban trees both suffer and benefit from anthropogenic factors.

When trees cope with these abiotic and biotic injuries, energy reserves can be depleted (Shigo 1982). Wounds that break the bark's surface (Figure 1) and expose internal wood are detrimental to tree health and growth by interrupting the vascular cambium used for the translocation of water and nutrients (Neely 1988). Thus, once wounded, trees experience a heightened ecological trade-off when diverting limited resources to wound repair and chemical responses rather than growth and reproduction (Shortle 1979). Furthermore, when trees lack the energy requirements needed to sustain optimal growth, they are subject to added stress, loss of vigor, or even premature death.

Bacteria, fungi, parasites, insects, and mammals all act as biotic sources of tree wounding. Bacterial infections (such as common leaf blights and leaf scorches) affect wounded trees by reducing growth, delaying flower and fruit production, and instigating premature death (Blaedow 2011). Fungal infections caused by wood-decaying microorganisms such as *Armillaria* root rot (*Basidiomycota*) and Dutch elm disease (*Ascomycota*) affect hundreds of species of trees throughout North America (Williams *et al.* 1989). Wood-boring vector insects such as the destructive Emerald ash borer (EAB) and the elm bark beetle have drastically reduced two of North America's more widely distributed tree genera—ash (*Fraxinus* spp.) and elm (*Ulmus* spp.; Herms and McCullough 2014). Currently, 47 counties in Tennessee are under quarantine for the transfer of nursery stock, green lumber, and firewood in an attempt to restrict further spread of the EAB throughout the state (tn.gov). Lastly, mammals also heavily influence seedling and sapling mortality, especially in species of maple (*Acer* spp.), ash (*Fraxinus* spp.), and cherry (*Prunus* spp.) which are subject to repeated attacks by preferential browsers like the white tailed deer (Long *et al.* 2007).

After a wound breaks through the bark's surface, a myriad of wood-decaying microorganisms including wood-inhabiting bacteria and fungi such as *Basidiomycota*, *Ascomycota*, and *Deuteromycota* all lie in wait ready to instigate decay in a tree (Shigo 1982, 1984). Once the decay process is initiated, it cannot be reversed; it can only be delayed by chemical and mechanical defenses (Gozzo 2003; Shigo 1982). A tree's ability to effectively close a wound depends on the environment in which it resides, its vigor, and the vulnerability of the tree's defense mechanisms against varying microorganisms (Shigo 1982).

Tree wounding, healing, and wood decay rates further vary among tree genera and species (Neely 1991; Luley *et al.* 2009). *Acer* spp., *Quercus* spp., and *Ulmus* spp. are highly susceptible to damage from ice storms, while *Fraxinus* spp. and *Ulmus* spp. can be more vulnerable to disease (Rhoades and Stipes 1999). *Acer* spp. is particularly prone to internal trunk rot as a result of wounding (Rhoades and Stipes 1999). Wood decay rates are heavily influence by tree circumference and trunk density (Hérault *et al.* 2010). While trees with decay may stand for many years, they are more vulnerable to limb or structural failures when exposed to further attacks from insects, birds, mammals, and the elements.

Though humans have also played a role in tree care for more than 4,000 years, they are also a major source of biotic tree wounding (Neely 1979). Anthropogenic wounding in urban trees can lead to decay in the branches and trunk sections, thereby creating associated hazards and risks to both people and property. Given that trees are massive structures, the addition of natural forces such as wind, ice, and rain can make them more hazardous, especially those with decay which are already prone to branch or even total tree failure. To handle the threats posed by urban trees, a new industry was born—urban arboriculture. The number of urban arboricultural businesses experienced a 21% growth rate over a ten year period from 1992 – 2002 (defined by more than 80,000 establishments), which resulted in a 12% growth rate in employment (employing nearly 160,000 people), and in 2002 alone, generated revenues in excess of $9 billion (O'Bryan *et al.* 2007).

Additional studies from 1995-2007 uncovered that 407 deaths in the United States were due to wind-related tree failures (Schmidlin 2009). During this same twelve-year period, 1285 tree care workers were killed while performing tree care operations. 42% of the deaths were from trees or branches striking or pinning workers against an object, while 34% were from limbs or trees falling to a lower level and striking an individual (cdc.gov 2009). While these high numbers can be attributed to improper training, lack of experience, or absence of proper protective gear, this statistic signifies the importance of early identification of hazardous trees. All too often, tree care workers only become involved once a tree becomes extremely hazardous—a point at which the tree has already begun dropping large-diameter dead branches due to extensive internal decay.

Urban city trees experience a shorter average life span (~32 years) than trees in rural metropolitan areas (~150 years; Iakovoglou *et al.* 2002). Meanwhile, trees found in primary, old-growth forest environments may last for more than a millennium (Stephenson 2000). Given the adverse growing conditions discussed above, it makes sense that urban trees have a shorter life span than their forest counterparts. We hypothesize that trees found in urban environments will display a greater frequency of wounding (in both the number and size of wounds) than conspecifics in forest environments and, furthermore, that these wounds will lead to lower overall tree condition rankings in our five chosen genera (Table 1).

To test this hypothesis in determining wounding rates among urban and forest environments, the author, an International Society of Arboriculture (I.S.A.) Certified Arborist (Rumble, SO-6435A 2010), analyzed eight types of common wounds (Table 2) found in five tree genera throughout middle Tennessee: maple (*Acer* spp.), hackberry (*Celtis* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.), and elm (*Ulmus* spp.; Figure 2). Since wounding leads to eventual decay, this study emphasizes not only the importance of risk evaluation of trees, but also the sociological and ecological roles they play. By observing multiple sites of wounding, this study can help provide insight as to how anthropogenic activities lead to hazardous trees found in urban environments and allow for better recognition of the associated risks.

II. Thesis Statement

Trees found in urban environments are routinely forced to deal with a multitude of adverse growing conditions created by humans. Due to this anthropogenic activity, we hypothesize that wounding in urban trees (in both number and size) will occur at a greater frequency when compared to forest trees. This will lead to urban trees exhibiting a lower overall tree condition ranking when compared to conspecifics in forest environments.

III. Materials and Methods

Site Description

The sample for this study consists of a total of 600 trees from five different genera (n = 120 trees genera^{-1}) across two distinct environments (urban and forest) at eight sites (n=15 trees genera $^{-1}$ site $^{-1}$) throughout Tennessee. Surveys were done between December, 2014 and August, 2015. The four urban sites selected included: Middle Tennessee State University Campus (Murfreesboro), Ellington Agricultural Center (Nashville), Vanderbilt University (Nashville), and Maryland Farms Industrial Plaza (Brentwood; Figure 3). Urban sites were defined by the presence of nearby paved parking lots, abundant vehicular traffic, and nearby pedestrian sidewalks.

The four forest sites selected included: Rock Island State Park (Rock Island), Percy Warner Park (Nashville), Tims Ford State Park (Winchester), and Long Hunter State Park (Nashville; Figure 3). In contrast to urban sites, these were designated as *forest* sites due to their lack of nearby paved parking lots, associated vehicular traffic and pedestrian sidewalks. However, forest trees identified in this study were not absent of anthropogenic activities. All were found within 15' of walking trails. Verbal permissions were granted at each site to complete this non-destructive tree survey.

Genera Description

Trees were visually identified by bark, leaf (when possible), and growth patterns (Figure 2). Trees with trunk circumferences greater than 350 cm were excluded from the study in order to minimize variation. Wound metrics were taken from the lower trunk section of all trees to a height of 3 m. Lateral branches and wounds beyond 3 m were not counted, though visual identifications were noted on paper.

Initial measurements included assigning each tree a unique identification number. The tree's lower trunk section was photographed with a GPS-enabled camera in order to obtain GPS coordinates (Table 3a-h). Tree circumference was measured at a height of 1.37 m from the highest point on the soil line. Trees from five different genera were randomly selected at each site. The five genera included: maple (*Acer* spp.), hackberry (*Celtis* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.), and elm (*Ulmus* spp.).

Acer spp. is found worldwide, and includes some 120 species. Maples become large dominant shade trees, which are easily distinguished by their unique leaf shape and winged samaras (Dirr 2009). Common species found in the survey sites included *A. rubrum, A. saccharinum,* and *A. saccharum*.

Celtis spp. is known for its vigorous growth and adaptability to adverse growing conditions. Hackberry trees have persistent fruits, maturing late in October, which remain a staple for birds and wildlife prior to winter. The genera include some 60 species, though only *C. occidentalis* and *C. laevigata* are commonly found in Tennessee (Dirr 2009).

Fraxinus trees are successful due to their adaptability to soil types, flooding, and air pollution (Karnosky and Steiner 1980, Schaub *et al.*, 2002). However, ash tree populations in the United States have been drastically reduced since the introduction of the invasive EAB in 2002 (Herms and McCullough 2014). In southeast Michigan, where EAB originated, more than 99% of *Fraxinus* trees have been killed and, now, millions of widely distributed *Fraxinus* trees including *F. pennsylvanica, F. americana, and F. nigra* are being impacted (Herms and McCullough 2014). Currently, 47 counties in Tennessee are affected by EAB including Davidson and Rutherford counties.

Quercus is a widespread tree genera consisting of more than 500 species (Dirr 2009). Easily identified by the presence of hanging acorns, Oak trees develop into large, dominant shade trees with massive trunks which are used for hardwood production. *Q. rubra*, *Q.alba*, *Q. macrocarpa*, and *Q. palustris* are commonly found throughout Tennessee, and were commonly surveyed species in the study.

Ulmus americana was planted extensively in the 1930's throughout New England. Elm tree populations have been drastically reduced due to the spread of Dutch elm disease (a fungal infection carried by beetles) leading to phloem necrosis and tree death (Parker and Leopold 1983). Hundreds of cultivars have since been bred from more than ten species (Dirr 2009). *U. parvifolia* shows promising resistance to Dutch elm disease, though it is now being overplanted, becoming a dominant landscape tree. Common surveyed species in this study were *U. rubra*, *U. parvifolia*, and *U. ame*ricana.

Wound Survey Methods

Twelve metrics were surveyed at each tree (Table 2), with the main focus on eight wounding metrics to quantify the frequency in which trees exhibited varying types of easily identifiable wounds. Wounds that expose internal wood (Figure 1) were measured and assigned an open-wound number. Open wound measurements were taken with a tape measure at the wound's widest and highest points to give an approximate rectangular-dimensional wound area. In order to decrease variance among trees, small wounds < 2

cm^2 were limited to 300 wounds $tree^{-1}$. Lastly, the total number of closed (fully compartmentalized) wounds was tallied.

Presence / absence categorical counts were assigned to root wounds, fungal conks, pruning cuts, and girdling roots. Each tree was also assigned an overall condition ranking from 1 – 5 based on the authors fourteen years of arboricultural experience. This number was based on a visual identification of the tree's upper canopy health (Table 1).

Statistical Analysis

Statistical analysis on numerical data including number of open wounds (m^{-2}), wound area (cm^2), number of wounds < 2 cm^2 (m^{-2}), and number of closed wounds (m^{-2}) were analyzed on IBM SPSS predictive analytics software (Armonk, NY) and graphed with GraphPad Prism (La Jolla, CA).

Single comparisons of wounding such as wounding rates between *genera*, *environment*, or *environment x genera* (interaction) were factored into ANOVA (2-way ANOVA, $df = 4$, $\alpha = 0.05$; Zar 1974). Comparisons of one genus against another, or one genus among multiple sites were analyzed using ANOVA (1-way ANOVA with Tukey post-test, $df = 4$, $\alpha = 0.05$; Zar 1974). Presence or absence categorical wound measurements including root wounds, fungal conks, pruning cut wounds, and girdling roots were analyzed using chi-square (χ^2, $df = 1 - 4$, $\alpha = 0.05$). Within a genus, urban and forest environments were analyzed using t-tests (2-tailed t-test, $df = 1$, $\alpha = 0.05$).

IV. Results

Number of Open Wounds (m^{-2})

Both environment type ($p < 0.001$) and tree genera ($p = 0.002$) had a significant effect on the normalized number of open trunk wounds, although there was no interaction among these factors ($p = 0.43$, $df = 4$; Table 4). In urban environments, the number of open wounds in *Acer* spp. (0.7 +/- 0.1) was significantly higher than that of *Ulmus* spp. (0.3 +/- 0.1, $p = 0.01$, $n = 60$; Figure 4). No significant differences were detected among remaining genera ($p > 0.05$). In forest environments, no significant differences were detected among tree genera ($p = 0.08$, $n = 60$; Figure 4). Both *Fraxinus* spp. ($p < 0.001$) and *Ulmus* spp. ($p = 0.03$) had significantly more wounds in urban environments than conspecifics in forest environments ($n = 60$, $\alpha = 0.05$; Figure 4). No significant differences were detected in remaining genera among environments ($p > 0.05$).

