Urban Street Trees as a Potential Source of Timber in Washington, DC

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ACADEMIC ABSTRACT

Recycling felled urban trees that are hazardous or unhealthy is increasingly viewed as a viable practice to control disposal costs, promote environmental practices, and support local commerce. Wide spread waste wood utilization is encumbered by numerous presumptions about wood quantity, quality, accessibility, and presence of foreign objects; yet there is almost no scientific literature about these presumptions. Without this knowledge, informed decisions cannot be made about the viability of waste wood utilization. In this study, we assessed the quality and quantity of timber in street trees scheduled for routine removal by the District of Columbia (the District) using a modified timber grading protocol adapted from the United States Forest Service. We developed a second protocol to assess the feasibility of timber salvage by identifying physical barriers commonly encountered in urban areas (e.g., high volume traffic, utilities around the tree, and infrastructure). The randomized sampling scheme was stratified by land-use zones and focused on the six most abundant tree species: *Acer platanoides, Acer rubrum, Acer saccharum, Quercus palustris, Quercus phellos, Quercus rubra*. Our findings suggest the majority of condemned street trees are of too poor quality to contain timber (58% cull rate); however, trees that contain merchantable logs are likely to be easily removed. A notable discovery that could prove problematic for wood salvage was that the majority of trees (88%) contained superficial metal items embedded in the trunk surface. Furthermore, presence or absence of a merchantable-sized log ($p=0.0445$) depended on the tree's species, as did the average volume observed ($p<0.0001$). Additionally, land-use zones had an effect on the removal

feasibility scores ($p=0.0257$) but had no effect on log presence or log volume. Throughout the District, we estimated that 36,500 board feet of merchantable logs are generated from routine removals of our top six species annually. These findings provide empirical data pertaining to urban timber salvage, which might aid decisions on the investment worthiness of utilizing urban street trees.

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Recycling felled urban trees that are hazardous or unhealthy is increasingly viewed as a viable practice to control disposal costs, promote environmental practices, and support local commerce. Wide spread waste wood utilization is encumbered by numerous presumptions about wood quantity, quality, accessibility, and presence of foreign objects; yet there is almost no scientific literature about these presumptions. Without this knowledge, informed decisions cannot be made about the viability of waste wood utilization. In this study, we assessed the quality and quantity of timber in street trees scheduled for routine removal by the District of Columbia (the District) using a modified timber grading protocol adapted from the United States Forest Service. We developed a second protocol to assess the feasibility of timber salvage by identifying physical barriers commonly encountered in urban areas (e.g., high volume traffic, utilities around the tree, and infrastructure). The randomized sampling scheme was stratified by land-use zones and focused on the six most abundant tree species: *Acer platanoides, Acer rubrum, Acer saccharum, Quercus palustris, Quercus phellos, Quercus rubra*. Our findings suggest the majority of condemned street trees are of too poor quality to contain timber (58% cull rate); however, trees that contain merchantable logs are likely to be easily removed. A notable discovery that could prove problematic for wood salvage was that the majority of trees (88%) contained superficial metal items embedded in the trunk surface. Furthermore, presence or absence of a merchantable-sized log ($p=0.0445$) depended on the tree's species, as did the average volume observed ($p<0.0001$). Additionally, land-use zones had an effect on the removal feasibility scores (p=0.0257) but had no effect on log presence or log volume. Throughout the District, we estimated that 36,500 board feet of merchantable logs are generated from routine removals of our top six species annually. These findings provide empirical data pertaining to urban timber salvage, which might aid decisions on the investment worthiness of utilizing urban street trees.

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CHAPTER 1 – INTRODUCTION

Cities and urban centers continue to increase in size and population across the globe, increasing pressure on infrastructure and resources. For example, 80 percent of the U.S. population dwell in urban areas that make up three percent of the total land area (Nowak 2006). Urban populations continue to increase; one estimation suggests the increase in size of urban land by 2050 will be equivalent to the size of the state of Montana (Nowak 2006). As urban areas increase in size, urban forest will also increase as officials, activists, and volunteers plant trees in parks, along streams, and next to roads to increase the benefits urban trees offer (Wolf 2005, Nowak 1993, Booth et al. 2002).

Roughly 4.9 billion trees grow intertwined with the city landscape in urban areas across the United States (Nowak et al. 2013) making up urban forests. Urban forests are an integral component of the health of many cities providing numerous benefits beyond aesthetics such as; improving business (Wolf 2005), removing air pollution (Nowak 1993, Nowak et al. 2006), intercepting storm water (Booth et al 2002, Xiao et el. 1998), and sequestering carbon (Nowak et al. 2013). To maximize the benefits of urban forests, many communities promote tree stewardship and planting programs. However, despite these efforts urban forests are continually losing trees to senescence, decay, hazards, and catastrophes such as insect outbreaks or storms (Poland et al. 2006). The biomass generated from these trees are landfilled or mulched (Endahl 2015), and while recognizing that mulch can be an environmentally friendly alternative to landfills, other alternatives may be more sustainable and economically beneficial (Bratkovich et al. 2011) including the production of higher-value wood products (MacFarlane 2007). However, not all urban waste can be made into higher-valued wood products. Urban timber—

one component of urban wood—is generated from larger intact tree trunks with low defects. Trees with low crowns, many knots, and small diameters may not qualify for timber. By using residual wood for wood products, such as furniture and building material, municipalities can store carbon that would otherwise be released into the atmosphere (Bratkovich et al. 2011). Harvesting urban trees slated for removal could also potentially increase the urban forest value (e.g., increased carbon storage, reduced transportation and reduced disposal costs) by adding an additional use to the forest. Furthermore, urban areas may present themselves as a more sustainable alternative and local source of timber. Often urban timber especially from known street trees has the potential to carry sentimental value attached to neighborhood trees that in turn could be made into wood products. Underutilization of the urban forest as a resource contributes to timber waste and increased greenhouse gas emissions, causing economic and environmental concern.

Though salvaging urban timber has the potential to be a great alternative to current utilization practices, there are concerns over the viability of timber from urban trees as a source of revenue. Prospective users of urban wood are divided in opinion over its reliability. On one side, arborists and forest product manufacturers argue urban forests have insufficient amounts of timber volume, and the quality is too poor to be considered a viable raw material stream (Sherrill 2003). Sawmill owners are concerned that the presence of foreign objects—specifically metal items—would ruin saw blades, slow production, and be a safety concern (Sherrill 2003). Furthermore, in the absence of reliable information about timber quality, municipalities are reluctant to offer storage areas and instead seek to dispose of wood waste as quickly as possible. On the other side, small-scale wood workers and sustainability advocates argue that urban timber is being underutilized, but do not have data to validate this claim. Along with being a timber resource, timber utilization can mitigate landfill disposal fees, a main motivator for use (Endahl 2015). An exploratory study determined a sufficient quantity of residual wood exists in urban areas, but is still being underused (MacFarlane 2007). Unfortunately, research in this field has not yet come into full fruition, leaving many questions about urban forest timber left unanswered, especially in street trees. The needs for this research arise partly because little to no empirical evidence exists to refute or support claims made by those in the profession who believe urban street trees are not worth harvesting.

We have chosen to exclusively study potential timber utilization in street trees to close a gap in the literature: street trees as a source of timber. Interest in the fate of street trees is gaining traction throughout the country but empirical data on urban street trees utilization is not available. Street trees differ from woodland trees because they are often isolated and open grown as street trees receive light from multiple sides. Furthermore, they are more susceptible to anthropogenic disturbance (e.g., pollution, salt, and vandalism). Furthermore, streets are constantly under management from municipalities and arborists alike (Welch 1994) further affecting their growth patterns. Street trees also serve as kiosks and bulletin boards resulting in an increased likelihood of embedded foreign objects (e.g., office staples and nails) in the wood.

Our research partially answers the questions and fills in gaps in the literature that arise from these assumptions—low quantity and volume—by qualifying and quantifying timber in street trees slated for removal. The study focuses on Washington, DC (the District), a city with a progressive urban forest in the temperate United States. Trees in the District are regularly removed as they outlive their benefits to the city and become a liability. Of the over 143,000 street trees in the city, roughly 2,100 are removed annually. The District's mid-Atlantic region, allows an array of hardwood species found throughout many other major cities in the United

States to thrive, thus allowing for comparisons and data relevance for other major cities. In an attempt to characterize the timber resource in the District's street trees, we quantified the amount of available timber in street trees slated for removal to clarify unanswered questions about how much high-quality (lumber grade) timber is available and how feasible it is to salvage this timber. In order to measure the quantity and quality of street tree timber, we conducted an observational field study in the District and measured tree attributes related to timber volume using protocols adapted from the United States Forest Service (USFS) for timber grading. To make sufficient statistical comparisons characterizing the street trees, we focused the study on the six most abundant tree species (*Acer platanoides, Acer rubrum, Acer saccharum, Quercus palustris, Quercus phellos,* and *Quercus rubra*) throughout the District's different land use zones. We developed a protocol to determine the feasibility of log removal based on tree characteristics and surrounding infrastructures. Finally, we visually inspected the trunk of each tree to determine whether metal was present.

1.1 Research Objectives and Questions

(1) Quantify the amount of urban forest timber in the six most common street tree species slated for removal in Washington, DC.

   i. How much volume of timber exists in DC street trees slated for removal?

   ii. Of the most common species, which have the greatest volume of timber?

   iii. Which land-use zones contain the largest volumes of street tree timber?

(2) Characterize the quality of urban forest timber in the six most common street tree species slated for removal in Washington, DC.

   i. What is the overall quality of street tree timber in DC?

   ii. Which of the species studied has the best quality timber in DC?

iii. Which land-use zones possess the highest quality street tree timber?

(3) Examine the logistical site feasibility of salvaging urban forest timber in the six most common street tree species slated for removal in Washington, DC.

i. What is the general feasibility of salvaging street tree timber based on characteristics of the site and the tree?

ii. Which characteristics of the site and the tree most frequently impede the feasibility of timber salvage?

iii. Which species afford the greatest feasibility of timber salvage?

iv. Which land use-zones afford the greatest feasibility of timber salvage?

(4) Characterize the prevalence of superficial metal objects embedded in street tree.

i. What is the prevalence of all metal in trees and non-office staples metal in trees?

ii. Which land-use zones have the highest prevalence of metal in trees?

iii. Which species have the highest prevalence of metal in trees?

CHAPTER 2 – LITERATURE REVIEW

2.1 Urban Wood Waste Availability

This literature review encompasses peer-reviewed literature, anecdotal data, and reports referring to urban trees and more specifically street trees as a possible source of timber. Urban trees are abundant throughout the United States and much of their biomass is removed annually through routine pruning and tree removal. With the removal of biomass comes the generation of wood waste. Municipalities, tree care companies, and wood workers, want to find alternative fates for this wood waste—which is most often mulched or landfilled—such as wood products. However, barriers exist that deter people from using urban trees. This literature review aims to address the current research on the notion of urban trees as a source of timber, and the barriers associated with using such timber in the United States, specifically in Washington, DC.

2.1.1 Urban Forests

Population trends suggest that people will continue migrating into urban areas which will continue to impact these areas (Nowak et al. 2005). Between 1990 and 2000, urban areas grew by three percent in the United States, or roughly the size of the state of Vermont. Projections suggest that by 2030, 70 million acres will be converted to developed land, thus increasing the size of the urban forests and, bringing with it a myriad of benefits and challenges (Alig et al., 2004).

The United States has over 4.9 billion trees in its urban areas (Nowak 2013), of which over 1.9 million are found in Washington DC's national and city parks, private land, and streets (Nowak 2006). Of the 1.9 million trees, 143,000 are street trees (Corletta 2016). These billions of trees in the urban forest provide a multitude of benefits to the urban centers' environment, economy, and citizens. As an integral component of a city's health, urban trees not only provide aesthetics they also improve business (Wolf 2005), remove air pollution (Nowak 1993, Nowak et al. 2006), intercept storm water (Booth et al 2002, Xiao et el. 1998), and sequester carbon (C) (Nowak et al. 2013).

As the urban tree population grows and sequesters more carbon from the atmosphere, the trees accumulate biomass (McPherson 2015). The urban forest currently contains 1.3 billion tons of biomass (McPherson 2015). Although this carbon storage is beneficial, it only last for as long as the tree grows. An externality resulting from the senescence of these trees include biomass waste. Urban forests generate about 26 million tons of biomass from the systems due to tree mortality (McPherson 2015). Extrapolating these findings to Washington, DC, would conclude that 10,081 tons for biomass are stored in Washington, DC's urban trees of which 201 tons are removed from the system annually due to mortality.

2.1.2 Urban Forest Waste

The enormous waste generated from these urban forests is often mulched, or landfilled throughout the United States; the same trends are likely to be found in DC (Records do not currently capture the fate of DC wood waste). The estimation of 26 million tons of biomass removed from tree mortality (McPherson 2015) is consistent with the amount of urban forest waste produced from tree removal characterized in other academic studies. MacFarlane (2007) extrapolated the results of a southeastern Michigan study and determined 22.2 million tons of wood waste were removed annually from the region's urban centers.

Current practices lead to the urban forest waste generated often ending up in a landfill or as mulch (Endahl 2015, Sherrill 2003), whereas other solutions, such as wood products, are infrequently chosen (Endahl 2015). In regards to DC, we are unsure of the current fate of the urban forest waste; DC contracts the material to third parties. Currently, there is a lack of information on the fate of the urban forest waste generation in their system. However, thesis work in the neighboring state of Virginia (Endahl 2015) can give plausible explanations to the fate of urban forest waste in the Washington DC area, especially because the research conducted separated out private entities. In Virginia, roughly half of the urban forest waste is mulched at the landfill and a quarter is converted to compost. However, the remainder of the urban forest waste consisted of logs, chips, and brush (a log being defined as a large section of wood most commonly found in the trunk (Rast et al.1973)) which demonstrated the existence of urban timber potential in urban trees.

Many practices currently implemented for urban wood waste are cost intensive (Endahl 2015). The creativity of entrepreneurs; in maximizing the utility of urban forest waste can help alleviate some of these detriments. Urban forest waste use, especially that of the highest value, is the most desirable outcome of this generated biomass for a variety of reasons (MacFarlane 2007, ANSI A300, Sherrill 2003). First landfills require tipping fees that can quickly accumulate with the amount of biomass leaving the system while new environmental legislation makes landfills an increasingly difficult option by prohibiting the disposal of wood material (Inventory of US Greenhouse 2011). Mulching, though a better alternative to landfilling, reduces any quality wood to the lowest value—the same that would be used in yard trimmings—not allowing the wood to be used to its fullest potential. Finally, compost created from mulch releases carbon into the atmosphere as it decays. Though this mimics the natural process, the carbon released should not be ignored as it contributes to overall atmospheric carbon levels (Reijnder 2008). McPherson (2015) suggests 17 million tons of carbon could potentially be released annually as urban forest waste—including mulch and compost—decomposes. However, the possibility exists to store carbon in wood products for a set period of time (MacFarlane 2007, Sherrill 2003). Local and creative solutions using reclaimed urban timber (part of the urban wood waste) can be found throughout the country in large and small operations that help alleviate economic and environmental concerns while promoting sustainability and local commerce (Sherrill 2003).

Knowing where the urban waste falls within the spectrum of the highest valued use is required to divert the biomass from the landfill. The ANSI A300 part 11, which is currently in a working draft stage, has contributed to the discussion suggesting a variety of products that can be created from the different generated waste (Table 2.1). Urban logs or urban timber is a component of urban forest waste that comprises the best wood in the waste and has the potential to be crafted into high-valued products.

Table 2.1. Uses for wood salvaged from urban forests (Tree Care Industry Association, Inc. 2013).

Milled Urban Forest Products (Higher Valued)		Non-milled Urban Forest Products (Lower Valued)	
Veneer	Artisan Items	Firewood	Mulch
Furniture	Lumber	Pulpwood	Sawdust
Cabinetry	Bats	Biomass Fuel	Engineered Lumber
Flooring	Railroad Ties	Chips	

ANSI A300 goes on to state that arborists should be on the “lookout” for high-quality trees. As the quality of the product increases the qualifications also increase. Therefore, the amount of usable urban forest waste decreases. However, the majority of urban trees are not capable of generating high-valued logs. This is well documented in survey work done in Virginia, in which less than a third of the waste generated from urban trees was in the form of logs (Endahl 2015). The study did not delve into the quality of wood; thus the amount of usable logs is likely much different.

Using logs for urban timber is part of maintaining a sustainable urban forest as it fits in with the sustainable urban forest model developed by Clark et al. (1997). By investing in urban timber, thus using some of the urban forest waste to its highest potential, communities can contribute to this model. Urban timber brings stakeholders together building community through a network of commerce (Bratkovich et al. 2014). For example, using wood generated from local trees to create products such as benches or playground equipment can carry significant sentimental value to those in the community; this urban grown timber is seen by some as an excellent way to promote environmental sustainability. Wood products are increasingly seen as units of carbon storage. Furthermore, locally grown timber cuts on transportation emissions of both transporting the product and transporting the waste (McPherson 2015). Moreover, less organic matter sent to the landfill decreases the amount of methane produced from anaerobically decomposing materials (El-Fadel 1997). Finally, economic sustainability can be further strengthened as not only are tipping fees avoided saving the producer financial resources, but local commerce enables small business growth and the opportunity for creative artistry products to enter local markets (Sherrill 2003). The urban forest is already heavily managed and adding reclaimed timber is just one more cog that can allow it to be managed in a more sustainable manner. In order to maintain sustainable urban forests, the resource needs to be measured and characterized in order to decipher whether urban wood is a worthy investment. This has been done in countless studies for planting, forest health, standing biomass, and ecosystem services. However, measuring the final stage of the trees in the urban forests—waste generation—has largely been ignored.

In order for urban wood utilization to occur, characterization of the resource, specifically quantifying it, is necessary. Survey reports throughout the southeast have recently been conducted to try to understand how much waste is generated. The overall conclusions of these reports show that there is great variation in the quantity generated and that most of the waste generated is in the form of brush and other forms of wood which would not meet the requirement for high-wood products (Endahl 2015).

MacFarlane (2007) attempted to quantify the amount of urban timber located in southeastern Michigan, a highly-developed region, using USFS grading techniques. His results concluded that though high quality logs were infrequent in condemned trees throughout the study site, there was a quality and quantity generated significant enough to fuel five small saw mills. However, his study looked across all species and included the likes of street trees, private yard trees, and public park trees not giving empirical data specific to street trees alone.

2.2 Reclamation of Timber from Urban Wood Waste

The lack of empirical data on the subject of the availability of urban timber has not deterred craftsmen, artisans, portable saw mill owners, and even some municipalities from already using condemned trees for timber use. Anecdotes of urban timber use and urban timber products are found throughout local and national newspapers, fill presentation slots at professional conferences, and find their way into local bulletins. However, the practice is not confined to single-man operations. Large-scale operations are in the works, including, Michigan State Shadows and the Baltimore Wood Project, in which trees that are owned and removed by these entities are made into products and sold for revenue (Jolley 2016, US Forest Service Research & Development 2013).

Despite the lack of empirical data, urban timber reclamation is nothing new and these older projects can offer inspiration for future urban wood enthusiast. As far back as 1928, the city of Detroit chose to mill 5000 trees during a street widening project. The benefits included the generation of $50,000, avoided waste transportation, and using sustainable practices (Bratkovich et al. 2014). Today the project is considered to be innovative and ahead of its time. Recycling urban timber is again, peaking the interest of city dwellers.

Small-scale operations exist in virtually every major city throughout the United States and are prevalent in organizations such as the Illinois Wood Utilization Team, which strives to connect these local owners to each other, the resource, and potential markets. Dovetail Reports which most recently gave an assessment to the cities of Richmond, Virginia, and Raleigh, North Carolina further tried to connect small-business owners and word workers in the cities and stressed the importance of frameworks for the entrepreneur. One example of a small-scale operation is West Coast Arborist Inc. outside of Los Angeles; the company has made furniture from local urban trees that were in poor health. The president of the company had the motivation of sustainability and wanted to put urban wood to its highest potential from making wood products (Sherrill 2003). Operations are occurring near Washington, DC as well. In 2002, musical instruments were made from a 600-year-old tulip poplar as a testament to the tree's significance and legacy in Annapolis, Maryland (Sherrill 2003). Even elected officials and their spouses have opinions; Judy O'Bannon, the governor's wife of Indiana could not stand the thought of quality wood from the lawn of the Governor's mansion in Indianapolis, Indiana being landfilled and thus created a program for Indiana school students to make furniture from the felled trees' wood. These are just some of the many examples in which local wood is successfully harvested for sentimental, environmental, and practical purposes (Sherrill 2003).