Average Wound Area (% trunk wounded)

Tree genera ($p = 0.001$) had a significant effect on wound area, while environment type ($p = 0.18$) did not. Furthermore, there was no interaction among these factors ($p = 0.3$, $df = 4$; Table 4). In urban environments, the wound area in *Fraxinus* spp. (1.7 +/- 0.5) was significantly greater than that of *Quercus* spp. (0.4 +/- 0.3) and *Ulmus* spp. (0.4 +/- 0.1). Wound area for *Acer* spp. (1.0 +/- 0.2) and *Celtis* spp. (1.3 +/- 0.5) was significantly greater than that of *Quercus* spp. and *Ulmus* spp. ($p = 0.01$, $n = 60$; Figure 5). No significant differences were detected between *Acer* spp. and *Celtis* spp., or between *Quercus* spp. and *Ulmus* spp. ($p > 0.05$). In forest environments, there were significant differences in wound area among genera ($p = 0.04$, $n = 60$; Figure 5), but post hoc analyses were not able to determine where differences lie. *Ulmus* spp. ($p = 0.02$) had a significantly greater wound area in urban environments than conspecifics in forest environments ($n = 60$, $\alpha = 0.05$, Figure 5). No significant differences were detected in remaining genera among environments ($p > 0.05$).

Number of Wounds less than 2cm^2(m^{-2})

Both environment type ($p = 0.007$) and tree genera ($p < 0.001$) had a significant effect on the normalized number of trunk wounds, although there was no interaction among these factors ($p = 0.31$, $df = 4$; Table 4). In urban environments, the number of wounds < 2cm^2 in *Acer* spp. (7.7 +/- 1.6) was significantly higher than that of *Fraxinus* spp. (1.8 +/- 0.6, $p = 0.01$, $n = 60$; Figure 6). No significant differences were detected among remaining genera ($p > 0.05$). In forest environments, the number of wounds < 2cm^2 in *Acer* (6.7 +/- 1.8) was significantly higher than *Celtis* spp. (2.7 +/- 0.6), *Fraxinus* spp. (1.4 +/- 0.8), *Quercus* spp. (1.1 +/- 0.5), and *Ulmus* spp. (0.7 +/- 0.2, $p < 0.001$, $n = 60$; Figure 6). No significant differences were detected among remaining genera ($p > 0.05$). Only *Quercus* spp. ($p = 0.003$) had significantly more wounds < 2cm^2 in urban environments than conspecifics in forest environments ($n = 60$, $\alpha = 0.05$, Figure 6). No significant differences were detected in remaining genera among environments ($p > 0.05$).

Number of Closed Wounds (m^{-2})

Environment type ($p < 0.001$), tree genera ($p < 0.001$), and interaction ($p < 0.001$) all had a significant effect on the normalized number of closed wounds ($df = 4$; Table 4).

In urban environments, there were significant difference in the number of closed wounds among genera ($p = 0.05$, $n = 60$; Figure 7), but post hoc analyses were not able to determine where differences lie. In forest environments, the number of closed wounds in *Acer* spp. (19.4 +/- 5.7) was significantly higher than *Celtis* spp. (6.3 +/- 1.5), *Fraxinus* spp. (0.7 +/- 0.2), *Quercus* spp. (2.9 +/- 0.8), and *Ulmus* spp. (5.6 +/- 2.2, $p < 0.001$, $n = 60$; Figure 7). No significant differences were detected among remaining genera ($p > 0.05$). *Acer* spp. ($p = 0.005$), *Celtis* spp. ($p = 0.001$), and *Ulmus* spp. ($p = 0.03$) had significantly more closed wounds in forest environments than conspecifics in urban environments ($n = 60$, $\alpha = 0.05$; Figure 7). No significant differences were detected in remaining genera among environments ($p > 0.05$).

Tree Circumference (cm)

Environment type ($p < 0.001$), tree genera ($p < 0.001$), and interaction ($p < 0.001$) all had a significant effect on tree circumference ($df = 4$; Table 4). In urban environments, there were significant differences in tree circumference among genera ($p = 0.04$, $n = 60$; Figure 8), but post hoc analyses were not able to determine where differences lie. In forest environments, there were significant differences in tree circumference among genera. *Quercus* spp. was significantly larger (135.3 +/- 9.8) than *Acer* spp. (76.4 +/- 6.0), *Celtis* spp. (64.8 +/- 5.1), *Fraxinus* spp. (108.8 +/- 6.5), and *Ulmus* spp. (65.8 +/- 4.0, $p < 0.001$, $n = 60$; Figure 8). *Fraxinus* spp. was significantly larger than *Acer* spp., *Celtis* spp., and *Ulmus* spp ($p < 0.001$, $n = 60$; Figure 8). No significant differences were detected between *Acer* spp., *Celtis* spp., and *Ulmus* spp. ($p > 0.05$). All five genera, *Acer* spp. ($p < 0.001$), *Celtis* spp. ($p < 0.001$), *Fraxinus* spp. ($p <$

0.001), *Quercus* spp. ($p < 0.01$), and *Ulmus* ($p < 0.001$) had significantly larger circumferences in urban environments than conspecifics in forest environments ($n = 60$, $\alpha = 0.05$, Figure 8).

Overall Tree Condition Ranking

Environment type ($p < 0.001$), tree genera ($p = 0.04$), and interaction ($p < 0.01$) all had a significant effect on overall tree condition ranking ($df = 4$; Table 4). In urban environments, there were significant differences in overall tree condition ranking among genera ($p = 0.05$, $n = 60$; Figure 9), but post hoc analyses were not able to determine where differences lie. In forest environments, there were significant differences in average tree condition ranking among genera. *Ulmus* spp. was in better condition (4.3 +/- 0.1) than *Quercus* spp. (3.6 +/- 0.1; $p = 0.004$, $n = 60$, Figure 9). No significant differences were detected between *Acer* spp., *Celtis* spp., and *Fraxinus* spp. ($p > 0.05$). *Celtis* spp. (p < 0.001), *Fraxinus* spp. ($p < 0.002$) and *Ulmus* spp. ($p < 0.001$) had significantly higher condition rankings in forest environments than conspecifics in urban environments ($n = 60$, $\alpha = 0.05$, Figure 9). No significant differences were detected in remaining genera among environment ($p > 0.05$).

Frequency of Pruning Cuts

Environment type ($p < 0.001$, $df = 1$) had a significant effect on the frequency of pruning cuts. Tree genera ($p = 0.74$, $df = 4$) and interaction ($p = 0.58$, $df = 4$) had no significance on the frequency of trees with pruning cuts. In urban environments, the frequency of pruning cuts was significantly greater in all five tree genera: *Acer* spp. (p <

0.001), *Celtis* spp. ($p < 0.001$), *Fraxinus* spp. ($p < 0.001$), *Quercus* spp. ($p < 0.001$), and *Ulmus* spp. ($p < 0.001$, $df = 1$; Table 5) than conspecifics in forest environments.

<u>Frequency of Girdling Roots</u>

Both environment type ($p < 0.001$, $df = 1$) and tree genera ($p < 0.001$, $df = 4$) have a significant effect on girdling root frequency, although there was no interaction among these factors ($p = 0.86$, $df = 4$). In urban environments, the frequency of girdling roots was significantly higher in *Acer* ($p < 0.001$), *Celtis* ($p = 0.04$), *and Ulmus*, ($p = 0.017$, $df = 1$; Table 5) than conspecifics in forest environments. No significant environmental effects were found for *Fraxinus* or *Quercus* ($p > 0.05$; Table 5).

<u>Frequency of Root Wounds</u>

Environment type ($p < 0.001$, $df = 1$) had a significant effect on the frequency of root wounds. Tree genera ($p = 0.08$, $df = 4$) and interaction ($p = 0.75$, $df = 4$) had no significance on the frequency of trees with root wounds. In urban environments, the frequency of root wounds was significantly higher in *Acer* ($p < 0.001$), *Celtis* ($p = 0.002$), *and Ulmus* ($p = 0.043$, $df = 1$; Table 5) compared to conspecifics in forest environments. No significant environmental effects were found for *Fraxinus* or *Quercus* (p > 0.05; Table 5).

<u>Frequency of Fungal Conks</u>

Neither environment type ($p = 0.53$, $df = 1$) nor tree genera ($p = 0.45$, $df = 4$) had a significant effect on the presence of trees with fungal conks, although there was interaction among these factors ($p < 0.001$, $df = 4$). In urban environments, the frequency of fungal conks was significantly higher in *Celtis* spp. than conspecifics in forest environments ($p < 0.001$, $df = 1$; Table 5). In forest environments, the frequency of fungal conks was significantly higher in *Ulmus* spp. than conspecifics in urban environments ($p < 0.001$, $df = 1$; Table 5). No significant environmental effects were detected among *Acer*, *Fraxinus*, or *Quercus* ($p > 0.05$; Table 5).

V. Discussion

In our study, we surveyed over 17,000 wounds found on 600 trees throughout middle Tennessee to determine if trees in urban environments exhibited higher frequencies of wounding in metrics such as large open wounds, small wounds < 2 cm^2, wound area, and multiple categorical presence / absence wounds when compared to trees found in forest environments. We used this study as a diagnostic tool to define the frequency of wounding among five tree genera and determine if these wounds lead to lower overall tree condition rankings. All five genera of trees surveyed in urban environments exhibited higher frequencies of open wounds, small wounds < 2 cm^2, pruning cuts, fungal conks, open root wounds, and girdling roots when compared to trees in forest environments.

<u>Number of Open Wounds</u>

All five tree genera in our study exhibited more open wounds in urban environments than conspecifics in forest environments (Figure 4). The higher frequency of wounding in urban trees suggests that exposure to adverse growing conditions including toxic air pollutants, compacted soils, road and sidewalk installation, and improper landscaping practices (Gregg *et al.* 2003; Rhoades and Stipes 1999) increases the rate of wounding in urban trees. In a separate study of 200 trees from eight species on the Virginia Tech campus, nearly 49% exhibited some form of physical or disease injury (Rhoades and Stipes 1999). In our study, environment type played a significant role in the number of open wounds found in urban environments as a result of anthropogenic wounds. Given that these wounds can ultimately lead to decay and tree failure, this is in line with previous research that urban trees have significantly shorter life spans than forest trees. This research included nationwide survey data from more than 300 U.S. cities and found urban trees averaged a life span of 32 years, while rural trees averaged 150 years (Iakovoglou *et al.* 2001).

A higher frequency of open wounds in urban environments led to lower overall tree condition ranking in four of the five genera, with *Quercus* spp. being the exception (Figures 4 and 9). Although Oak trees in urban environments exhibited a higher frequency of wounding, the sum of their wound area (% of trunk wounded) was found to be less than conspecifics in forest environments. Bark thickness increases with trunk diameter (Schafer *et al.* 2015). Since urban Oak trees had significantly larger trunk circumference (177.00 +/- 11.65 cm) than their forest counterparts (135.30 +/- 9.780 cm), the gradual development of a thicker, more furrowed bark, may explain their reduced wound area.

Wound Area

Wound area was determined by the total area of open wounds in the lower 3 m section of trunk. Only *Ulmus* spp. displayed significant differences in wound area among environment. This could be a result of the vast circumference differences between urban and forest elm trees (Figure 8). Forest trees (65.75 +/- 3.97 cm) were nearly one third the circumference of their urban counterparts (185.90 +/- 10.45 cm). Many of the *Ulmus* trees surveyed in forest environments were young (< 15 years old) and had small trunk circumferences, absent of open wounds (DLR, personal observation). Many small wounds < 2 cm^2 were already fully compartmentalized from the natural shedding process of lateral branches that is typical of young forest trees. In contrast, *Ulmus* trees in urban environments were quite large making them more prone to anthropogenic wounding.

The size and shape of tree wounds affect closure rates (Neely 1979). Wound area is an important metric to study, as exposed internal wood relates to future decay and provides a better understanding wound closure rates. In a study of trees from a logging site ten years post-harvest, wounds were inspected at five and ten year intervals to determine closure rates. Of 45 wounds less than 322 cm^2, 58% had fully compartmentalized (closed) after a five year period, while 96% had closed after a ten year period. In contrast, of 27 wounds greater than 974 cm^2, 0% had fully closed after a five year period, and only 7% had closed after a ten year period (Smith *et al.* 1994). This highlights the importance of wound size, on a tree's ability to effectively close wounds. While our study was different in that we summed wound area to create a total % of trunk wounded, the Smith *et al.* study helps us to recognize that small wounds close faster than large wounds. Since large wounds remain open longer, the chance of decay becomes greater.

Number of Wounds less than 2cm^2

Doccola *et al.* noted that there is a positive correlation between small wound closure and tree health in *Fraxinus* spp. (2011). While small wounds can become sites of infection leading to decay and possible structural damage, a study of 63 anthropogenically-created small holes left from systemic insecticide and fungicide trunk injections, revealed that healthy trees (76.2%) were able to rapidly close these wounds with new growth. While Doccola *et al.* measured tree health by annual radial growth rates over a four year period, our study instead used an overall tree condition ranking system due to time constraints (Table 1).