Large-scale operations have been focused on special cases in which access to wood becomes available through catastrophic events such as storms or insect outbreaks, but are increasingly focused on the steady stream of potential urban timber. An example of such a case is the Wisconsin Wood Project. The non-profit organization was founded to help provide solutions for timber made quickly available from the dead and dying ash trees attacked by the Emerald Ash Borer. However, the project has moved to seek any available condemned trees that may be of use to local artisans (Wisconsin Reclamation Project 2014). Michigan State University has made use of condemned trees on campus converting the wood into specialty items such as diploma frames (Jolley 2016). On an even greater scale, the Baltimore Wood Project is incorporating urban timber into a larger project that attempts to count and use all available wood within the city using trees that would also be otherwise be disposed as well as using wood already in the form of timber in old houses and construction. Though these programs have already come into fruition, there are many barriers preventing others from following the path.

2.2.1 Barriers to Urban Timber

Many assumptions are made about urban trees that deter the use and the generation of wood products. Concerns are primarily due to the form urban trees take on affecting their quality and potential timber quantity. Other barriers include anthropogenic factors: extraction logistics, foreign objects embedded in the wood, and market connections (MacFarlane 2007, Sherrill 2003). Urban wood utilization is a multi-facet topic. However, this literature is more interested in the use of street trees. Therefore, urban timber markets will be left to a study more centered around economics and will not be discussed here.

2.2.2 Urban Timber Quality

Trees have similarities throughout different locations; however, urban trees have different functions as well as different life spans. Urban street trees have intense interactions with humans that their rural counterparts often avoid. Urban street trees provide shade, add aesthetic beauty, calm traffic (Wolf et al. 2006) and mitigate storm water (Booth et el. 2002), which are drastically different from forested trees or plantation trees used for timber production, wildlife habitat, and recreation. However, urban trees are only expected to live an average of 17 to 28 years (Roman and Scatena 2011), a shorter life span than their rural counterparts. The short life span requires heavy management as trees are constantly planted and removed. Furthermore, street trees need constant attention, in the forms of pruning (Shigo 1991). Even when street trees end their growth and begin to senesce, they require human intervention so that they are taken down safely, before they become a hazard.

Street trees' growth patterns and subsequent form make them less desirable for timber than their rural counterparts. Urban trees are developed from open growth form: a direct effect from an abundance of light. This often results in short crowns that stretch wider and have less of a dominant leader (Shigo 1991), are full of knotty wood, and are often stunted (DeBell et al. 1994, Uusitalo and Isotalo 2005). Further exacerbating growth differences caused by greater light exposure, street trees may fork more often causing an unbalance of weight resulting in a higher likelihood of falling limbs (Shigo 1991). Furthermore, street trees may have more exposure to extreme elements, including wind and pollution, which also may alter and stunt their growth (Gregg et al. 2003). Trees planted after infrastructure was laid are often confined to small planting strips constraining roots, stunting the overall tree growth. Street trees are also constantly being used and abused. People often hit trees with vehicles damaging bark and drill holes (allowing a gateway for pathogens and insects).

Municipal trees must be removed before the tree becomes a liability: falling on a building, vehicle, or person. However, these trees are often removed before they fully decay and often have available timber in them. One study found only 46%-75% of trees removed had some decay (Terho and Hallaksela 2008) giving the chance for urban timber to be found in half the street trees. Internal stem decay can often be detected through external defects (Koeser et al. 2016) allowing for standing timber to be graded and judged for its usability.

The USFS grading protocol for hardwood trees gives direction on how to grade timber. There are five classes in which a log can be classified: Factory grades 1, 2 and 3, construction grade, and log grades. Factory grades are the higher-quality logs with grade 1 being the highest; this set of logs are prime for furniture, flooring and other higher valued wood products (Rast et al. 1973). Construction and local log grades are inferior to factory logs and used for building construction and railroad ties.

MacFarlane (2007) found the quality of urban timber to be less than the quality of traditional forest stands. However, the difference was small and his results suggested that an abundance of quality timber existed in condemned trees with 22% of the urban grown trees to be of the two highest timber grade classes.

2.2.3 Urban Timber Volume

Many concerns specific to the volume of urban timber contribute to the prevention of its use: lack of overall volume, distance between trees that contain volume and the lack of predictability of potential volume generation as in the case of insect and disease outbreaks

(Poland et al. 2006). Volume of timber is directly related to timber quality, thus if the quality is lacking there will be no available timber.

To our knowledge, there are no studies measuring the volume of urban timber from street trees. Estimates put the annual urban green waste at over 22 billion tons, more than the weight of that which is harvested by the USFS (Sherrill 2014). However, this number does not account for the amount coming exclusively from high quality timber. MacFarlane (2007) determined there was enough high quality timber—over 560,000 board feet—generated annually from condemned urban trees in the southeastern counties of Michigan to operate five small sawmills.

2.2.4 Urban Timber Accessibility

To make urban wood utilization a reality, there must not only be sufficient volume of quality wood, but it must also be feasibly felled in order to recover the potential logs. This can be difficult for a variety of reasons: tree rot, infrastructure interference, and traffic disruption. Cutting trees for disposal is different from trees for saw timber (Sherrill 2003). Most often trees must be removed piece by piece from the top downward (Shigo 1991), not ideal for log extraction where the logs should be as long as possible. Yet larger sections can and are taken down with care (Shigo 1991) thus, increasing the chance of urban logs. If the timber cannot be removed and is not accessible then it becomes useless (MacFarlane 2007), something that should be avoided if possible.

According to the ANSI A300 part 11, standards do not exist for log removal in the urban setting. Therefore, those wishing to extract valuable logs from urban trees have no guidelines or evaluations in which to follow. Without any empirical data, log removal feasibility becomes a guess, resulting in the further avoidance of log use by municipalities and other decision makers who do not want to invest a great effort and cost in a resource with minimal value. One possible method of measurement is to determine how easy a tree log can be taken down and loaded onto a truck. MacFarlane (2007) used this method and formed three classes in which a tree would be classified for accessibility. This method primarily focused on how many pieces the log would be sectioned into as it was removed from the tree. Though his methods could be useful, his criteria were ambiguous, leaving the grader much to discern on his or her own. Furthermore, he focused primarily on very few aspects of tree removal: property damage and log size; without regards to other causes of concern (e.g., traffic and pedestrian use). Therefore, more categories are needed to assess the feasibility to understand the true barriers of obtaining urban saw logs. We have consulted with urban forestry professionals to determine which variables are of concern when trees are removed in the urban setting (Appendix C).

2.2.5 Urban Timber Metal Prevalence

Even if the quality and volume existed and the tree could be feasibly removed, urban trees—specifically street trees—are often embedded with foreign objects that have been placed by citizens throughout the tree's life (Sherrill 2003). These foreign objects are often in metal form: nails, spikes, and wires. This presumption deters wood workers who are concerned about safety and equipment damage (Sherrill 2003). Though modern mills are equipped to handle such objects (Bratkovich 2001), mill owners are still hesitant to use such wood fearing metal objects embedded in the wood, will slow production.

Urban timber could still potentially be used even with the presence of foreign objects. Logs can and should be screened for metal first through a visual inspection and then by using a metal detector or other device according to the ANSI A300 standards. The majority of metal objects found in logs are within the first four to six feet. Screening in this location is more necessary as the likelihood of metal detection is much greater than in higher parts of the tree. In most cases, wood embedded with metal can be isolated and removed maintaining a high log grade before the log is sent to the mill.

CHAPTER 3 – MATERIALS AND METHODS

3.1 Study Area

We conducted an observational study in Washington, DC from fall 2015 to spring 2016 to assess the quantity and quality of timber found in street trees condemned for removal by the District of Columbia Department of Transportation (DDOT). The feasibility of recovering logs from these trees during their removal, as influenced by various site conditions, was also examined. These same attributes were concurrently evaluated for a representative sample of street trees not condemned for removal during the study period. All street trees included in the study were either in a planting strip, sidewalk cut out, or on a lawn, within five feet from the street curb.

Washington, DC (38.9072° N, 77.0369° W) is located in the Mid-Atlantic region of the United States. The District lies within the coastal plain region of the mid-Atlantic, bound between Maryland and Virginia, comprising of 68.34 square miles, 61.05 of which are land and a population density of 956.2 persons per square mile of land (District of Columbia 2012). The southern border of the District is defined by the Potomac River while the eastern and western borders are defined by Eastern Ave. and Western Ave., respectively. The District experiences a subtropical climate with average temperatures ranging from 39°F in January to 81°F in July. The mean annual precipitation is 30.7 inches. The city is home to 672,228 residents (US Census 2012).

DDOT monitors 143,000 street trees within the District planting, pruning, and removing them as needed. One aspect of this monitoring is maintaining a continuously updated list of trees condemned for removal events. Trees are removed within one to nine months after being condemned, usually due to declining health, poor structure, or site conflicts. At any given time, between 1,400 and 2,100 trees are on the condemned tree list (personal communication, Corletta 2016).

3.1.1 Sampling Design

DDOT provided us with a list of standing street trees condemned for removal on March 18, 2016. This list was used as the basis for our study design and sampling frame. First, we constrained the sampling frame to species and DBH sizes that would merit attention for timber recovery and salvage. We limited our study to only hardwood species and condemned trees large enough to be converted into saw logs, i.e., trees larger than 12 inches in diameter at 4.5 feet above ground line (DBH). Trees larger than 12 inches DBH are more likely to have enough volume and value to merit recovery (Michigan State University 2007). These constraints whittled the sampling frame down to 711 hardwood trees. From there, we selected the six most abundant species, resulting in 486 trees: *Quercus palustris (139), Quercus rubra (84), Quercus phellos (45), Acer rubrum (81), Acer platanoides (73),* and *Acer saccharum (64)*. A second sampling frame was devised comprising street trees of the same species composition and minimum DBH threshold, but not condemned for removal.