We saw higher frequencies of wounds < 2 cm^2 among all five tree genera in urban environments, with *Acer* spp. exhibiting the highest number of wounds < 2 cm^2 (Figure 6). The majority of wounds < 2 cm^2 identified in this study were the result of boring insects (where boring dust was identified) or woodpecker damage (defined by uniform circular wounds in horizontal and vertical rows). Smiley *et al.* noted that the main cause of woodpecker damage in *A. saccharum* was a result of the yellow-bellied sapsucker (2007). This might imply a link for the significant differences we saw in *Acer* spp. in comparison to other tree genera in our study. While a common belief is that woodpeckers are seeking out wood boring insects, there is not always a correlation between insect infestations and the presence of woodpecker injuries (Zobrist 2014). Insects are a significant part of a woodpecker's diet; though they often feed on the sap-filled phloem and xylem layers, especially during the summer breeding season (Smiley *et al.* 2007). We suspect many of the wounds < 2 cm^2 to be the result of woodpecker or insect damage, especially as seen in *Acer* spp.

On the opposite end of this spectrum, *Fraxinus* spp. displayed the fewest number of wounds < 2 cm^2. This is likely as a result of the thick bark that forms on *Fraxinus* trunks, or a possible connection that decreased sap flow (due to low tree condition ranking) discouraged sapsuckers altogether. Yet, not all wounds < 2 cm^2 come from insects and sapsuckers. Small wounds are also a result of anthropogenic activities found in the form of nail holes, staples, and from systemic trunk injections. In healthy trees, small wounds < 2 cm^2 can close within one growing season as wound closure rates are correlated to tree vigor, and radial trunk growth. The smaller the wound, the less time required to heal, depending on the vigor of the tree (Doccola *et al.* 2011; Neely 1979). Wounds < 2 cm^2 were rarely a result of anthropogenic activities in forest environments, but rather, the majority of these wounds were created by woodpecker damage as indicated by the persistent and symmetrical-sized holes in horizontal patterns associated with woodpeckers.

Number of Closed Wounds

Wounds vary in their rate of closure among tree species (Neely 1991). Within our chosen genera, Neely found *Acer* spp., *Quercus* spp., and *Ulmus* spp. to have the highest closure rates, followed closely by *Celtis* spp. (1991). He noted that determining closure rates among genera was challenging due to inter-and intraspecific differences in growth rates. We also observed non-uniform closure rates in our study, leading to a wide variance of closure rates by genera and environment (Figure 7).

Wound closure rates were significantly affected by *environment*, *genera*, and *environment x genera*. In the *Acer, Celtis, and Ulmus* genera, our data supported that wound closure is more effective in healthier trees, as maple, hackberry, and elm trees in forest environments ranked higher than their urban counterparts. *Quercus* spp. in urban environments, had a higher tree condition ranking, and thus were more efficient at compartmentalizing wounds than their forest counterparts. As Neely noted in his research, *Quercus* spp. trees had the greatest closure rates with both 25 mm and 50 mm wounds (Neely 1991). Our data supports this as we saw the greatest number of closed wounds in the urban environment on *Quercus* spp. One possibility that requires further research is that *Quercus*, spp. may likely be tolerant to wounds created by anthropogenic activities.

Four of the five tree genera in our study displayed a positive correlation between tree health and wound closure rates (Doccola *et al.* 2011) with the exception of *Fraxinus* spp. which had a lower overall tree condition ranking in the urban environment, yet still closed more wounds than forest counterparts. Since the number of open wounds was higher in all urban tree genera, it is likely that the decrease in closed wounds was a result of more recent wounding from anthropogenic activities. The time needed to close these open wounds in the urban environment was likely delayed by the recent removal of numerous branches, thus slowing photosynthesis. Given that urban environments experience a heat island effect with increased temperatures, the additional exposure to ozone and sulfur dioxide further predisposes urban trees to reduced photosynthetic rates (Gregg *et al.* 2003; Felzer *et al.* 2007). The sudden and abundant loss of foliage due to pruning, along with the negative effects of soil compaction, toxic air pollutants, and construction practices, reduce the ability of urban trees to close wounds.

In forest environments, *Acer* spp. had the largest number of closed wounds. This is not surprising given that small wounds tend to close more quickly (Luley *et al.* 2009; Neely 1991) and the majority of closed wounds identified in *Acer* spp. were those < 2 cm^2.

Frequency of Fungal Conks

Environment and *genera* were not significant factors in the presence of fungal conks. Fungal conks were found growing on all five tree genera, with significant differences detected only in *Celtis* spp. and *Ulmus* spp. All fungal conks identified in the *Celtis* genera were found growing on trees in urban environments, whereas all fungal conks identified for *Ulmus* spp. were growing on trees in forest environments. Fungal conks often follow wounding further promoting decay, as wood decaying microorganisms swarm the site of the wound (Deflorio *et al.* 2008; Shigo 1985). Our study did not identify the types of fungi present on trees or root systems, which is important to note because not all fungi are hazardous to trees (Deflorio *et al.* 2008). Some fungi are weakly invasive leading to smaller quantities of decay which do not necessarily increase the chance of mechanical tree failures.

Ulmus spp. in forest environments ranked the highest among all genera in overall tree condition rankings yet, interestingly, fungal conks were abundant. This may be attributed to varying moisture differences among urban and forest environments. *Ulmus* trees surveyed in urban environments were free-standing trees where air circulation patterns would have allowed tree trunks and root systems to dry completely after rains; whereas those in forest environments were surrounded by many other trees, decreasing airflow and retaining moisture on the stems and root systems. Fungi such as *Armillaria* spp. can be found during periods of high moisture. Producing honey colored mushrooms at the base of the tree, this fungus infects the root systems of live trees and spreads via underground hyphae (Pijut 2006).

Frequency of Girdling Roots

Acer spp. exhibited the largest frequency of girdling roots (Table 5). Nearly one third of *Acer* trees surveyed in the urban environment had visible girdling roots, while one quarter of those surveyed in forest environments displayed them. Many nursery stocks for the *Acer* genera are either container-grown, balled-and-burlapped, or bare root transplants. Container-grown and balled-and-burlapped trees are often the preferred type of tree transplants when planting in an urban setting since much larger trees can be planted (Jack-Scott 2012). Unfortunately, once purchased from a nursery, little care is given to tease roots apart or ensure proper planting depths are achieved prior to setting these established root systems into a planting hole (Harris 2010). This, in turn, sets trees up for failure as roots continue to grow, encircling themselves throughout the loose, newly modified soil rather than voyaging into the native soils just beyond the planting hole.

Girdled roots reduce tree health and add stress by limiting nutrients through compression of the vascular cambium. This severely limits (or even cuts off) the water and nutrient flow to the tree. In trees, this stress may not be visible for years after the planting has been completed, making diagnosis challenging and treatment nearly impossible.

Frequency of Pruning Cuts

Intuitively, it makes sense that pruning cuts would be found at a higher frequency in urban environments as pruning is an essential horticultural practice (Neely 1991). Trees in urban environments are pruned to elevate lower canopies to increase line of sight views; provide clearance around signs, roadways, and walkways; and to remove broken, dead, or storm damaged limbs. Our study found that all five tree genera in urban environments received significantly more pruning cuts than trees in forest environments

(Table 5) although pruning cuts were also found in all five tree genera in forest environments.

Forest trees located alongside trails and trailheads were receiving pruning cuts in order to allow clearance for hikers or signs (DLR, personal observation). Since the four forest collection sites fell under the FAO's definition of a naturally regenerated forest (where noticeable human activities were present), the presence of pruning cuts is not unexpected (FAO 2015). However, the total number of trees with open pruning cuts among all five tree genera in forest environments (n = 19) was minimal in comparison to their presence in urban environments (n = 263). This is likely due to the fact that many of these trees had been pruned years prior to make way for the trail. In other words, the cuts from years prior may have been hidden by increased tree girth, or could have been tallied instead as a closed wound metric.

Even the best intentions from a well-executed pruning cut invites insects, microorganisms, bacteria, and fungi to the site of the newly exposed wound (Neely 1991; Shigo 1982). If a proper cut is made at the branch protection zone (*i.e.*, branch collar), the branch collar seals itself with structurally distinct xylem cells now housing decay-resistant compounds (Gilman and Grabosky 2006; Shigo 1985). This implies that trees that are healthy and vigorously growing should be able to effectively close these wounds. The correlation of environment, tree health, and annual stem growth on wound closure rates has already been identified (Doccola *et al.* 2011; Neely 1989). Since trees in forest environments are consistently ranking higher in overall tree condition, it appears that the development of this resistant callus tissue in forest trees is better able to close the sites of these pruning cuts.

In a forest environment, a tree growing close to a trail may have only three or four branches removed from the trail side of the tree to provide adequate clearance. This is in stark contrast to an urban tree, where symmetry is often desired over tree health. In urban environments, excessive pruning cuts often appeared on the trunk sections of trees to provide adequate clearance. Removal of entire radial sections of limbs was often seen, and in many cases, multiple radial sections were removed to varying heights to achieve adequate clearance. When pruning trees, it is essential to understand that each cut removes foliage, thereby taking away from the tree's photosynthetic capacity.

Root Wounds

Root systems anchor and support the mass of a tree, absorb water and nutrient solutions, and provide gaseous exchange. They are vital to the success of not only new plantings, but also mature, old-growth forest stands (Day and Bassuk 1994). Roots can also be damaged in many ways. They can be cut by digging machinery, contaminated by pollutants, desiccated by road salts, crushed by soil compaction, and become girdled by improper planting practices. Since all five tree genera exhibited more root wounds in urban environments, *environment* had a significant effect on the presence of root wounds (Table 5). In urban trees, root systems often lack the protective layer of organic leaf litter found in forest environments. Without this layer of protection, urban soils are exposed to higher soil temperatures, soil compaction, and experience wind and water erosion. Compaction of soils is particularly harmful in that it alters the structure by compressing soil aggregates, and thus decreasing porosity (Kozlowski 1999). The reduction of porosity leads to decreased water infiltration rates at the base of the tree, increasing water runoff and erosion. Tree roots then become exposed, allowing for a greater injury potential. Root wounds act similarly to trunk wounds as the vascular cambium is found throughout all parts of the tree, including the roots. Once a wound breaks through the root surface, microorganisms and fungi are able to infect the site of the wound, and thus spread, leading to increased decay rates (Shigo 1982, 1984; Pijut 2006).

Conclusion

Considering the variety of wounds identified in this study, it becomes clear that not all trees are wounded the same way. Wounds come in many different sizes and shapes and trees vary in their tolerance, susceptibility, and survivability in different environments. Urban forests are complex ecosystems that increase biodiversity and promote sociological well-being. With the rapid growth of the population, urban forests are becoming more distinctive attributes in our cities. Greater awareness and resources need to be identified for the proper planning and management of these trees. Just as the types of wounds can differ, so must our management approaches.

For all five genera, a greater frequency of wounding was found in urban environments for six of the eight surveyed metrics. The tree ranking system designed for this study (Table 1) was a good estimation in determining overall tree condition, as condition rankings were found to be lower in urban environments for four of the five genera (Figure 9). Since we saw a greater number of wound occurrences in urban environments in many metrics, it stands to reason that these trees would also rank lower in overall condition. These data support our overall hypothesis that a greater wounding frequency (in number and size of wounds) in urban trees would lead to lower overall tree condition rankings.

While many factors contribute to tree health, this study can be used to compare and contrast trees found in urban and forest environments. By implementing the beneficial factors seen in forest environments (thick organic layers covering root zones, the absence of monoculture practices, limited pruning, and non-compacted soils) into urban environments, we can approach urban arboriculture with a new mindset, thus sustaining our urban forests for years to come.

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VII. Definition of Terms

Angiosperm – A tree that produces flowers, fruit, and has seeds (containing endosperm) enclosed in an ovary. Most angiosperm trees are deciduous.

Autotroph – A primary producer capable of creating its own sugars using light reactions (photosynthesis) or inorganic chemical reactions.

Chlorosis – A symptom from the insufficient production of chlorophyll leading to visible changes in the leaf surface; leaves often appears as a yellow.

Circumference – Circumference around tree (measured at 1.37 m from the highest point on the soil surface).

Compartmentalization – A trees active, boundary-setting process that resists the spread of decay from invading microorganisms.

Decay –The process in which microorganisms break down wood—initiated by any wound created in the bark which exposes internal wood.

Deciduous – A plant that sheds its foliage at the end of each growing season.

Evergreen – A plant that retains its foliage throughout each new growing season.

Fungal Conk – Perennial or persistent annual fruiting bodies that grow on tree trunks, branches, or roots.

Girdling Roots – Roots which encircle the lower trunk section of a tree chocking off other nearby roots. A result of improper planting practices from plant stocks which are container grown.

Gymnosperm – A tree that lacks flowers, fruit, and has unenclosed (naked) seeds contained in cones. Most gymnosperms are evergreen, retaining their photosynthetic parts annually.

Heartwood – Wood that forms late in the season. Dead wood cells contained within the inner-most (and oldest) formed column of a perennial, long-lived plant.