We obtained a list of non-condemned trees from the open archives data set provided by DDOT on the District's website. The list contained about 143,000 street trees. A link to a map showing all street trees in the District can be found below.
(https://www.arcgis.com/home/item.html?id=fea6079cf9bc4310a8b6c94f8c2bf1da)

From the list of 143,000 trees, 17,021 met our criteria: size, condition, and species for sampling. Therefore, the metrics were the same as the condemned trees. All of these trees had been denoted as “good condition” in the inventory by DDOT arborists and were above twelve inches in DBH. Furthermore, all trees sampled from the non-condemned list were chosen from the lowest density housing zone: R-1 (Appendix D) which includes detached homes on larger plots distant from one another.

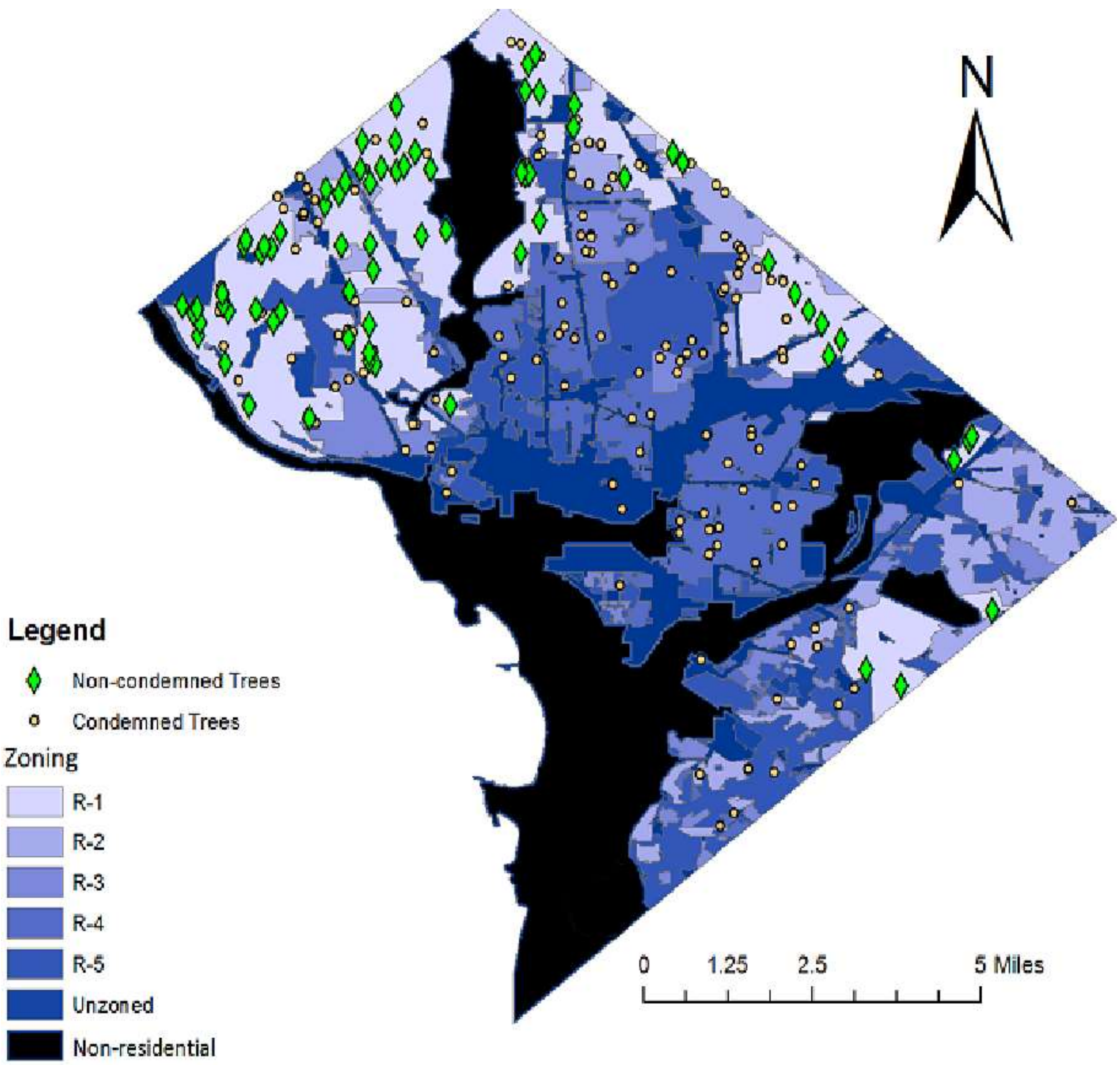

Figure 3.1. Map of Washington, DC showing the location of street trees sampled in this study. Condemned street trees are those identified for removal by the Washington, DC Urban Forestry program due to issues with tree health, safety, or site compatibility. Non-condemned street trees are represented by "good condition" trees. The base map is color coded by land use zoning, which was used in stratification of the street tree sampling.

We anticipated that land-use zoning might influence timber quality, quantity, and salvage feasibility of the District's street trees. Therefore, we stratified the study area into six different land use zones based on the District's zoning map (Table 3.1). The overwhelming majority

(92%) of trees in the sampling frame fell into areas zoned as residential. There were five subcategories of residential zoning, each differing in housing density. All remaining land area occupying non-residential land uses (e.g., commercial and industrial) was combined into one zone. Each of the six zones contained between 10% and 40% of the condemned trees in the sampling frame. Land use zones can be seen in Appendix D. Crossing each of the six zones with each of the six species yielded 36 combinations in which we attempted to obtain a sample size of five condemned trees. Due to uneven distribution of condemned trees across the species-zone combinations, we were unable to obtain five sample trees for every combination. Thus, the total sample for condemned trees was 149 trees, ranging from 20 to 30 trees per species and from 15 to 30 trees per land use zone. For the non-condemned trees, a sample size 72 was selected, all from the lowest-density (R-1) land use zone (Fig 3.1). We measured 12 trees from each of the top six species. We anticipated that this would give us the most favorable comparison between condemned and non-condemned trees because trees in the low-density zone would have the best growing environment possible.

Table 3.1. Sampling breakdown, street trees that have been slated for removal by the Washington, DC Urban Forestry program due to issues with tree health, safety, or site compatibility. Data shown are for the six most common tree species and are broken down by land-use zoning type.

	Acer platanoides	**Acer rubrum**	**Acer saccharum**	**Quercus palustris**	**Quercus phellos**	**Quercus rubra**	**Total**
Land-use Zone							
R-1	5	5	5	5	5	5	30
R-2	5	5	5	5	3	5	28
R-3	1	5	4	5	0	4	19
R-4	5	5	5	5	5	5	30
R-5	4	5	5	5	3	5	27
Non-Residential	1	1	0	5	4	4	15
Total Condemned	21	26	24	30	20	28	149
Total Non-Condemned	12	12	12	12	12	12	72

Prior to drawing the stratified random sample, all trees in the sampling frame were geocoded into ArcMap using their individual street address. In ArcMap, we were able to combine a layer of trees with a layer of city zones, thus determining where the trees were located and which city zone they were in. We then made lists with each category of trees in zones by species. For categories with more than five trees in the sampling frame, we randomly selected five trees using the random function in Microsoft Excel, which assigned random numbers to each tree. From the randomized list, we selected the trees with the five highest random numbers as our sample. In the event that a tree had been removed or had an incorrect address at the time of our field visit, we selected the next highest-value tree on the list. For non-condemned trees, we applied the same random sampling technique except that we increased the sample size from five trees to twelve trees to reduce sampling error.

3.2 Field Data Collection

We adapted traditional forest mensuration and timber grading techniques to develop a field protocol. We tested it in Washington, DC to make appropriate modifications prior to data allocation. All field data were collected in the District between March and May 2016 by a team comprising one graduate student and one research technician. Physical measurements and visual ratings were made for each sampled tree and its surrounding environment. Field data were then compiled into a spreadsheet, screened for errors and omissions, and subjected to statistical analysis.

3.2.1 Timber Grading

All aspects of timber grading were performed on the intact standing street trees. To determine the quality of timber, we used a modified version of the USFS timber grading protocol (Rast et al. 1973). We evaluated each tree separately by first dividing the tree stem into four equal quarters (tree faces). We then assessed the second worst face determined by presence of defects including but not limited to knots, decay, scars, and other imperfections that would detract from the amount of clear wood. When grading standing timber, the worst face is excluded to better replicate sawmill grading pactices where it is assumed the worst face of the log is face down on the ground hidden from the timber grader (Rast et al. 1973).

Assessing the second worst face, we then determined the log quality by measuring the length of the log, the DBH, amount of clear (wood without any defects of at least two feet), and amount of number of visible defects using a range laser, DBH tape, and a hardwood grading guide (Rast et al. 1973). The hardwood grading is based on a visual examination in which the grader counts the number of knots and scars and compares the amount of wood with said defects to the rest of the log. Due to the difference in growth of urban trees compared to forest trees, we made some modifications, accepting log lengths as low as six feet (Lempicki and Cesa 2000) compared to what is commonly accepted: eight feet or sixteen feet (Rast et al. 1973). Instead of only measuring trees with a well-defined sixteen feet or eight feet log, we gave value to logs that met the requirements for a grade. For example, a tree that had six feet of clear wood in a seven-foot log would be overlooked in the forest. However, if the DBH was large enough, that six feet of clear wood could be used in a low-grade log because it met the grading requirements, thus having value. A tree with a higher percentage of clear wood, higher DBH, and fewer defects yields a higher quality log. Because it is a culmination of factors, there is no definite cutoff for each variable between log grades. Therefore, one must reference USFS log protocols for each tree and measure multiple attributes.

3.2.2 Timber Volume

Urban trees take on a different form from their rural counterparts, often resulting in lower crown height and faster growth in diameter (Wilson 1990). Therefore, the conventional means of measuring volume do not apply. Instead of considering the taper class associtated with forest-grown trees assuming the top diameter of the log is a certain amount smaller than the DBH—in our area usually 21% smaller than the DBH, we measured the top diameter of 41 trees in our sample creating a subsample. We then created a multiple regression equation—DBH and log height as the independent variables and top diameter as the dependent variable, which we applied to the rest of the sample trees. This provided a more accurate top diameter than the forest-grown taper classes, which we were then able to use to determine the volume of trees.