Necrosis – The premature death of living cells in plant tissues.

Samaras – A simple dry fruit produced by *Acer* spp. which exhibits paper-like flattened wings allowing them to be carried by wind currents far from the base of a tree.

Senescence – A gradual deterioration of the functional characteristics of a tree; ageing.

Softwood – Wood that forms early in the season. Living wood cells contained in the outer-most (and youngest) formed column of wood in a perennial, long-lived plant.

Urban forest – refers to trees found growing in urban and metropolitan sites.

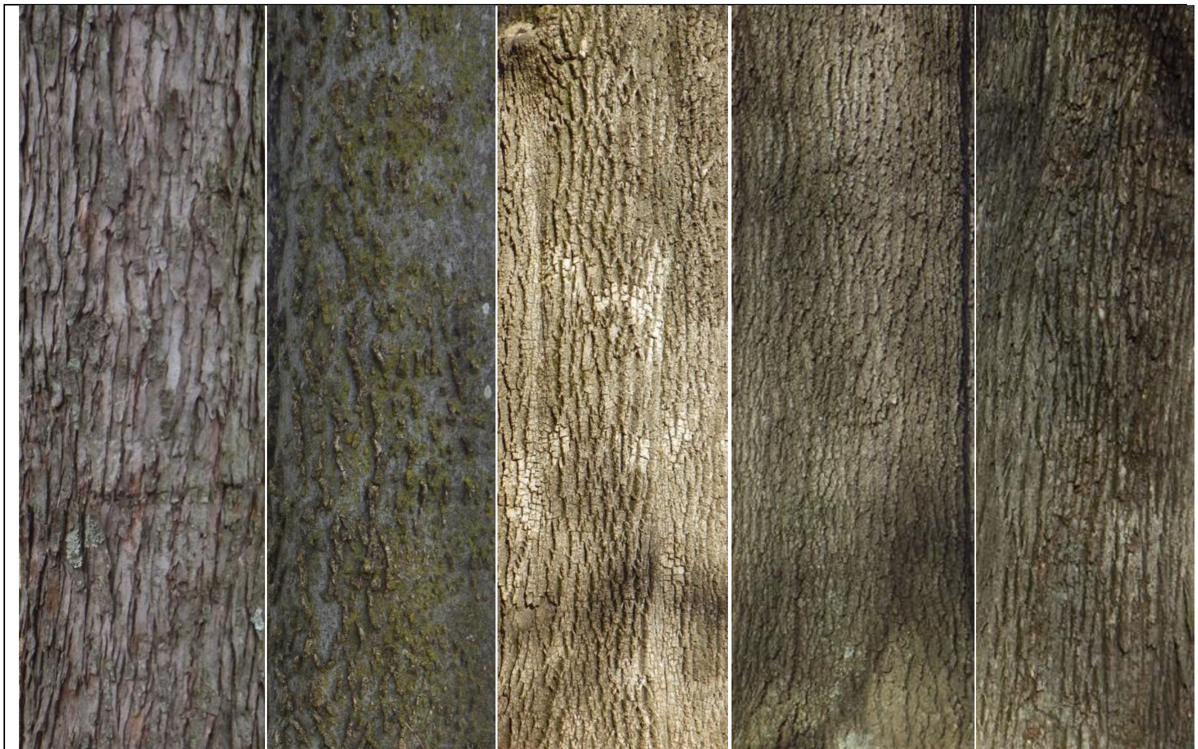
Vascular Cambium – A thin cylindrical layer of actively, cell-dividing layer in a tree's trunk, roots, and branches just beneath the barks surface that gives rise to xylem cells (to the inside of the tree), and phloem cells (to the outside of the tree).

Woodland forest – refers to the FAO's definition of a naturally regenerated forest—one with noticeable human activities.

Wound – Any break in the bark's surface that exposes internal wood.

VIII. Appendices

Figure 1: Example open wound for an elm (*Ulmus* spp.) Open wounds were identified and measurements were taken at the wound's widest and highest points to give an approximate wound area as a rectangle. Measurements taken did not include any compartmentalized wood, and only accounted for the open portion of the wound exposing internal wood.



Maple	**Hackberry**	**Ash**	**Oak**	**Elm**
(*Acer* spp.)	(*Celtis* spp.)	(*Fraxinus* spp.)	(*Quercus* spp.)	(*Ulmus* spp.)

Figure 2: Bark of five tree genera used for visual identification in this study: *Acer* spp., *Celtis* spp., *Fraxinus* spp., *Quercus* spp., and *Ulmus* spp.

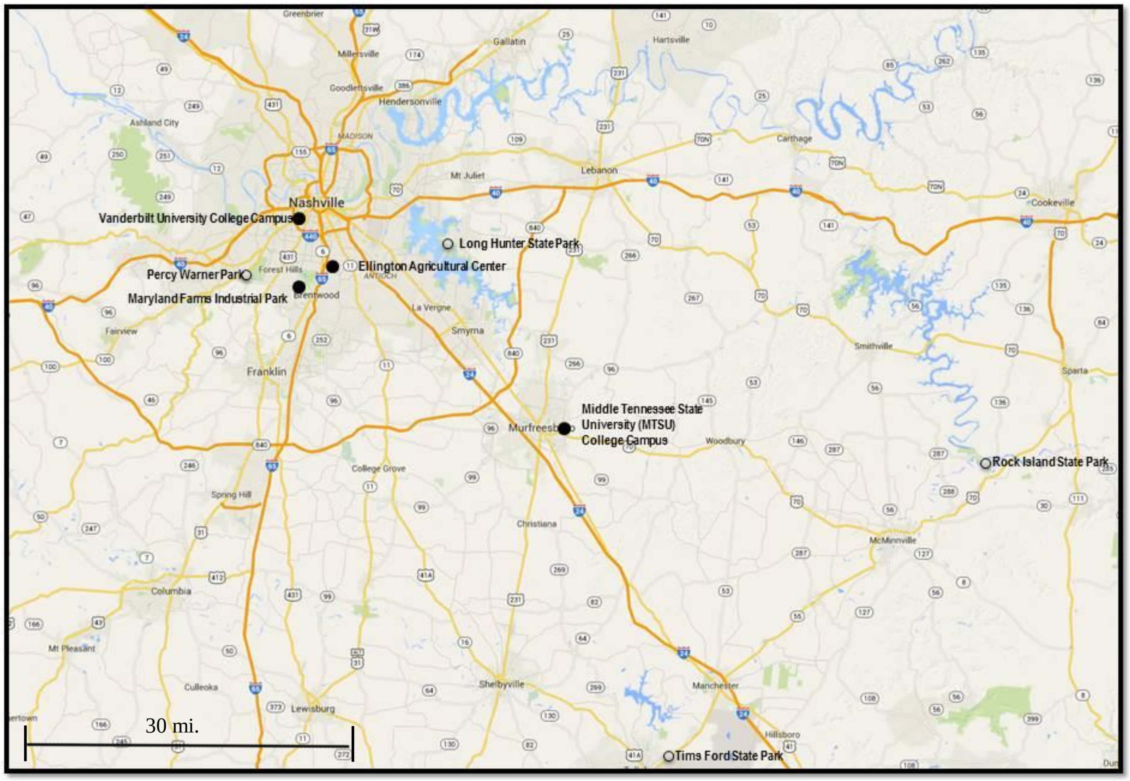


Figure 3: Map showing location of survey sites throughout middle Tennessee (n = 8). Black dots denote urban sites and grey dots denote forest sites.

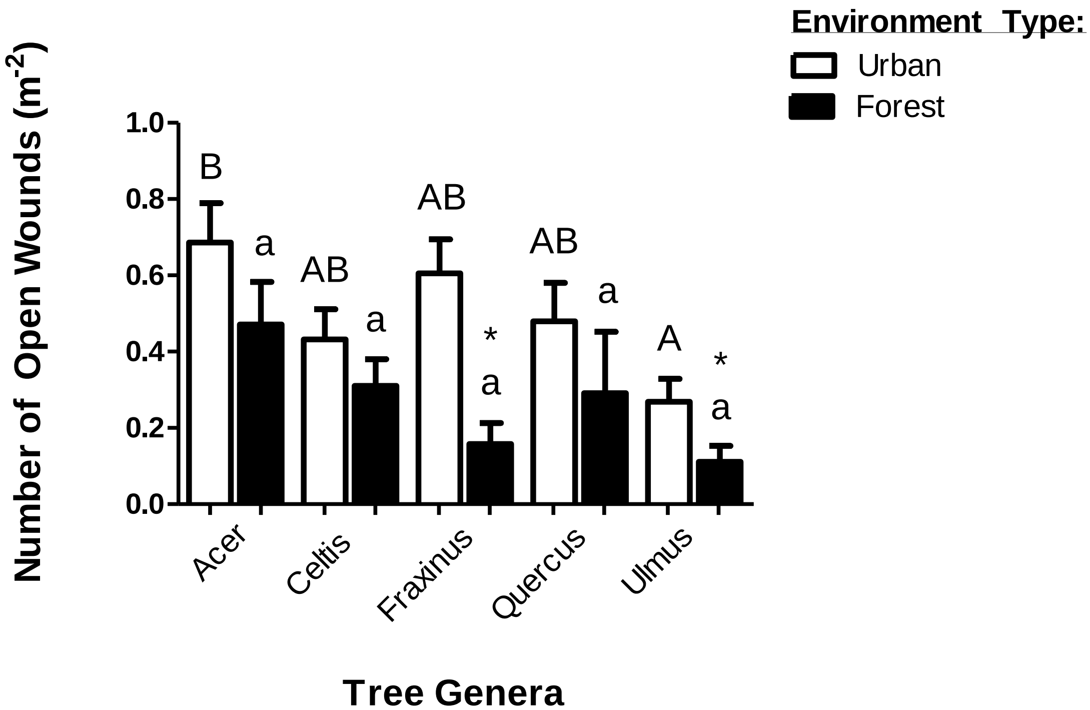


Figure 4: Number of open wounds (m^{-2}) for five genera of trees found in urban and forest environments (n = 60 trees $genera^{-1}$ $environment^{-1}$). Differences in number of open wounds among genera within an environment determined by 1-way ANOVA w/ Tukey post test, and denoted by distinct capital letters (for urban) or lower-case letters (for forest). Significant differences in number of open wounds between environments within a species are denoted by an asterisk (*, 2-tailed t-test, $\alpha = 0.05$).

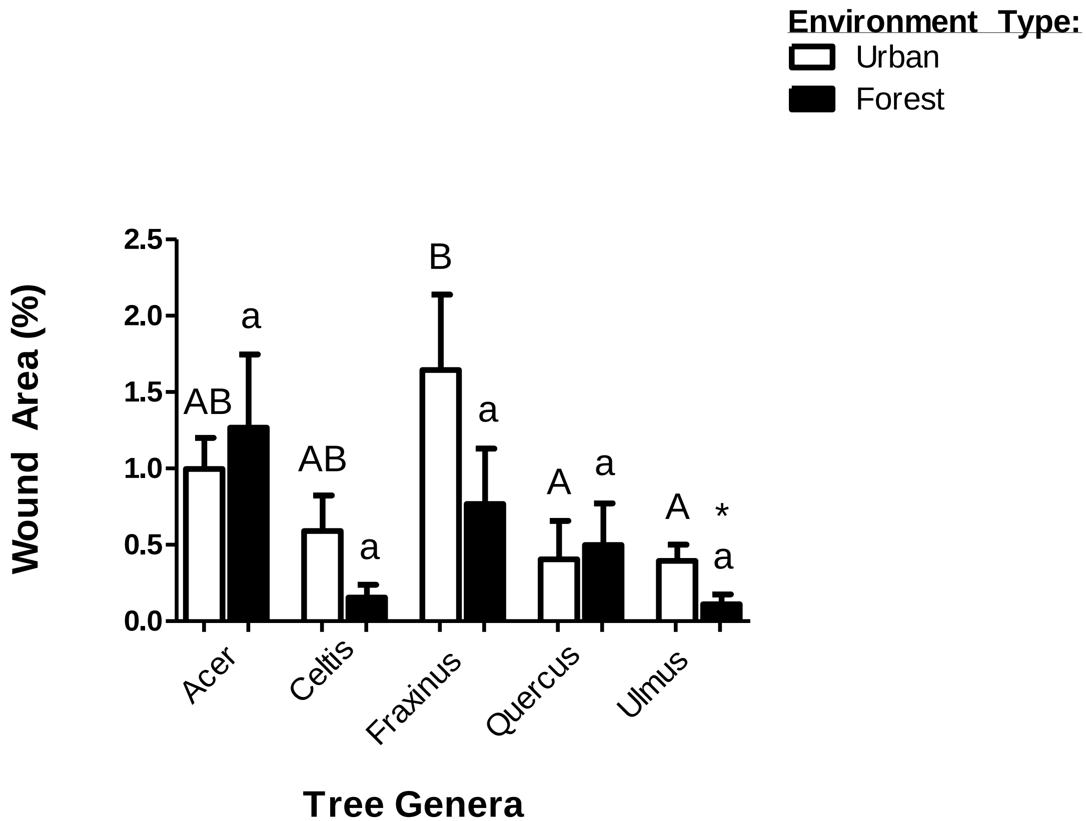


Figure 5: Wound area (% trunk) for five genera of trees found in urban and forest environments (n = 60 trees genera^{-1} environment^{-1}). Statistical significance determined as in figure 4.

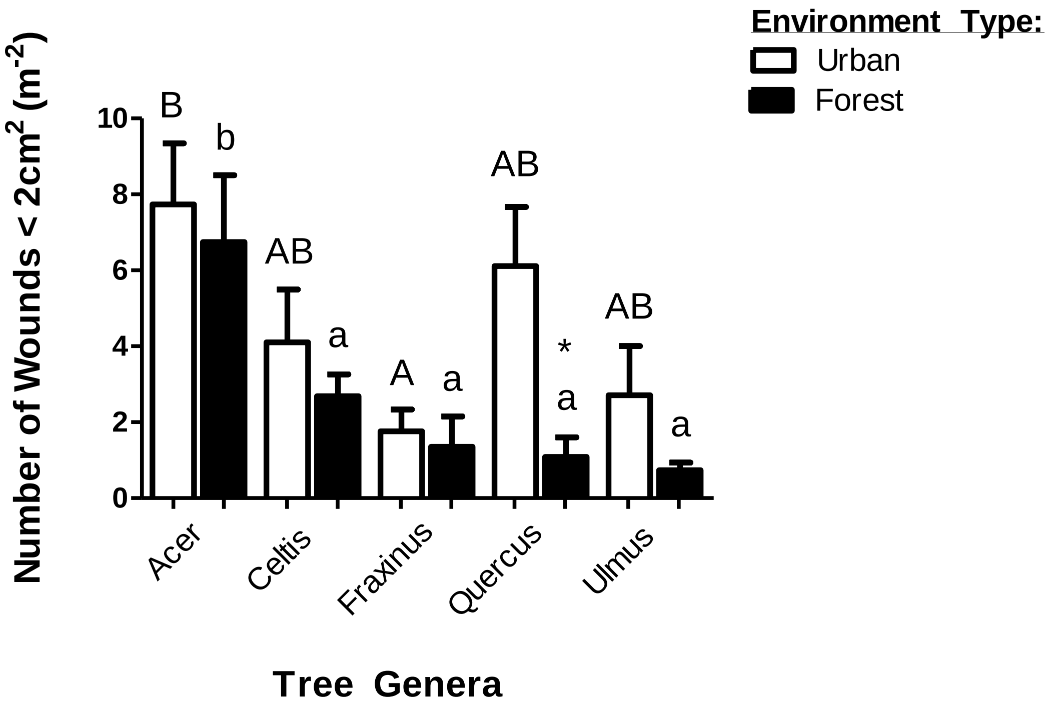


Figure 6: Number of wounds less than 2cm^2 (m^{-2}) for five genera of trees found in urban and forest environments (n = 60 trees genera^{-1} environment^{-1}). Statistical significance determined as in figure 4.

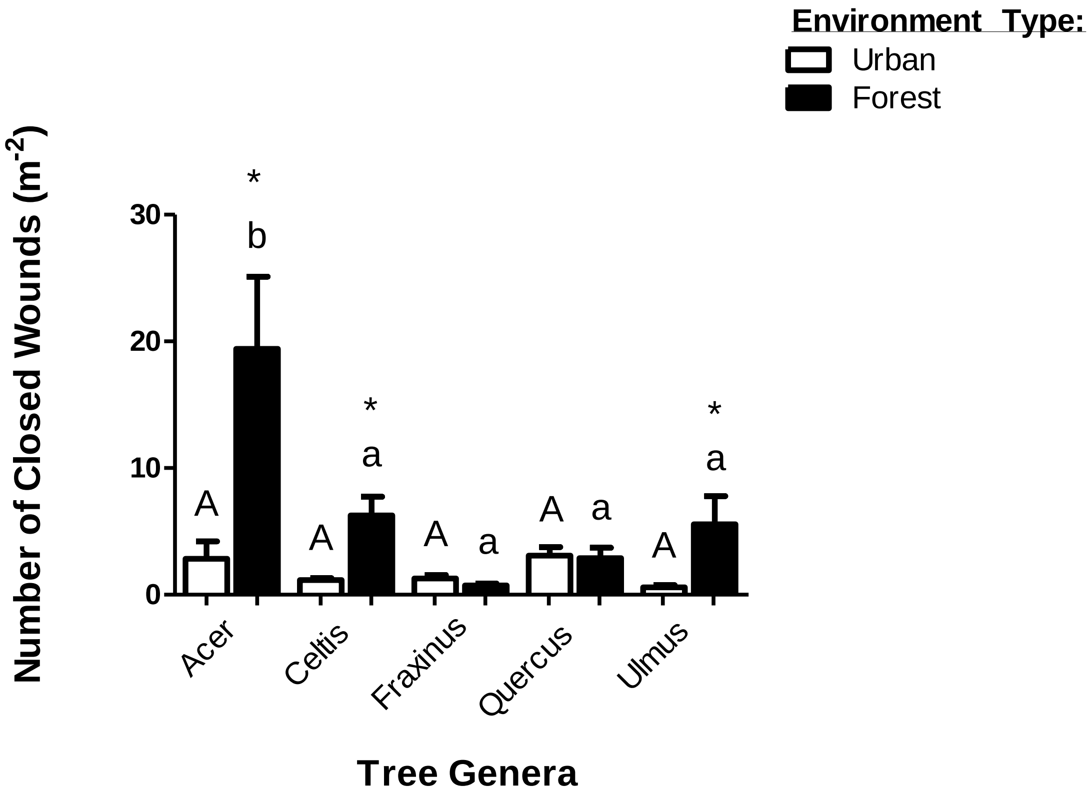


Figure 7: Number of closed wounds (m^{-2}) for five genera of trees found in urban and forest environments (n = 60 trees $genera^{-1}$ $environment^{-1}$). Statistical significance determined as in figure 4.

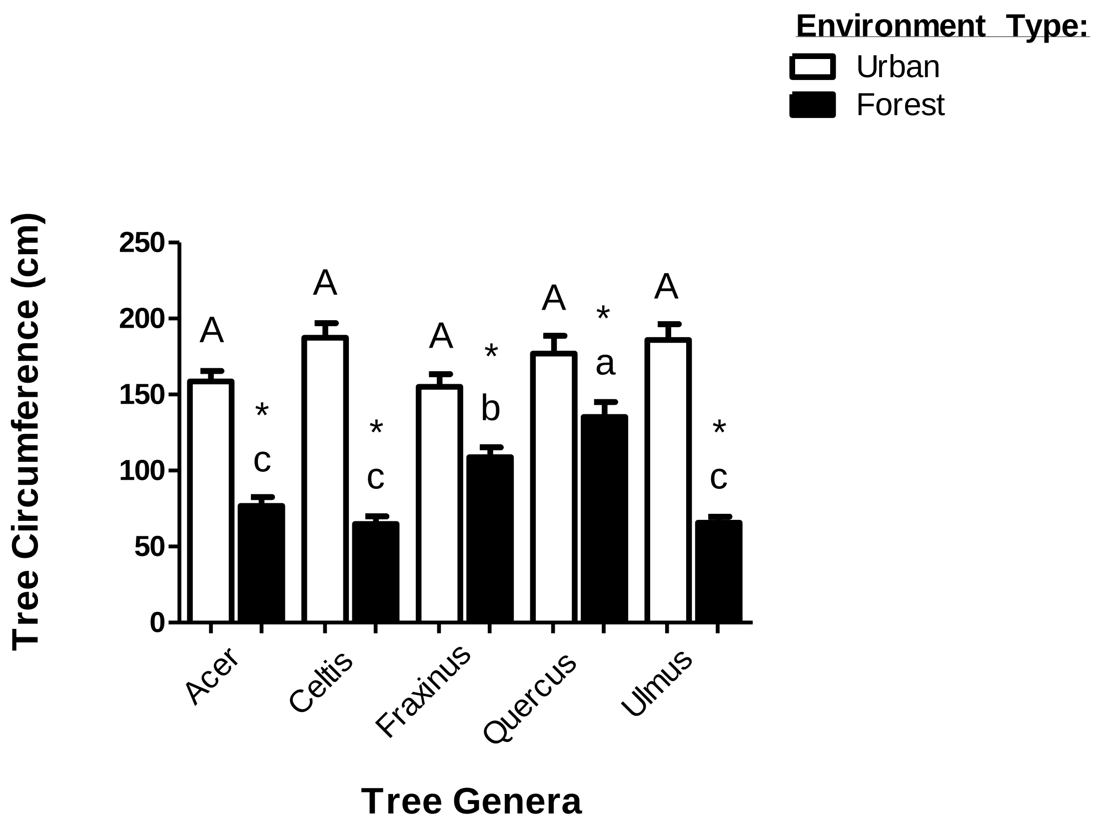


Figure 8: Average tree circumference (cm) for five genera of trees found in urban and forest environments (n = 60 trees $genera^{-1}$ $environment^{-1}$). Statistical significance determined as in figure 4.

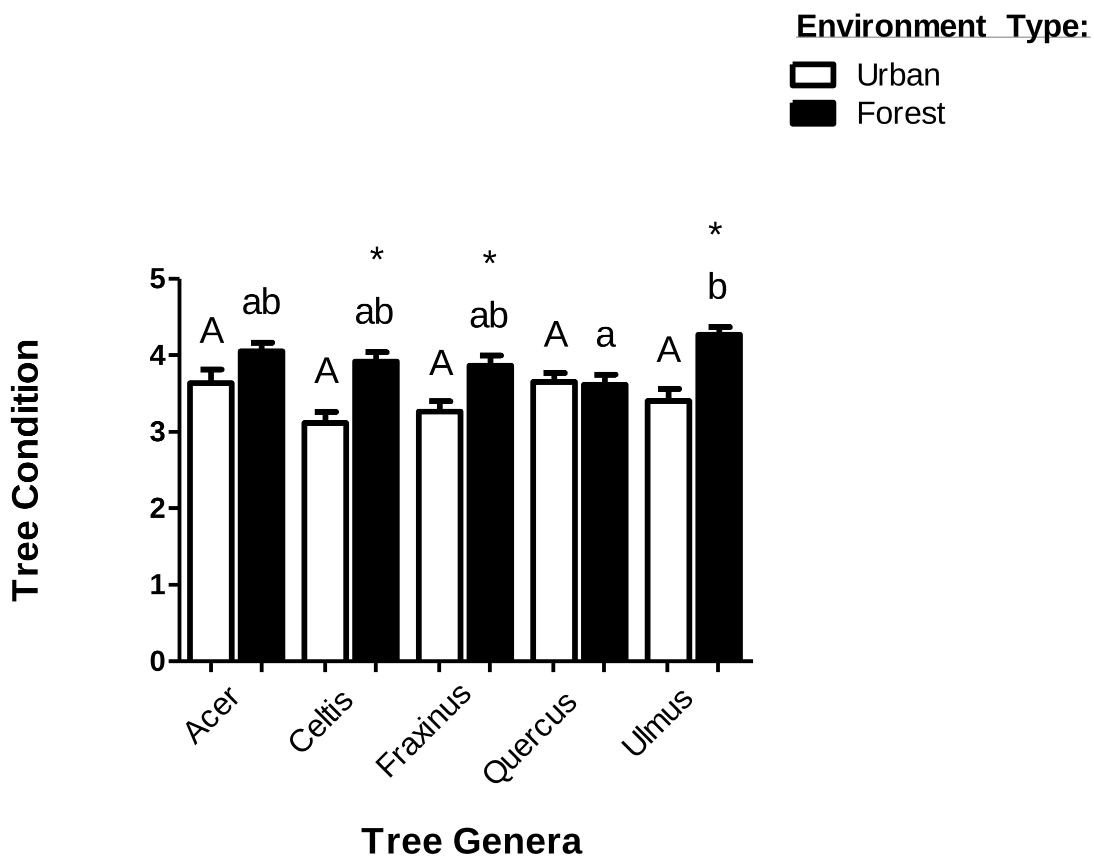


Figure 9: Average tree condition (ranked 1-5; Table 1) for five genera of trees found in urban and forest environments (n = 60 trees genera^{-1} environment^{-1}). Statistical significance determined as in figure 4.

Table 1: Tree condition ranking system originated by the author, from a fourteen-year working knowledge of trees found in both urban and forest environments. The following parameters were used on all trees (*n* = 600) to classify the overall health of a tree's upper canopy.