To calculate volume, we measured two of the trees dimensions: log lengths and DBH. The log length is the length of the trunk of which can be extracted for timber usually between the root flare and the tree crown. We used a range laser to determine the log length. We used a DBH tape to accurately measure the trees' DBH. However, timber volume excludes bark, thus the DBH of inner bark need to be measure or in our case the smaller end's diameter. Inner bark could not be measured directly because all logs were part of standing timber. To account for this issue, we used inner bark calculations to determine the inner bark (Smith 1985). The calculation used was not specific to individual species but an amalgam of many hardwood species. Once the smaller diameter was determined, we calculated the total log volume using the international ¼-inch log rule, selected for its high accuracy and common use (Avery and Burkhart 2002). The international log rule has already been applied to the urban setting (Cesa 2003). The log volume equation is as follows:

$$\text{Board Feet International} = 0.04976191 \times L \times D^2 + 0.006220239 \times L^2 \times D - 0.1854762 \times L \times D + 0.000259176 \times L^3 - 0.01159226 \times L^2 + 0.04222222 \times L$$

Where: D = Diameter

L = Log Length

To determine the timber volume for the District overall, we extrapolated the sample to the overall street tree population of the six-most-common-condemned street trees. Courtesy of DDOT, we obtained a list of open removals in April—used in our sampling frame—in which we determined the proportion of the top six species to the overall species population for DBH classes in six inch intervals. We also obtained another data set from DDOT for all tree removals in the prior year. We took the proportion of the top six species from the open-removal list and applied it to the data set of all trees removed in a given year to estimate the tree population of condemned street trees for the top six species. The estimation for the overall volume was calculated along with 95% confidence intervals for the mean of trees in each DBH class and the total for each DBH class.

3.2.3 Timber Salvage Feasibility

In addition to assessing timber quality and quantity, we also evaluated timber salvage feasibility of each sampled street tree. This was not an assessment of economic feasibility of salvage, but rather logistical feasibility, based on characteristics of the tree and its surroundings. We identified eleven criteria, based on literature review and discussions with arboriculture experts that affect the ease of tree removal as it relates to public safety, ease of equipment access, space for felling timber, integrity of the tree trunk, and presence of infrastructure and other obstacles (Appendix C). These obstacles include infrastructure presence: signs, fences, utility poles; and logistical interferences: vehicle and pedestrian traffic. These criteria were assembled into a scoring matrix that was assessed in the field. We rated the criteria numerically by observing each tree and its surroundings. The rating for each criterion ranged from a value of one (indicating that there were no impediments to salvage associated with the criterion) to a value of four (indicating that there were significant impediments to salvage associated with the criterion). The scores for the criteria were then summed for a total salvage feasibility score. The absolute value of the score for each tree ranged from 11 to 44.

3.2.4 Tree Metal Presence

We anticipated that superficial metal objects (e.g., office staples, nails, wire, stakes, signage) would be commonly encountered in street trees, which diminishes the value of saw timber. We evaluated the prevalence of superficial metal objects by tallying all visible objects on the surface of the tree trunk within three feet above and below breast height (4.5 feet above ground line). We categorized the metal objects into three groups: office staples (the most common form of metal), nails, and all other items. The last category included metal pieces larger than nails that may have been more hazardous to a sawmill (e.g., metal stakes). We were not able to assess metal objects embedded below the surface of the tree trunks since we only used visual methods for metal detection.

3.3 Statistical Analysis

With regard to timber characteristics, we conducted three types of statistical analysis of the data collected from the field study on tree measurements. First, we generated descriptive statistics for the District as a whole as well as individual zoning areas, and for each individual species. Second, since we stratified the sample by zoning species and removal status we created two-way ANOVA tables across the six distinctive zoning categories: residential zones 1-5 and the combination of the other zones (commercial, industry, and mixed use), the six most abundant tree species (*Quercus palustris, Acer platanoides, Acer rubrum*, *Acer saccharum, Quercus rubra*, and *Quercus phellos),* and tree status (condemned and non-condemned trees). ANOVA tables allowed us to test our hypotheses about which areas have the most available timber, most trees, highest quality timber, and easiest removability. Third, we used Chi-square to determine the frequencies outputs for log presence, log distribution, and metal presence of both all metal and metal excluding office staples. Like the ANOVA testing, we measured our output variables by tree removal status, land-use zone, species, and grade. When the assumptions of the Chi-square were not met as in the case of log distribution and metal without office staples, we used a Fischer's Exact Test to delineate the difference between various independent variables.

CHAPTER 4 – RESULTS

4.1 Introduction

The sample size was 149 for condemned trees, and 72 for non-condemned trees. Originally we planned for a condemned-tree sample size of 160. However, several trees planned for sampling had been removed before measuring took place. Since of the stratified sampling methods, there were not enough non-sampled trees to replace missing trees, thus reducing our sampling frame (Figure 4.1).

All sampled trees were individually measured yielding results for tree characteristics: DBH (inches), logs (both presence and grade distribution) timber volume, removal feasibility (for trees with logs), and presence of metal. All of these measured characteristics became output variables and were compared across tree removal status, land-use zones, species, and log grade. Grade was reported in frequency of logs and grade distribution which encompassed four grades: factory grades 1, 2, and 3; and cull (Figure 4.1). Trees with the presence of logs were characterized by DBH distribution, log length and defect presence on a per log basis. Volume of timber was calculated for trees with a presence of logs and reported in board feet. Trees with logs were then appraised for their ease of removal through a feasibility rating ranging from 11-44. Finally, trees with a presence of logs were visually examined for the presence of metal including all metal and metal excluding office staples.

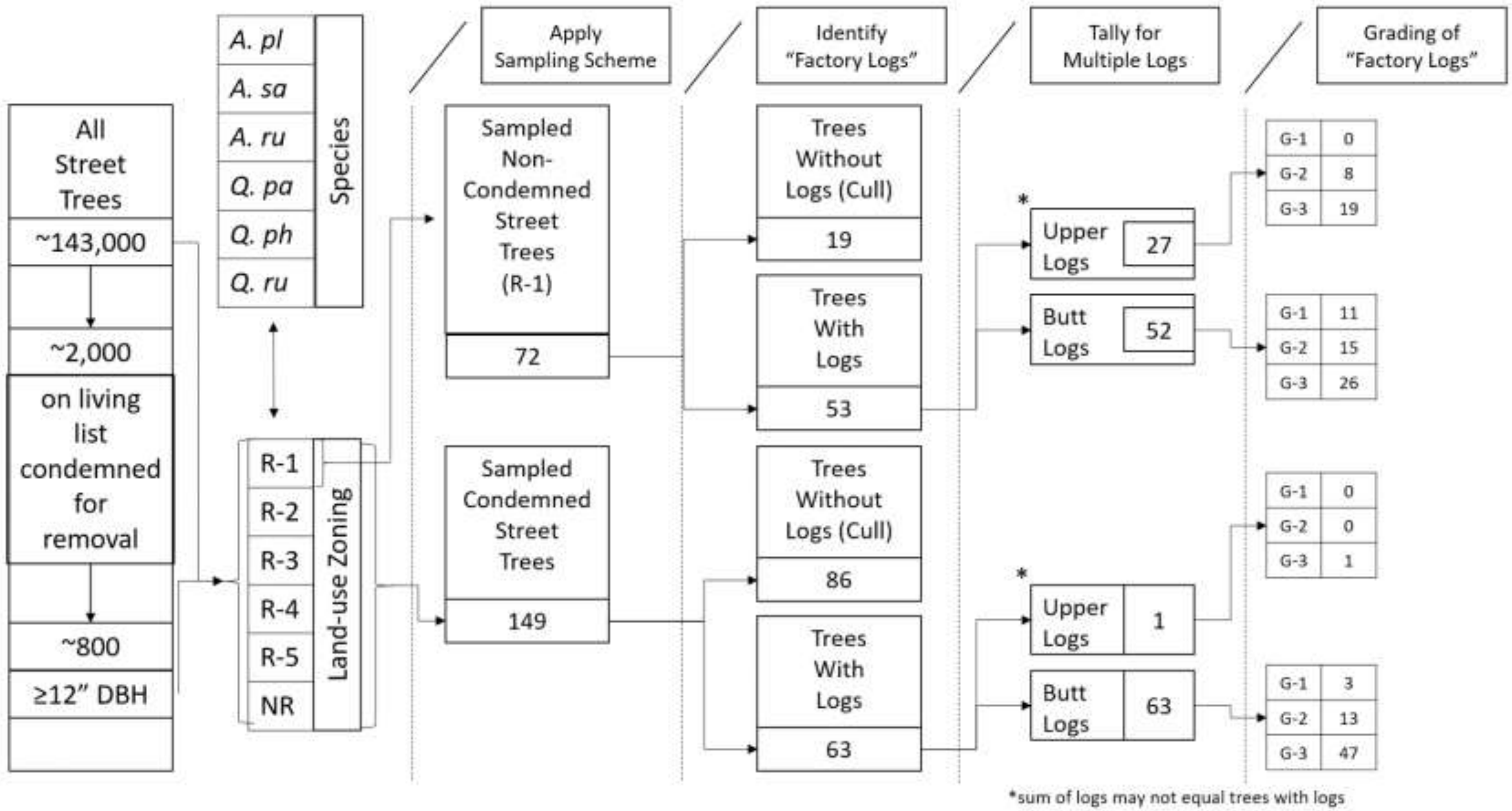

Figure 4.1. Conceptual map of the Washington, DC street tree population that was sampled in this study. The map tracks the population though the sampling scheme and log grading process to arrive at the intermediate sample sizes used in the study for the top six species: *Acer platanoides, Acer saccharum, Acer rubrum, Quercus palustris, Quercus phellos, and Quercus rubra.*

4.1.1 Trunk Diameter (DBH) Distributions in the Sample

All sample tree DBH measurements were taken to help determine the volume of a log (if present) and also to help describe the overall size of trees sampled in this study. The DBH distribution did not follow a normal distribution; therefore, we performed a $\log_{10}$ transformation for our statistical analysis. There was virtually no distinction between removal status (p=0.5712). Condemned trees had a slightly higher mean DBH in inches of 23.0 compared to 22.3 of non-condemned trees. There was also no detectable difference across land-use zones (p=0.5702), which ranged from a low of 21.2 in R-2 to a high of 25.3 in R-5. Measuring DBH across species, an ANOVA test revealed a very significant difference across species. The range was much more significant for species than land-use zone; on the low end, *A. platanoides* had an average DBH of 16.4, on the high end, *Q. phellos* had an average DBH in inches of 30.7. Because there was a significant difference, a pairwise analysis was conducted indicating *Q. phellos* and *Q. rubra* were significantly different from *Q. palustris*, *A. saccharum, A. rubrum,* and *A. platanoides*. *A. platanoides* had a DBH in inches so small it was significantly different from all other species (note the different letter denotations in table 4.1 under the pairwise column). There was no significance between log grades (p=0.0973). However, there was an obvious trend in the data: as the grade increased, the DBH increased (table 4.1).