Rating	Condition	Description
1	**Very Poor:**	The tree displays extensive dieback throughout the upper canopy and many large branch failures have occurred. Multiple exposed wounds in excess of 12.7cm (5") in diameter exist throughout the upper canopy.
2	**Poor:**	The tree displays notable dieback throughout the upper canopy though large branch failures have yet to occur. Dead branches greater than 12.7cm (5") in diameter exist throughout the upper canopy.
3	**Fair:**	The tree displays no notable dieback. Internal, small dead branches less than 7.6cm (3") exist throughout the upper canopy, though these exist as a result of over-shading as opposed to the consequences of observable trunk wounding.
4	**Good:**	The tree displays no notable dieback. Internal dead twigs are abundant throughout the upper canopy yet, are less than 7.6cm (3") in diameter. These dead twigs occur as a natural shedding process as outer canopy increases the over-shading of these small, internal dead branches.
5	**Very Good:**	The tree displays no notable dieback. Internal dead branches are non-existent. Tree is vigorous and no dead branches or wounds are found throughout the upper canopy.

Table 2: Demographic, wounding, categorical, and tree condition ranking measurements completed for all trees surveyed (*n* = 600).

Demographic Measurements	**Measurement Description**
Tree Identification Number	Each tree was assigned a unique tree identification number as follows: *Acer* spp. (**1**), Celtis spp. (**2**), *Fraxinus* spp. (**3**), *Quercus* spp. (**4**), and *Ulmus* spp. (**5**). At each site fifteen trees of each genera were surveyed and assigned an alphabetized letter (**A-O)** corresponding to its genus number. (*i.e.*, **3F** = *Fraxinus* spp., #6).
GPS Coordinates	Physical tree locations were recorded. Each tree trunk was photographed with an *Pentax Optio WG-II Digital Camera*. All photos were tagged with a searchable GPS coordinate listed in degrees, minutes, and seconds (Table 3a and 3b).
Tree Circumference (cm)	Tree circumference was measured from the highest point on the soil line, at a height of 1.37 meters to the nearest millimeter.
Wounding Measurements	**Measurement Description**
Number of Open Wounds *(m^{-2})*	Wounds that break through the bark's surface and expose internal wood were assigned an open-wound number, and tallied.
Number of Wounds Less than 2cm^2 *(m^{-2})*	Small wounds, less than 2cm^2 were tallied with a handheld clicker. This number was limited to 300 wounds to decrease variance among trees found with an excessive number of small wounds compared to non-wounded trees.
Number of Closed Wounds *(m^{-2})*	Fully compartmentalized (closed) wounds were tallied. They were identified by the zone of swelling created on the bark's surface.
Wound Area *(% of trunk wounded)*	Open wounds were measured with a 300 cm retractable tape measure (to the nearest millimeter). Measurements were taken at the wound's widest and highest points to determine the wound as a rectangle (cm^2). Measurements only accounted for the open portion of the wound exposing internal wood. Wound area is given as a percentage of the trunk exhibiting open wounds.
Categorical Measurements Presence or Absence (per tree)	**Measurement Description**
Root Wounds	Exposed, above-ground root wounds visible were identified and counted. No soil or leaf litter was moved to identify girdling roots.
Fungal Conks	Fungal conks visible on the trunk section or root systems were idenfitifed.
Pruning Cut Wounds	Pruning cuts were identified. Pruning cut measuremnets only included cuts made on the trunk and did not include cuts made on scaffold branches.
Girdling Roots	Girdling roots that encircle each other, or the trunk section of the tree were identified when observed. No soil or leaf litter was moved to identify girdling roots.
Tree Ranking Measurement	**Measurement Description**
Overall Tree Condition Ranking	Overall tree condition rankings werebased on a visual identification of the tree's upper canopy health. Ranked from 1 (very poor condition) – 5 (very good condition; Table 1).

Table 3a: *Urban site*—GPS coordinates for trees surveyed at MTSU College Campus (*n* = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 35°50'49"	W 086°21'38"	2A	N 35°50’54”	W 086°22’11”	3A	N 35°50'59"	W 086°22’10”	4A	N 35°50'47"	W 086°21'38"	5A	N 35°51’01”	W 086°21’41”
1B	N 35°50'44"	W 086°21'53"	2B	N 35°50’54”	W 086°22’11”	3B	N 35°51’01”	W 086°21’41”	4B	N 35°50'50"	W 086°21'47"	5B	N 35°50’59”	W 086°22’03”
1C	N 35°50'45"	W 086°21'54"	2C	N 35°50’43”	W 086°22’00”	3C	N 35°50’52”	W 086°22’05”	4C	N 35°50'50"	W 086°21'47"	5C	N 35°50’53”	W 086°22’13”
1D	N 35°51’01”	W 086°21’48”	2D	N 35°50’52”	W 086°22’08”	3D	N 35°50’55”	W 086°22’03”	4D	N 35°50'44"	W 086°21'53"	5D	N 35°51’00”	W 086°22’04”
1E	N 35°51’01”	W 086°21’48”	2E	N 35°50’ 52”	W 086° 22’ 08”	3E	N 35°51’02”	W 086°21’50”	4E	N 35°50’57”	W 086°21’50”	5E	N 35°51’10”	W 086°21’34”
1F	N 35°50’54”	W 086°21’53”	2F	N 35°50’45”	W 086°22’10”	3F	N 35°51’01”	W 086°21’35”	4F	N 35°50’57”	W 086°21’50”	5F	N 35°51’11”	W 086°22’03”
1G	N 35°50’49”	W 086°22’08”	2G	N 35°50’43”	W 086°22’10”	3G	N 35°51’09”	W 086°21’35”	4G	N 35°50’56”	W 086°21”55”	5G	N 35°51’12”	W 086°21’37”
1H	N 35°50’49”	W 086°22’08”	2H	N 35°50’43”	W 086°22’10”	3H	N 35°51’09”	W 086°21’35”	4H	N 35°50’56”	W 086°21’54”	5H	N 35°50’43”	W 086°22’14”
1I	N 35°50”52”	W 086°22’05”	2I	N 35°50’43”	W 086°22’10”	3I	N 35°51’11”	W 086°22’03”	4I	N 35°50’54”	W 086°21’53”	5I	N 35°50’43”	W 086°22’14”
1J	N 35°50’55”	W 086°22’03”	2J	N 35°50’46”	W 086°22’07”	3J	N 35°51’11”	W 086°21’37”	4J	N 35°50’46”	W 086°22’06”	5J	N 35°50’45”	W 086°22’14”
1K	N 35°51’01”	W 086°21’35”	2K	N 35°50’46”	W 086°22’07”	3K	N 35°51’11”	W 086°21’37”	4K	N 35°50’52”	W 086°22’05”	5K	N 35°50’46”	W 086°22’17”
1L	N 35°51’10”	W 086°21’34”	2L	N 35°50’45”	W 086°22’06”	3L	N 35°51’11”	W 086°21’37”	4L	N 35°50’39”	W 086°21’34”	5L	N 35°51’03”	W 086°21’40”
1M	N 35°51’11”	W 086°21’43”	2M	N 35°50’45”	W 086°22’06”	3M	N 35°51’12”	W 086°21’37”	4M	N 35°50’56”	W 086°21’31”	5M	N 35°51’03”	W 086°21’40”
1N	N 35°51’11”	W 086°21’43”	2N	N 35°50’44”	W 086°21’43”	3N	N 35°50’43”	W 086°22’14”	4N	N 35°51’00”	W 086°21’57”	5N	N 35°51’10”	W 086°21’32”
1O	N 35°51’00”	W 086°21’57”	2O	N 35°50’44”	W 086°21’43”	3O	N 35°50’45”	W 086°22’14”	4O	N 35°51’00”	W 086°21’57”	5O	N 35°51’ 10”	W 086°21’32”

Table 3b: *Urban site*—GPS coordinates for trees surveyed at Ellington Agricultural Center (*n* = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 36°03'39"	W 086°44'54"	2A	N 36°03'43"	W 086°44'48"	3A	N 36°03'43"	W 086°44'45"	4A	N 36°03'38"	W 086°44'48"	5A	N 36°03'43"	W 086°44'45"
1B	N 36°03'39"	W 086°44'55"	2B	N 36°03'41"	W 086°44'52"	3B	N 36°03'40"	W 086°44'55"	4B	N 36°03'40"	W 086°44'51"	5B	N 36°03'43"	W 086°44'47"
1C	N 36°03'43"	W 086°44'51"	2C	N 36°03'41"	W 086°44'54"	3C	N 36°03'43"	W 086°44'51"	4C	N 36°03'40"	W 086°44'51"	5C	N 36°03'43"	W 086°44'47"
1D	N 36°03'45"	W 086°44'52"	2D	N 36°03'41"	W 086°44'54"	3D	N 36°03'49"	W 086°44'50"	4D	N 36°03'40"	W 086°44'51"	5D	N 36°03'42"	W 086°44'51"
1E	N 36°03'49"	W 086°44'55"	2E	N 36°03'38"	W 086°44'54"	3E	N 36°03'48"	W 086°44'50"	4E	N 36°03'41"	W 086°44'52"	5E	N 36°03'50"	W 086°44'55"
1F	N 36°03'49"	W 086°44'51"	2F	N 36°03'41"	W 086°44'51"	3F	N 36°03'44"	W 086°44'55"	4F	N 36°03'38"	W 086°44'56"	5F	N 36°03'49"	W 086°44'51"
1G	N 36°03'48"	W 086°44'47"	2G	N 36°03'43"	W 086°44'51"	3G	N 36°03'44"	W 086°44'32"	4G	N 36°03'48"	W 086°44'47"	5G	N 36°03'50"	W 086°44'40"
1H	N 36°03'48"	W 086°44'44"	2H	N 36°03'45"	W 086°44'52"	3H	N 36°03'52"	W 086°44'29"	4H	N 36°03'49"	W 086°44'42"	5H	N 36°03'48"	W 086°44'41"
1I	N 36°03'48"	W 086°44'47"	2I	N 36°03'45"	W 086°44'53"	3I	N 36°03'52"	W 086°44'30"	4I	N 36°03'49"	W 086°44'45"	5I	N 36°03'48"	W 086°44'43"
1J	N 36°03'53"	W 086°44'51"	2J	N 36°03'49"	W 086°44'55"	3J	N 36°03'55"	W 086°44'28"	4J	N 36°03'49"	W 086°44'47"	5J	N 36°03'48"	W 086°44'43"
1K	N 36°03'49"	W 086°44'37"	2K	N 36°03'48"	W 086°44'42"	3K	N 36°03'54"	W 086°44'29"	4K	N 36°03'51"	W 086°44'48"	5K	N 36°03'52"	W 086°44'50"
1L	N 36°03'49"	W 086°44'37"	2L	N 36°03'48"	W 086°44'43"	3L	N 36°03'51"	W 086°44'31"	4L	N 36°03'50”	W 086°44'50”	5L	N 36°03'49"	W 086°44'37"
1M	N 36°03'51"	W 086°44'36"	2M	N 36°03'49"	W 086°44'48"	3M	N 36°03'48"	W 086°44'31"	4M	N 36°03'52"	W 086°44'49"	5M	N 36°03'49"	W 086°44'37"
1N	N 36°03'51"	W 086°44'36"	2N	N 36°03'50”	W 086°44'50”	3N	N 36°03'49"	W 086°44'31"	4N	N 36°03'44"	W 086°44'55"	5N	N 36°03'49"	W 086°44'37"
1O	N 36°03'51"	W 086°44'36"	2O	N 36°03'53"	W 086°44'46"	3O	N 36°03'50"	W 086°44'31"	4O	N 36°03'45"	W 086°44'54"	5O	N 36°03'45"	W 086°44'55"