Table 4.1. Trunk diameter (4.5 feet above ground line) of all street trees sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Statistical significance of group main effects using ANOVA are denoted with p-values. Where main effect was significant, group level differences using all pairwise comparisons are denoted with letter scripts.

		Trunk Diameter (inches)						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.5712)								
Condemned	149	12.0	23.0	20.6	49.7	8.14	0.354	A
Non-condemned	72	12.2	22.3	20.6	44.5	7.58	0.335	A
Land-use zone (p=0.5702)								
R-1	30	12.0	22.5	20.2	42.9	8.14	0.362	A
R-2	28	12.0	21.2	20.1	37.2	6.77	0.319	A
R-3	19	12.1	23.1	22.2	44.5	7.99	0.346	A
R-4	30	13.0	23.3	21.9	39.1	6.80	0.292	A
R-5	27	12.6	25.3	22.4	49.7	11.5	0.455	A
Non-residential	15	14.1	22.2	20.0	34.8	5.76	0.259	A
Common species (p<0.0001)								
Acer platanoides	21	12.0	16.4	25.2	25.2	3.61	0.220	C
Acer rubrum	26	12.9	23.0	49.7	49.7	8.28	0.360	B
Acer saccharum	24	12.3	19.3	30.3	30.3	4.33	0.224	BC
Quercus palustris	30	13.4	20.4	30.9	30.9	4.44	0.218	B
Quercus phellos	20	12.0	30.7	49.2	49.2	9.64	0.314	A
Quercus rubra	28	14.2	28.2	49.5	49.5	7.78	0.276	A
Log grade (p=0.0973)								
Grade 1	3	26.3	32.4	28.1	42.9	9.10	0.281	A
Grade 2	14	16.6	23.3	20.9	39.1	6.65	0.285	A
Grade 3	47	12.1	24.2	21.6	49.2	8.23	0.340	A
Cull	86	12.0	21.9	21.9	49.7	8.09	0.369	A

4.1.2 Frequency of Logs in Trees Sampled

Sample trees varied by log presence in butt logs across removal status and species. Only one upper log existed in the condemned trees making statistical comparisons between land-use zones and species irrelevant. A Chi-square analysis revealed a statistical difference between the presence of butt logs in condemned trees (42%) compared to non-condemned trees (74%) ($p<0.0001$). There was no statistical difference in the frequencies between different land-use zones ($p=0.1200$). However, there was still a large range between the land-use zone frequencies: R-3 had the highest frequency, 68% of the trees having a log and non-residential had the lowest frequency of log presence of logs (27%). R-1 had the second highest frequency of butt logs (50%) but the most butt logs per zone (15) due to its larger sample size of 30 (Table 4.2).

There *was* a statistical difference across species ($p=0.0445$). *Q. phellos* had the highest frequency of logs per tree (60%), while *A. rubrum* had the lowest frequency of logs per tree (23%) and the lowest total log count (6). *Q. palustris* had the second highest frequency of logs (57%) but the highest amount of logs of trees sampled (17) which demonstrated a wide distribution range across species.

The majority of the upper logs were concentrated in non-condemned trees (18). Most of these trees had a butt log present. However, one tree was found in which an upper log existed without a corresponding butt log (Table 4.2).

Table 4.2. Count and frequency of logs in street trees sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grades. We ran a chi-square analysis test comparing the presence of butt logs. Significant differences ($p < 0.05$) between status, land-use zone, species, and grades are denoted in bold.

	Total Trees Sampled	**Trees with Butt Log Only**		**Trees with Upper Log Only**		**Trees with Butt and Upper Log**		**Total Logs**
	(n)	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**	**(%)**	**(#)**
Removal status (p<0.0001)								
Condemned	149	63	42	0	0	1	0	64
Non-condemned	72	53	74	1	1	18	25	80
Land-use zone (p=0.1200)								
R-1	30	15	50	0	0	0	0	15
R-2	28	10	36	0	0	0	0	10
R-3	19	13	68	0	0	0	0	13
R-4	30	10	33	0	0	1	3	11
R-5	27	10	37	0	0	0	0	10
Non-residential	15	4	27	0	0	0	0	4
Species (p=0.0445)								
Acer platanoides	21	8	38	0	0	0	0	8
Acer rubrum	26	6	23	0	0	1	4	7
Acer saccharum	24	7	29	0	0	0	0	7
Quercus palustris	30	17	57	0	0	0	0	17
Quercus phellos	20	12	60	0	0	0	0	12
Quercus rubra	28	13	46	0	0	0	0	13

4.1.2 Log Grade Distribution

A Chi-square analysis revealed no statistical difference across independent variables when comparing log distribution; this is most likely the result of a low sample size. However, trends in the data were still apparent (Table 4.3). The majority of logs were Grade 3 in the condemned trees (73.44%) and in the non-condemned trees (56.25%). The overall distribution of logs was marginally significant (p=0.0554). The difference between land use types was not statistically significant (p=0.6864). The majority of all logs were Grade 3 in each of the zones. Zone 1 had the highest frequency of the Grade 1 logs (13.33%), Zone R-5 had the highest frequency of Grade 2 (40%), and Zone 2 had the highest frequency of Grade 3 logs (80%).

There was also no statistically significant difference between the distribution of log grades across different species (p=0.2986). The majority of the logs in each species was in the Grade 3 class. All of the *A. platanoides* logs were Grade 3 quality. *Q. palustris* had the highest frequency of Grade 2 logs and *Q. rubra* had the highest frequency of Grade 1 logs (14.29%). Overall, the *Quercus* species tended to have higher value logs than the *Acer* species.

4.2 Characteristics of Trees with Logs Present

4.2.1 DBH Distribution of Sampled Trees with the Presence of Logs

All sample trees with the presence of logs had DBH measured in inches and analyzed to help determine the volume of a log to characterize the size of trees. The data did not follow a normal distribution. Therefore, a log transformation was performed before we conducted our statistical analysis. There no difference between removal status (p=0.3055); condemned trees were on average an inch larger than non-condemned trees: 24.4 verses 23.0 respectively (Table 4.4). There was also no difference across land-use zones (p=0.7286), which ranged from a low of 21.4 in non-residential to a high of 25.8 in R-4. Across species, an ANOVA test revealed a very significant difference ($p<0.0001$). The range was much more significant *A. platanoides* had the lowest mean DBH of 17.9 and *Q. phellos* had the highest mean DBH of 33.5 inches. Since a significant main effect existed, a pairwise analysis was made indicating that *Q. phellos* was significantly larger than all other species with the exception of *A rubrum*. *A. platanoides* had a DBH so small, it was significantly different from all other species. There was no statistical significance between log grades (p=0.2006). However, there was an obvious trend: as the grade increased, the DBH increased.

4.2.2 Log Length

An ANOVA test revealed that the difference of log lengths—another major aspect for characterizing logs—followed a similar trajectory with that of the DBH (table 4.5). There was no statistical difference between tree removal status or land use zone (p=0.4868 and p=0.9479, respectively). Condemned logs were less than a foot shorter on average than their non-condemned counterparts. Land-use zone had an effect on log length zone. The p-value comparing the different species was 0.0284 indicating a significant difference. *Q. phellos* had the longest mean logs (12.1 feet) closely followed by *A. saccharum* (11.0) while *A. rubrum* had the lowest mean log length (7.9 feet). There was also a significant difference between different grades and the log length (p=0.0136). A pairwise analysis revealed logs were significantly different from Grade1 to other grades. However, grades 2 and 3 were not significantly different from each other.

Table 4.3. Grading of logs (butt logs and upper logs) in street trees sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone and common species. A fisher's exact test was used to detect log distribution differences among species. Significant differences ($p < 0.05$) between status, land-use zone, species and grades, denoted in bold.

	Total Logs (#)	**Grade 1 Logs (#)**	**Grade 1 Logs (%)**	**Grade 2 Logs (#)**	**Grade 2 Logs (%)**	**Grade 3 Logs (#)**	**Grade 3 Logs (%)**
Removal status (p=0.0554)							
Condemned	64	3	5	14	22	47	73
Non-condemned	80	11	14	24	30	45	56
Land-use zone (p=0.7988)							
R-1	15	2	13	2	13	11	73
R-2	10	0	0	2	20	8	80
R-3	13	0	0	2	15	11	85
R-4	12	1	8	3	25	8	67
R-5	10	0	0	4	40	6	60
Non-residential	4	0	0	1	25	3	75
Species (p=0.2669)							
Acer platanoides	8	0	0	0	0	8	100
Acer rubrum	6	0	0	1	17	5	83
Acer saccharum	7	0	0	2	29	5	71
Quercus palustris	17	0	0	6	35	11	65
Quercus phellos	12	1	8	4	33	7	58
Quercus rubra	14	2	14	1	7	11	79

Table 4.4. Trunk diameter (4.5 feet above ground line) of street trees containing a butt log sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Statistical significance of group main effects using ANOVA are denoted with p-values. Where main effect was significant, group level differences using all pairwise comparisons are denoted with letter script.