Table 3c: *Urban site*—GPS coordinates for trees surveyed at Vanderbilt University (*n* = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 36°08'39"	W 086°48'11"	2A	N 36°08'39"	W 086°48'11"	3A	N 36°08'48"	W 086°48'06"	4A	N 36°08'41"	W 086°48'07"	5A	N 36°08'43"	W 086°48'11"
1B	N 36°08'41"	W 086°48'07"	2B	N 36°08'41"	W 086°48'07"	3B	N 36°08'48"	W 086°47'59"	4B	N 36°08'43"	W 086°48'11"	5B	N 36°08'48"	W 086°48'08"
1C	N 36°08'46"	W 086°48'08"	2C	N 36°08'43"	W 086°48'11"	3C	N 36°08'48"	W 086°48'03"	4C	N 36°08'43"	W 086°48'11"	5C	N 36°08'48"	W 086°48'08"
1D	N 36°08'46"	W 086°48'07"	2D	N 36°08'43"	W 086°48'11"	3D	N 36°08'49"	W 086°48'06"	4D	N 36°08'48"	W 086°48'07"	5D	N 36°08'48"	W 086°48'06"
1E	N 36°08'48"	W 086°48'06"	2E	N 36°08'48"	W 086°48'06"	3E	N 36°08'49"	W 086°48'16"	4E	N 36°08’39”	W 086°48’10”	5E	N 36°08'48"	W 086°48'06"
1F	N 36°08'48"	W 086°47'59"	2F	N 36°08'43"	W 086°48'13"	3F	N 36°08'52"	W 086°48'18"	4F	N 36°08’29”	W 086°48’19”	5F	N 36°08'48"	W 086°48'03"
1G	N 36°08'47"	W 086°47'59"	2G	N 36°08'48"	W 086°48'08"	3G	N 36°08'52"	W 086°48'16"	4G	N 36°08'43"	W 086°48'13"	5G	N 36°08'48"	W 086°48'08"
1H	N 36°08'46"	W 086°47'59"	2H	N 36°08'50"	W 086°48'12"	3H	N 36°08’39”	W 086°48’10”	4H	N 36°08'48"	W 086°47'59"	5H	N 36°08'48"	W 086°48'08"
1I	N 36°08'48"	W 086°48'13"	2I	N 36°08'48"	W 086°48'15"	3I	N 36°08'39"	W 086°48'11"	4I	N 36°08'48"	W 086°47'59"	5I	N 36°08'48"	W 086°48'12"
1J	N 36°08'47"	W 086°48'15"	2J	N 36°08'53"	W 086°48'13"	3J	N 36°08'39"	W 086°48'11"	4J	N 36°08’29”	W 086°48’21”	5J	N 36°08'47"	W 086°48'15"
1K	N 36°08'48"	W 086°48'15"	2K	N 36°08’39”	W 086°48’10”	3K	N 36°08'32"	W 086°48'19"	4K	N 36°08'48"	W 086°48'12"	5K	N 36°08'52"	W 086°48'18"
1L	N 36°08'48"	W 086°48'15"	2L	N 36°08'53"	W 086°48'12"	3L	N 36°08'29"	W 086°48'19"	4L	N 36°08'50"	W 086°48'17"	5L	N 36°08'53"	W 086°48'12"
1M	N 36°08'48"	W 086°48'15"	2M	N 36°08'43"	W 086°48'05"	3M	N 36°08'29"	W 086°48'21"	4M	N 36°08'52"	W 086°48'09"	5M	N 36°08'51"	W 086°48'08"
1N	N 36°08'52"	W 086°48'15"	2N	N 36°08'43"	W 086°48'05"	3N	N 36°08'27"	W 086°48'21"	4N	N 36°08'44"	W 086°48'05"	5N	N 36°08'43"	W 086°48'05"
1O	N 36°08'53"	W 086°48'12"	2O	N 36°08'43"	W 086°48'10"	3O	N 36°08'29"	W 086°48'23"	4O	N 36°08'43"	W 086°48'04"	5O	N 36°08'39"	W 086°48'11"

Table 3d: *Urban site*—GPS coordinates for trees surveyed at Maryland Farms Industrial Plaza (n = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 36°02'11"	W 086°48'48"	2A	N 36°02'10"	W 086°48'43"	3A	N 36°02'08"	W 086°48'53"	4A	N 36°02'11"	W 086°48'49"	5A	N 36°02'10"	W 086°48'43"
1B	N 36°02'11"	W 086°48'48"	2B	N 36°02'10"	W 086°48'43"	3B	N 36°02'08"	W 086°48'53"	4B	N 36°02'11"	W 086°48'49"	5B	N 36°02'10"	W 086°48'43"
1C	N 36°02'11"	W 086°48'49"	2C	N 36°02'11"	W 086°48'49"	3C	N 36°02'08"	W 086°48'53"	4C	N 36°02'12"	W 086°48'59"	5C	N 36°02'10"	W 086°48'43"
1D	N 36°02'11"	W 086°48'49"	2D	N 36°02'12"	W 086°48'59"	3D	N 36°02'10"	W 086°48'39"	4D	N 36°02'08"	W 086°48'53"	5D	N 36°02'10"	W 086°48'41"
1E	N 36°02'07"	W 086°47'42"	2E	N 36°02'12"	W 086°48'59"	3E	N 36°02'10"	W 086°48'41"	4E	N 36°02'05"	W 086°48'50"	5E	N 36°02'00"	W 086°48'33"
1F	N 36°02'07"	W 086°47'42"	2F	N 36°01'59"	W 086°47'44"	3F	N 36°02'10"	W 086°48'41"	4F	N 36°02'05"	W 086°48'50"	5F	N 36°02'05"	W 086°47'40"
1G	N 36°02'12"	W 086°47'41"	2G	N 36°01'59"	W 086°47'37"	3G	N 36°02'06"	W 086°48'39"	4G	N 36°02'05"	W 086°48'50"	5G	N 36°02'05"	W 086°47'40"
1H	N 36°02'12"	W 086°47'41"	2H	N 36°02'02"	W 086°47'35"	3H	N 36°02'06"	W 086°48'39"	4H	N 36°02'10"	W 086°48'41"	5H	N 36°02'03"	W 086°47'41"
1I	N 36°02'12"	W 086°47'41"	2I	N 36°02'07"	W 086°47'42"	3I	N 36°02'06"	W 086°48'39"	4I	N 36°02'10"	W 086°48'34"	5I	N 36°02'07"	W 086°47'42"
1J	N 36°02'12"	W 086°47'41"	2J	N 36°02'10"	W 086°47'41"	3J	N 36°01'59"	W 086°47'44"	4J	N 36°02'10"	W 086°48'34"	5J	N 36°02'07"	W 086°47'42"
1K	N 36°02'10"	W 086°47'41"	2K	N 36°02'10"	W 086°47'41"	3K	N 36°01'59"	W 086°47'44"	4K	N 36°02'10"	W 086°48'34"	5K	N 36°02'17"	W 086°48'15"
1L	N 36°02'10"	W 086°47'41"	2L	N 36°02'07"	W 086°47'42"	3L	N 36°02'02"	W 086°47'35"	4L	N 36°01'59"	W 086°47'44"	5L	N 36°02'17"	W 086°48'15"
1M	N 36°02'10"	W 086°47'41"	2M	N 36°02'17"	W 086°48'15"	3M	N 36°02'02"	W 086°47'35"	4M	N 36°02'07"	W 086°47'42"	5M	N 36°02'17"	W 086°48'15"
1N	N 36°02'17"	W 086°48'13"	2N	N 36°02'17"	W 086°48'15"	3N	N 36°02'03"	W 086°47'41"	4N	N 36°02'07"	W 086°47'42"	5N	N 36°02'17"	W 086°48'15"
1O	N 36°02'17"	W 086°48'13"	2O	N 36°02'17"	W 086°48'13"	3O	N 36°02'03"	W 086°47'41"	4O	N 36°02'02"	W 086°47'43"	5O	N 36°02'17"	W 086°48'13"

Table 3e: *Forest site*—GPS coordinates for trees surveyed at Rock Island State Park (n = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 35°48'14"	W 085°38'03"	2A	N 35°47'42"	W 085°37'51"	3A	N 35°48'03"	W 085°38'03"	4A	N 35°48'14"	W 085°38'03"	5A	N 35°47'55"	W 085°37'59"
1B	N 35°48'14"	W 085°38'03"	2B	N 35°48'06"	W 085°37'30"	3B	N 35°47'58"	W 085°38'01"	4B	N 35°48'14"	W 085°38'03"	5B	N 35°47'55"	W 085°37'59"
1C	N 35°48'12"	W 085°38'01"	2C	N 35°48'06"	W 085°37'30"	3C	N 35°47'50"	W 085°37'56"	4C	N 35°48'12"	W 085°38'02"	5C	N 35°47'52"	W 085°37'54"
1D	N 35°47'58"	W 085°38'02"	2D	N 35°48'37"	W 085°38'56"	3D	N 35°47'40"	W 085°37'39"	4D	N 35°48'08"	W 085°38'04"	5D	N 35°47'52"	W 085°37'55"
1E	N 35°47'53"	W 085°37'54"	2E	N 35°48'37"	W 085°38'57"	3E	N 35°47'47"	W 085°37'21"	4E	N 35°48'06"	W 085°38'03"	5E	N 35°47'44"	W 085°37'53"
1F	N 35°47'51"	W 085°37'55"	2F	N 35°48'37"	W 085°38'57"	3F	N 35°47'49"	W 085°37'20"	4F	N 35°47'02"	W 085°38'04"	5F	N 35°47'42"	W 085°37'50"
1G	N 35°47'41"	W 085°37'47"	2G	N 35°48'37"	W 085°38'57"	3G	N 35°47'53"	W 085°37'19"	4G	N 35°47'57"	W 085°38'59"	5G	N 35°47'42"	W 085°37'49"
1H	N 35°47'42"	W 085°37'42"	2H	N 35°48'08"	W 085°37'30"	3H	N 35°48'41"	W 085°38'50"	4H	N 35°47'53"	W 085°38'58"	5H	N 35°47'42"	W 085°37'42"
1I	N 35°47'48"	W 085°37'21"	2I	N 35°48'08"	W 085°37'30"	3I	N 35°48'37"	W 085°38'56"	4I	N 35°47'48"	W 085°38'57"	5I	N 35°47'43"	W 085°37'29"
1J	N 35°48'00"	W 085°37'20"	2J	N 35°48'05"	W 085°37'27"	3J	N 35°48'34"	W 085°39'00"	4J	N 35°47'47"	W 085°38'57"	5J	N 35°48'03"	W 085°37'24"
1K	N 35°48'02"	W 085°37'22"	2K	N 35°48'05"	W 085°37'27"	3K	N 35°48'37"	W 085°39'02"	4K	N 35°47'40"	W 085°38'39"	5K	N 35°48'05"	W 085°37'28"
1L	N 35°48'07"	W 085°37'32"	2L	N 35°48'13"	W 085°37'41"	3L	N 35°48'39"	W 085°39'00"	4L	N 35°48'51"	W 085°38'20"	5L	N 35°48'06"	W 085°37'29"
1M	N 35°48'07"	W 085°37'32"	2M	N 35°48'24"	W 085°37'55"	3M	N 35°48'38"	W 085°38'59"	4M	N 35°48'03"	W 085°38'24"	5M	N 35°48'07"	W 085°37'32"
1N	N 35°48'07"	W 085°37'32"	2N	N 35°48'53"	W 085°38'16"	3N	N 35°48'40"	W 085°39'03"	4N	N 35°48'04"	W 085°38'26"	5N	N 35°48'07"	W 085°37'38"
1O	N 35°48'07"	W 085°37'38"	2O	N 35°48'51"	W 085°38'12"	3O	N 35°48'45"	W 085°39'06"	4O	N 35°48'07"	W 085°38'32"	5O	N 35°48'06"	W 085°37'40"

Table 3f: *Forest site*—GPS coordinates for trees surveyed at Percy Warner Park (*n* = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 36°03'34"	W 086°54'46"	2A	N 36°03'34"	W 086°54'46"	3A	N 36°03'34"	W 086°54'46"	4A	N 36°03'31"	W 086°54'59"	5A	N 36°03'35"	W 086°54'41"
1B	N 36°03'31"	W 086°54'53"	2B	N 36°03'31"	W 086°54'53"	3B	N 36°03'32"	W 086°54'51"	4B	N 36°03'30"	W 086°54'58"	5B	N 36°03'34"	W 086°54'46"
1C	N 36°03'25"	W 086°55'00"	2C	N 36°03'30"	W 086°54'58"	3C	N 36°03'31"	W 086°54'53"	4C	N 36°03'30"	W 086°54'58"	5C	N 36°03'32"	W 086°54'53"
1D	N 36°03'22"	W 086°55'03"	2D	N 36°03'13"	W 086°54'49"	3D	N 36°03'31"	W 086°54'59"	4D	N 36°03'22"	W 086°55'03"	5D	N 36°03'25"	W 086°55'00"
1E	N 36°03'22"	W 086°55'03"	2E	N 36°03'13"	W 086°54'49"	3E	N 36°03'30"	W 086°54'58"	4E	N 36°03’33”	W 086°54’35”	5E	N 36°03'25"	W 086°55'00"
1F	N 36°03'16"	W 086°54'58"	2F	N 36°03'25"	W 086°54'33"	3F	N 36°03'11"	W 086°54'37"	4F	N 36°03'21"	W 086°54'32"	5F	N 36°03'13"	W 086°54'49"
1G	N 36°03'10"	W 086°54'42"	2G	N 36°03'30"	W 086°54'25"	3G	N 36°03'14"	W 086°54'39"	4G	N 36°03'26"	W 086°54'33"	5G	N 36°03'08"	W 086°54'43"
1H	N 36°03'14"	W 086°54'39"	2H	N 36°03'36"	W 086°54'27"	3H	N 36°03'30"	W 086°54'25"	4H	N 36°03'30"	W 086°54'25"	5H	N 36°03'12"	W 086°54'38"
1I	N 36°03'22"	W 086°54'32"	2I	N 36°03'37"	W 086°54'18"	3I	N 36°03'34"	W 086°54'23"	4I	N 36°03'34"	W 086°54'21"	5I	N 36°03'22"	W 086°54'32"
1J	N 36°03'23"	W 086°54'32"	2J	N 36°03'34"	W 086°54'23"	3J	N 36°03'34"	W 086°54'24"	4J	N 36°03'35"	W 086°54'30"	5J	N 36°03'29"	W 086°54'26"
1K	N 36°03'27"	W 086°54'33"	2K	N 36°03'36"	W 086°54'25"	3K	N 36°03'33"	W 086°54'25"	4K	N 36°03'35"	W 086°54'31"	5K	N 36°03'36"	W 086°54'17"
1L	N 36°03'36"	W 086°54'26"	2L	N 36°03'35"	W 086°54'27"	3L	N 36°03'33"	W 086°54'25"	4L	N 36°03'35"	W 086°54'28"	5L	N 36°03'33"	W 086°54'25"
1M	N 36°03'36"	W 086°54'23"	2M	N 36°03'33"	W 086°54'46"	3M	N 36°03'35"	W 086°54'31"	4M	N 36°03'36"	W 086°54'26"	5M	N 36°03'33"	W 086°54'29"
1N	N 36°03'35"	W 086°54'23"	2N	N 36°03'34"	W 086°54'47"	3N	N 36°03'36"	W 086°54'28"	4N	N 36°03'33"	W 086°54'49"	5N	N 36°03'36"	W 086°54'28"
1O	N 36°03'34"	W 086°54'24"	2O	N 36°03'33"	W 086°54'47"	3O	N 36°03'35"	W 086°54'28"	4O	N 36°03'32"	W 086°54'57"	5O	N 36°03'34"	W 086°54'46"

Table 3g: *Forest site*—GPS coordinates for trees surveyed Tims Ford State Park (*n* = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 35°13'02"	W 086°14'51"	2A	N 35°13'08"	W 086°15'10"	3A	N 35°13'01"	W 086°14'50"	4A	N 35°13'03"	W 086°14'50"	5A	N 35°13'01"	W 086°14'51"
1B	N 35°13'03"	W 086°15'08"	2B	N 35°13'16"	W 086°14'49"	3B	N 35°13'00"	W 086°15'07"	4B	N 35°13'01"	W 086°14'50"	5B	N 35°13'00"	W 086°15'07"
1C	N 35°13'03"	W 086°15'07"	2C	N 35°13'15"	W 086°14'46"	3C	N 35°13'24"	W 086°15'58"	4C	N 35°13'01"	W 086°14'51"	5C	N 35°13'05"	W 086°15'08"
1D	N 35°13'04"	W 086°15'06"	2D	N 35°13'14"	W 086°15'36"	3D	N 35°13'22"	W 086°16'00"	4D	N 35°13'03"	W 086°15'07"	5D	N 35°13'08"	W 086°15'12"
1E	N 35°13'08"	W 086°15'15"	2E	N 35°13'14"	W 086°15'36"	3E	N 35°13'26"	W 086°15'58"	4E	N 35°13'03"	W 086°15'06"	5E	N 35°13'03"	W 086°15'05"
1F	N 35°13'18"	W 086°14'48"	2F	N 35°13'23"	W 086°15'53"	3F	N 35°12'55"	W 086°14'50"	4F	N 35°13'03"	W 086°15'05"	5F	N 35°13'01"	W 086°15'02"
1G	N 35°13'11"	W 086°15'31"	2G	N 35°13'26"	W 086°15'57"	3G	N 35°12'55"	W 086°14'50"	4G	N 35°13'00"	W 086°15'05"	5G	N 35°13'18"	W 086°14'50"
1H	N 35°13'17"	W 086°15'32"	2H	N 35°13'29"	W 086°15'52"	3H	N 35°12'54"	W 086°14'49"	4H	N 35°13'00"	W 086°15'03"	5H	N 35°13'13"	W 086°15'22"
1I	N 35°13'15"	W 086°15'33"	2I	N 35°13'22"	W 086°15'34"	3I	N 35°12'54"	W 086°14'48"	4I	N 35°13'01"	W 086°15'01"	5I	N 35°13'11"	W 086°15'28"
1J	N 35°13'19"	W 086°15'35"	2J	N 35°13'16"	W 086°15'22"	3J	N 35°12'52"	W 086°15'04"	4J	N 35°13'14"	W 086°14'51"	5J	N 35°13'09"	W 086°15'31"
1K	N 35°13'20"	W 086°15'37"	2K	N 35°12'53"	W 086°14'49"	3K	N 35°12'54"	W 086°15'03"	4K	N 35°13'19"	W 086°14'49"	5K	N 35°13'10"	W 086°15'31"
1L	N 35°13'20"	W 086°15'37"	2L	N 35°12'51"	W 086°14'55"	3L	N 35°12'52"	W 086°14'55"	4L	N 35°13'18"	W 086°14'48"	5L	N 35°13'16"	W 086°15'36"
1M	N 35°13'24"	W 086°15'44"	2M	N 35°12'55"	W 086°15'04"	3M	N 35°12'53"	W 086°14'50"	4M	N 35°13'12"	W 086°14'49"	5M	N 35°13'16"	W 086°15'36"
1N	N 35°13'23"	W 086°15'45"	2N	N 35°12'55"	W 086°15'05"	3N	N 35°12'55"	W 086°14'49"	4N	N 35°13'17"	W 086°14'51"	5N	N 35°13'24"	W 086°15'46"
1O	N 35°13'23"	W 086°15'53"	2O	N 35°12'54"	W 086°15'05"	3O	N 35°12'56"	W 086°14'56"	4O	N 35°13'13"	W 086°15'22"	5O	N 35°13'20"	W 086°16'01"

Table 3h: *Forest site*—GPS coordinates for trees surveyed at Long Hunter State Park (n = 75).

Acer spp.			*Celtis* spp.			*Fraxinus* spp.			*Quercus* spp.			*Ulmus* spp.		
Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude	Tree:	latitude	longitude
1A	N 36°06'03"	W 086°33'19"	2A	N 36°06'04"	W 086°33'21"	3A	N 36°06'03"	W 086°33'19"	4A	N 36°06'04"	W 086°33'21"	5A	N 36°06'02"	W 086°33'30"
1B	N 36°06'03"	W 086°33'19"	2B	N 36°06'02"	W 086°33'32"	3B	N 36°06'03"	W 086°33'19"	4B	N 36°06'02"	W 086°33'22"	5B	N 36°06'02"	W 086°33'30"
1C	N 36°06'04"	W 086°33'21"	2C	N 36°06'02"	W 086°33'32"	3C	N 36°06'02"	W 086°33'22"	4C	N 36°06'05"	W 086°33'26"	5C	N 36°06'02"	W 086°33'30"
1D	N 36°06'02"	W 086°33'22"	2D	N 36°06'03"	W 086°33'37"	3D	N 36°06'05"	W 086°33'26"	4D	N 36°06'02"	W 086°33'40"	5D	N 36°06'02"	W 086°33'32"
1E	N 36°06'05"	W 086°33'26"	2E	N 36°06'02"	W 086°33'40"	3E	N 36°06'03"	W 086°33'37"	4E	N 36°06'00"	W 086°33'45"	5E	N 36°06'03"	W 086°33'37"
1F	N 36°06'03"	W 086°33'37"	2F	N 36°06'00"	W 086°33'44"	3F	N 36°06'02"	W 086°33'40"	4F	N 36°06'00"	W 086°33'47"	5F	N 36°05'59"	W 086°33'41"
1G	N 36°06'05"	W 086°33'40"	2G	N 36°06'00"	W 086°33'44"	3G	N 36°06'09"	W 086°33'44"	4G	N 36°06'05"	W 086°33'40"	5G	N 36°06'09"	W 086°33'44"
1H	N 36°06'05"	W 086°33'40"	2H	N 36°06'05"	W 086°33'40"	3H	N 36°06'11"	W 086°33'47"	4H	N 36°06'09"	W 086°33'44"	5H	N 36°06'11"	W 086°33'47"
1I	N 36°06'05"	W 086°33'40"	2I	N 36°06'11"	W 086°33'47"	3I	N 36°06'24"	W 086°33'48"	4I	N 36°06'09"	W 086°33'44"	5I	N 36°06'11"	W 086°33'47"
1J	N 36°06'15"	W 086°33'52"	2J	N 36°06'14"	W 086°33'48"	3J	N 36°06'24"	W 086°33'48"	4J	N 36°06'15"	W 086°33'52"	5J	N 36°06'14"	W 086°33'48"
1K	N 36°06'15"	W 086°33'52"	2K	N 36°06'19"	W 086°33'50"	3K	N 36°06'24"	W 086°33'48"	4K	N 36°06'11"	W 086°33'48"	5K	N 36°06'14"	W 086°33'48"
1L	N 36°06'15"	W 086°33'52"	2L	N 36°06'23"	W 086°33'48"	3L	N 36°06'14"	W 086°33'50"	4L	N 36°06'01"	W 086°33'30"	5L	N 36°06'14"	W 086°33'48"
1M	N 36°06'19"	W 086°33'50"	2M	N 36°06'23"	W 086°33'48"	3M	N 36°06'13"	W 086°33'46"	4M	N 36°06'03"	W 086°33'29"	5M	N 36°06'14"	W 086°33'48"
1N	N 36°06'19"	W 086°33'50"	2N	N 36°06'23"	W 086°33'48"	3N	N 36°06'11"	W 086°33'48"	4N	N 36°06'05"	W 086°33'29"	5N	N 36°06'14"	W 086°33'51"
1O	N 36°06'19"	W 086°33'50"	2O	N 36°06'24"	W 086°33'48"	3O	N 36°06'11"	W 086°33'48"	4O	N 36°06'05"	W 086°33'29"	5O	N 36°06'14"	W 086°33'51"

Table 4: Summary for wounding and demographic measurements of 600 trees surveyed among five genera of trees at eight sites in Middle Tennessee (n = 15 trees genera^{-1} site^{-1}). Significant differences are highlighted in bold type (2-way ANOVA, df = 4, α = 0.05). Significant differences were identified among *genera*, *environment*, and *environment x genera*.

Wounding Measurements	*Environment*	*Genera*	*Environment x Genera*
Number of Open Wounds (m^{-2})	***p* < 0.001**	***p* = 0.002**	p = 0.43
Number of Wounds Less than $2cm^2$ (m^{-2})	***p* = 0.007**	***p* < 0.001**	p = 0.30
Number of Closed Wounds (m^{-2})	***p* < 0.001**	***p* < 0.001**	***p* < 0.001**
Wound Area (% trunk wounded)	p = 0.18	***p* = 0.001**	p = 0.31

Demographic Measurements	*Environment*	*Genera*	*Interaction*
Overall Tree Condition Ranking (Ranked 1-5)	***p* < 0.001**	***p* = 0.04**	***p* = 0.007**
Average Tree Circumference (cm)	***p* < 0.001**	***p* = 0.001**	***p* < 0.001**

Table 5: Summary for categorical presence / absence wound measurements of 600 trees surveyed among five genera (n = 60 trees genera^{-1} environment^{-1}; χ^2; 0.05, df = 1). *P-values* showing significant differences between urban and forested trees within a genus are highlighted in bold text.

Categorical Measurements (Presence/Absence)	*Acer* spp. (Maple)				*Celtis* spp. (Hackberry)				*Fraxinus* spp. (Ash)				*Quercus* spp. (Oak)				*Ulmus* spp. (Elm)			
	Urban	Forest	χ^2	*p*-value	Urban	Forest	χ^2	*p*-value	Urban	Forest	χ^2	*p*-value	Urban	Forest	χ^2	*p*-value	Urban	Forest	χ^2	*p*-value
Presence of Fungal Conks (Raw count; (%))	12 (0.32)	5 (0.16)	3.36	p = 0.067	10 (0.26)	0 (0.00)	10.91	**p < 0.0001**	8 (0.21)	5 (0.16)	0.78	p = 0.38	8 (0.21)	10 (0.31)	0.26	p = 0.61	0 (0.00)	12 (0.38)	13.33	**p < 0.0001**
Presence of Girdling Roots (Raw count; (%))	42 (0.29)	23 (0.25)	12.12	**p = 0.0005**	32 (0.22)	21 (0.23)	4.09	**p = 0.043**	22 (0.15)	16 (0.18)	0.19	p = 0.66	25 (0.17)	19 (0.21)	1.29	p = 0.26	24 (0.17)	12 (0.13)	5.71	**p = 0.017**
Presence of Pruning Cuts (Raw count; (%))	56 (0.21)	5 (0.26)	86.72	**p < 0.0001**	54 (0.21)	5 (0.26)	80.06	**p < 0.0001**	48 (0.18)	4 (0.21)	65.70	**p < 0.0001**	56 (0.21)	1 (0.05)	101.09	**p < 0.0001**	49 (0.19)	4 (0.21)	68.43	**p < 0.0001**
Presence of Root Wounds (Raw count; (%))	46 (0.25)	27 (0.21)	12.63	**p = 0.0004**	41 (0.22)	24 (0.19)	9.70	**p = 0.002**	29 (0.16)	25 (0.20)	0.54	p = 0.46	36 (0.20)	29 (0.23)	1.64	p = 0.20	33 (0.18)	22 (0.17)	4.06	**p = 0.043**