		Trunk Diameter (inches)						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.3055)								
Condemned	63	12.1	24.4	21.7	49.2	8.05	0.330	A
Non-condemned	53	12.2	23.0	21.4	44.5	7.86	0.343	A
Land-use zone (p=0.7286)								
R-1	15	16.0	26.8	26.3	42.9	8.12	0.303	A
R-2	10	15.4	22.6	20.8	37.2	6.19	0.274	A
R-3	13	12.1	24.0	22.9	44.5	8.11	0.338	A
R-4	11	13.2	23.3	21.6	39.1	7.18	0.308	A
R-5	10	16.2	25.8	21.4	49.2	11.16	0.433	A
Non-residential	4	14.1	21.4	21.5	28.5	6.74	0.307	A
Species (p<0.0001)								
Acer platanoides	8	12.1	17.1	17.8	20.6	3.50	0.205	D
Acer rubrum	6	20.7	26.8	22.2	44.5	9.25	0.345	ABC
Acer saccharum	7	16.3	21.2	19.8	30.3	4.60	0.217	BCD
Quercus palustris	17	14.1	21.0	19.8	27.3	3.84	0.183	C
Quercus phellos	12	17.2	33.5	33.4	49.2	9.13	0.273	A
Quercus rubra	13	15.4	25.8	26.3	37.5	6.33	0.245	B
Log grade (p=0.2006)								
Grade 1	3	26.3	32.4	28.1	42.9	9.10	0.281	A
Grade 2	14	16.6	23.3	20.9	39.1	6.65	0.285	A
Grade 3	47	12.1	24.2	21.6	49.2	8.23	0.340	A

Table 4.5. Log length (butt log and upper log) of street trees containing a butt log sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Statistical significance of group main effects using ANOVA are denoted with p-values. Where main effect was significant, group level differences using all pairwise comparisons are denoted with letter scripts.

		Log Length (feet)						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.4868)								
Condemned	64	6.0	10.8	10.3	16.0	2.70	0.251	A
Non-condemned	80	6.0	11.1	10.0	16.0	2.76	0.248	A
Land-use zone (p=0.9479)								
R-1	15	7.0	11.0	10.0	16.0	3.48	0.316	A
R-2	10	7.0	10.6	10.5	16.0	2.59	0.244	A
R-3	13	7.0	10.7	12.0	16.0	2.50	0.233	A
R-4	12	6.0	10.9	11.0	16.0	3.15	0.289	A
R-5	10	7.5	10.1	10.0	13.0	1.80	0.179	A
Non-residential	4	9.0	11.5	12.3	12.5	1.68	0.146	A
Common species (p=0.0284)								
Acer platanoides	8	7.5	10.6	10.3	16.0	2.63	0.248	ABC
Acer rubrum	6	6.0	7.9	7.8	11.0	1.69	0.214	C
Acer saccharum	7	7.0	11.0	12.0	16.0	3.00	0.273	AB
Quercus palustris	7	9.0	12.1	12.0	16.0	2.30	0.190	A
Quercus phellos	17	8.0	11.1	12.0	16.0	2.26	0.203	AB
Quercus rubra	12	7.0	10.0	8.5	16.0	2.99	0.299	BC
Log grade (p=0.0136)								
Grade 1	3	12.5	14.8	16.0	16.0	2.02	0.136	A
Grade 2	14	7.5	11.2	11.0	16.0	2.67	0.238	B
Grade 3	47	6.0	10.4	10.0	16.0	2.55	0.246	B

4.2.3 Superficial Defects by Potential Logs of All Trees

The evaluation of defects was included in the grading of the logs. Defects on the potential log made the wood "unclear" meaning it could not be used as saw-timber (factory logs) and would subtract from the quality of timber. Unclear wood was measured as a percentage of the overall log. There were no statistical differences across any of the independent variables: removal status, land-use zone, or grade. However, trends in the data persisted (table 4.6). Condemned had an average of over a percent more unclear wood than non-condemned trees. R-1 had the lowest average of unclear wood per log (16%) and non-residential had the highest average unclear wood per log (18.8 %); a high p-value (0.5688) suggested no statistical difference between the different zones.

There was a marginally significant difference when comparing amount of defects across species (p=0.0631). Though the difference is not definitive, the range varies drastically across the difference species. *A. saccharum* had the highest average unclear wood (30.7%). *A. rubrum* and *Q. rubrum* both had the lowest average unclear wood (15%) each.

Due to a low sample size, there was not a statistical difference between log grades; however, a trend in the data suggest that as the log -grade quality increased, the amount of unclear wood decreased. Grade 3 had the highest average amount of unclear wood (19.4%) and Grade 1 had the lowest amount of unclear wood (11.7%).

Table 4.6. Superficial defects on street trees sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Significant differences ($p < 0.05$) between status, land-use zone, species and grades are denoted in bold.

		Superficial Defects (% of Trunk Surface)						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.7060)								
Condemned	64	0	18.3	15.0	60	11.76	0.643	A
Non-condemned	80	0	16.9	15.0	45	9.63	0.570	A
Land-use zone (p<0.5688)								
R-1	15	0	16.0	15.0	30	8.90	0.556	A
R-2	10	10	17.0	17.5.	35	7.89	0.464	A
R-3	13	5	17.6	20.0	60	17.58	0.999	A
R-4	12	5	16.3	15.0	30	9.80	0.601	A
R-5	10	10	18.0	12.5	50	13.00	0.722	A
Non-residential	4	10	18.8	17.5	30	8.54	0.454	A
Species (p=0.0631)								
Acer platanoides	8	10	20.6	20.0	35	9.04	0.439	A
Acer rubrum	6	5	15.0	12.5	30	8.94	0.596	A
Acer saccharum	7	10	30.7	20.0	60	21.68	0.706	A
Quercus palustris	17	0	17.4	15.0	50	17.35	0.997	A
Quercus phellos	12	0	16.3	17.5	30	9.08	0.557	A
Quercus rubra	14	5	15.0	12.5	30	7.60	0.507	A
Log grade (p=0.4048)								
Grade 1	3	5	11.7	10.0	20	7.64	0.653	A
Grade 2	14	0	16.1	15.0	50	12.43	0.772	A
Grade 3	47	0	19.4	15.0	60	11.73	0.605	A

4.2.4 Urban Timber Volume

To determine the difference in volume by zones and species, ANOVAs were conducted. However, the data did not follow a normal distribution. To correct for this, a log transformation was performed leading to a normal distribution of the data which could then be analyzed. There was not a statistical difference between the removal status (p=0.9324), Non-condemned trees had more volume than condemned trees: 183.1 board feet per tree versus 217.9 board feet per tree respectively.

There was no significant difference significance between different land use zones (p=0.6697). However, the range was substantial. The means varied from a high of 225.5 board feet in non-residential areas to 130.9 board feet per tree (table 4.7). However, species did have a significant difference in volume. Across all species there was as a statistical difference (p value <0.0001). *Q. phellos* had an average volume of 373.3 board feet of timber per tree and was statistically larger than each of the other species when pairwise analysis was conducted. Further investigating species pairwise, *Q. rubra* had a significant higher volume than *A. platanoides* (p=0.0157) and *Q. palustris* (p=0.0458). *A saccharum* had a significantly larger volume than *A. platanoides* (p=0.0458). *A. platanoides* had the lowest volume (79.1 board feet per tree) and was statistically different from all other species except *A. saccharum.*

Log volumes were divided into four classes (G1, G2, G3, and cull). All cull logs were not included in comparing volume because they automatically had no volume. Between the three different remaining classes, a p-value of 0.0280 demonstrated a significant difference between the logs. Grade 1 had the largest volume per tree (400.4 board feet per tree) and Grade 2 had the smallest volume (160.8 board feet per tree). When a pairwise analysis was conducted, Grade 1 had a significant difference between Grade 2 (p=0.0144) and Grade 3 (p=0.0119). However, there was no detectable difference between Grade 2 and Grade 3 (p=0.9132).

Butt log volume varied drastically between the different DBH classes. DBH is one of the primary variables used to calculate the volume, thus as the DBH increased so did the volume. The smallest average volume average per tree occurred in the 12-18 DBH size class: 51 board feet. The largest average occurred in the 42.1 DBH size class and above: 426 board feet.

The total board feet ranged from 3684 board feet in the 12-18 DBH class to 8816.5 board feet in the 36.1 to 42 DBH classes. Unlike the average DBH, the total volume does not necessary increase as the DBH classes increase. Different DBH classes have vastly different sample sizes resulting in varying total estimates. The total volume generated for a given year in DC was estimated to be 36,500 with the confidence intervals between 22,500.7 to 53,156.7.

The confidence intervals also vary greatly between different DBH class distributions. The smallest confidence interval is found in the smallest DBH class. The largest confidence interval is found in the largest Diameter class, in which the confidence interval is over 100% of the estimator.

Table 4.7. Butt log volume of street trees containing a butt log sampled in Washington, DC to determine timber characteristics. Feasibility scores ranged from 11 (more feasible) to 44 (less feasible). Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Statistical significance of group main effects using ANOVA are denoted with p-values. Where main effect was significant, group level differences using all pairwise comparisons are denoted with letter scripts.

		Butt Log Volume (board feet)						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.9324)								
Condemned	63	36.0	183.1	127.6	688.3	147.66	0.806	A
Non-condemned	53	31.1	217.9	124.9	960.9	216.34	0.993	A
Land-use zone (p=0.6697)								
R-1	15	65.7	224.7	218.5	636.3	156.91	0.698	A
R-2	10	71.1	153.2	109.1	472.6	122.70	0.801	A
R-3	13	36.0	154.6	138.1	418.3	99.59	0.644	A
R-4	11	38.7	168.0	137.2	344.1	106.50	0.635	A
R-5	10	65.6	225.5	108.5	688.3	244.82	1.086	A
Non-residential	4	44.8	130.9	118.7	241.6	87.25	0.666	A
Species (p<0.0001)								
Acer platanoides	8	36.0	79.1	82.3	121.6	32.29	0.408	D
Acer rubrum	6	87.3	172.9	122.8	418.3	124.42	0.710	BC
Acer saccharum	7	85.1	124.3	98.1	207.0	46.61	0.375	BCD
Quercus palustris	17	44.8	123.3	110.5	267.1	62.72	0.509	CD
Quercus phellos	12	83.7	373.3	321.5	688.3	210.27	0.563	A
Quercus rubra	13	71.1	186.4	215.6	332.0	90.64	0.486	B
Log grade (p=0.0280)								
Grade 1	3	232.9	400.4	332	636.3	210.23	0.525	A
Grade 2	14	65.6	160.8	110.5	449.5	117.44	0.730	A
Grade 3	47	36.0	175.5	127.6	688.3	143.49	0.818	A

Table 4.8. Butt log volume of street trees containing a butt log sampled in Washington, DC to determine total timber volume from trees removed in the prior year between May 2015 to May 2016. Trees condemned for removal are further broken down by land-use zone, common species, and log grade.

Log Diameter	N[1]	n[2]	Mean Butt Log Volume (board feet)	95% CI of Mean Butt Log Volume (board feet)	Standard Deviation of Mean	Total Butt Log Volume (board feet)	95% CI of Total Butt Log Volume (board feet)
12.0–18.0 in.	72	11	51.1	46.7 – 55.5	16.7	3684.0	2874.0 – 4494.1
18.1–24.0 in.	72	25	76.9	71.1 – 82.7	26.5	5554.4	4751.4 – 6357.5
24.1–30.0 in.	40	15	158.5	149.9 – 167.2	52.2	6317.5	5166.6 – 7468.4
30.1–36.0 in.	20	5	222.6	213.1 – 232.1	46.1	4403.7	3271.4 – 5536.0
36.1–42.0 in.	30	4	292.3	282.1 – 302.5	49.6	8816.5	6437.3 – 11195.6
42.1 in. and greater	18	3	426.0	384.8-467.2	230.2	7729.4	0-18105.2
Total	252	63	NA	NA	NA	36505.5	22500.7-53157.8

[1] The population of trees in each DBH class.

[2] The trees sampled in each DBH class.

4.2.5 Removal Feasibility Scores

The feasibility scores had the possibility to be ranked from 11 to 44. The higher scores denoted the more difficulty of log extraction meaning the log salvage was less feasible. The data followed a normal distribution, which allowed all ANOVAs and a *t*-test to be performed without any transformations. There was no statistical difference between the removal statuses (condemned trees and non-condemned) (p=0.8239). The ranges between the different removal statuses were also virtually the same 15 to 33 in condemned trees and 15 to 34 in non-condemned trees averaging 23.8 and 23.9, respectively.

There was a statistical difference between different land-use zones (p=0.0257). R-5 had the lowest average removal feasibility score (20.9) while the R-3 zone had the highest average removal feasibility score (26.5). R-5 had the lowest minimum feasibility ranking (15) and R-3 had the highest maximum feasibility rankings. Both R-1 and "Non-residential" had the lowest maximum feasibility. Non-residential had the least amount of variation with the lowest coefficient variance (0.083). R-4 had the greatest difference between the minimum value and maximum value and subsequently the highest coefficient of variance (0.2109). Comparing the different zones, R-3 had the highest feasibility score but only differed statistically with R-1, and R-4.

There was no statistical difference in feasibility across species (p=0.6909). *A. saccharum* had the highest mean feasibility score (26) and *A. platanoides* had the lowest mean removal feasibility score (23). There was also no significant difference between the different log grades (p=0.1574). However, a trend in the data suggest an inverse relationship between feasibility score and log quality; as grade increased, the feasibility score decreased.

Table 4.9. Salvage feasibility of street trees sampled in Washington, DC to determine timber characteristics. Scores range from 11 to 44. The lesser the score, the higher the feasibility. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. Statistical significance of group main effects using ANOVA are denoted with p-values. Where main effect was significant, group level differences using all pairwise comparisons are denoted with letter scripts.

		Salvage Feasibility Score						
	n	**Min**	**Mean**	**Median**	**Max**	**Standard Deviation**	**Coefficient of Variation**	**Pairwise Comparisons**
Removal status (p=0.8239)								
Condemned	63	15	23.8	23.0	33	4.202	0.177	A
Non-condemned	53	15	23.9	24.0	34	3.819	0.159	A
Land-use zone (p=0.0257)								
R-1	15	18	22.9	22.0	29	3.399	0.149	BC
R-2	10	21	23.8	23.5	28	2.860	0.120	ABC
R-3	13	18	26.5	28.0	33	4.648	0.175	A
R-4	12	17	23.5	22.0	30	4.967	0.211	ABC
R-5	10	15	20.9	21.0	28	3.725	0.178	C
Non-residential	4	24	26.0	25.5	29	2.160	0.083	AB
Species (p=0.6909)								
Acer platanoides	8	15	23.0	23.0	30	5.127	0.223	A
Acer rubrum	6	21	22.3	22.5	24	1.211	0.054	A
Acer saccharum	7	17	26.0	29.0	32	5.686	0.219	A
Quercus palustris	17	18	24.1	25.0	30	3.903	0.162	A
Quercus phellos	12	17	23.4	23.0	30	4.033	0.172	A
Quercus rubra	13	17	23.6	23.0	33	4.388	0.186	A
Log grade (p=0.1574)								
Grade 1	3	17	19.3	20.0	21	2.081	0.108	A
Grade 2	14	17	23.2	23.0	30	4.902	0.211	A
Grade 3	47	15	24.2	24.0	33	3.972	0.164	A

4.2.6 Superficial Metal Objects Observed in Street Trees

We looked at superficial metal objects in all sampled street trees and conducted statistical analysis only on trees with the logs present. A Chi-square analysis revealed a statistical difference in all metal frequency including office staples across tree removal status and a statistical difference of non-office staples metal objects across tree removal status (p=0.0097 and p=0.0006, respectively). Of the condemned trees, 80% had some metal while only 38% had a metal item that did not include office staples. Of the non-condemned trees, 59% had some metal with 11% having a nail or other non-staple metal item. When comparing different land use zones, there was not a statistical difference considering all metal and non-staple metal objects (p=0.3560 and p=0.5412 respectively). R-2 had 100% metal detection and R-1 had the lowest metal detection (67%). R-3 had the highest non-staple metal objects (54%) while R-2 had the lowest (20%).

A Fisher's exact test revealed that among the different species, there was not a statistical difference with metal frequencies including office staples (p=0.5029) or with non-staple metal objects (p=0.7353). *A. saccharum* had the highest frequency of any metal (100%) and *A. rubrum* had the lowest (67%). *Q. phellos* had the highest frequency of non-staple metal items (58.33%) and *A. platanoides* had the lowest frequency (25%). Finally, there was not a statistical difference between log grades in all metal (p=0.1287) and no statistical difference when comparing non-staple metal items in different log grades (p=0.5717). Grade 3 had the highest metal frequency (85%) and Grade 1 had the lowest metal frequency (33.33%). For non-staple metal items, Grade 3 had the highest frequency (40%) and Grade 1 had the lowest frequency with no metal recorded. Thus, as the grade quality increased the metal frequency tended to decrease.

Table 4.10. Superficial metal objects and nails observed in street trees sampled in Washington, DC to determine timber characteristics. Trees condemned for removal are further broken down by land-use zone, common species, and log grade. We ran a chi-square analysis to note difference in metal presence among removal status, zones, species, and grade. Significant differences ($p < 0.05$) between status, land-use zone, species and grades are denoted in bold.

	Total Butt Logs	**Logs with Any Metal Object**		**Logs with Nails**	
	(#)	**(#)**	**(%)**	**(#)**	**(%)**
Removal status			**(p=0.0097)**		**(p=0.0006)**
Condemned	63	51	80	24	38
Non-condemned	53	32	59	6	11
Land-use zone			**(p=0.3560)**		**(p=0.5412)**
R-1	15	10	67	4	27
R-2	10	10	100	2	20
R-3	13	11	85	7	54
R-4	11	8	73	5	45
R-5	10	8	80	4	40
Non-residential	4	4	100	2	50
Species			**(p=0.5029)**		**(p=0.7353)**
Acer platanoides	8	6	75	2	25
Acer rubrum	6	4	67	2	33
Acer saccharum	7	7	100	2	29
Quercus palustris	17	15	88	6	35
Quercus phellos	12	10	83	7	58
Quercus rubra	13	9	69	5	38
Log grade			**(p=0.1287)**		**(p=0.5717)**
Grade 1	3	1	33	0	0
Grade 2	13	10	77	5	38
Grade 3	47	40	85	19	40

CHAPTER 5 – DISCUSSION

5.1 Introduction

The future practices of urban waste utilization, specifically urban timber, partly rely on empirical information regarding the characteristics of urban timber quality, quantity, and accessibility of logs in the urban area. Currently, little data supports or refutes the assumptions about urban tree characteristics inhibiting their use. The results from this research—focused on condemned street trees—confirm assumptions that overall there is low quality and quantity and high frequency of metal. However, this research does not negate the possibility of high quality timber available, although it does vary by species. Our research indicates trees are likely to be removed without interference from infrastructure, or other factors that may affect the tree removal feasibility. Furthermore, the methods for grading timber is borrowed from the USFS and may not be the most appropriate grading system as it degrades trees with defects that would be unattractive to a sawmill but could be desirable to an artisan. This discussion will delve into the meaning of each section of the results: urban timber grading, volume, removal feasibility, implications this research has for the field, limitations in the study, conclusions, and recommendations for future research.

5.1.1 Trunk Diameter (DBH) Distribution of Sampled Trees

The DBH distribution of sampled trees had a slight "inverse J" shape distribution skewing to the right, indicating that the majority of the trees are concentrated around the 12-18 diameter class. Most uneven-aged forests often display an "inverse J" distribution (Avery and Burkhart, 2002). Therefore, the trees we are sampling "somewhat" mimic the natural distribution of forests. However, as a part of the study design, trees were only measured above

12 inches. Therefore, the smaller distribution end begins at twelve inches as opposed to seedlings one might expect to find in a natural-grown forest.

Trees did not differ in diameter across land-use zones. However, because we only measured trees larger than twelve inches, we automatically eliminated smaller trees. Furthermore, we did not measure tree age, another component needed for consideration before making this claim. This may be contrary to some practices in which smaller trees are planted in denser areas (Sæbø et al. 2013). However, we did find differences between species (table 4.1), which could be a direct result of tree age varying among different species or the adaptability of certain species better thriving in the urban environment (Bassuk et al. 2009).

5.1.2 Frequency of Logs

Of the trees measured, the majority of trees did not contain a factory log, due to the poor conditions and the dilapidated state of the tree trunks. Because urban trees are not presently removed for the purpose of log extraction, this prior statement comes as no surprise; urban trees-specifically street trees are commonly removed due to poor condition. Therefore, one should not expect street trees—which are further damaged through anthropogenic means—to have the same log grade distribution as those trees in the traditional uneven-age stand setting. Our study is the only known study specifically grading street trees. Therefore, little comparisons can be made comparing the results of this study with others.

The low presence of trees that contain logs validates the assumptions that urban street trees are low in timber quality. However, since the log presence exceeds one third of the trees sampled (42%), there are plenty of high quality trees removed each year with the potential to be used for higher-valued wood products. The results in this study suggest more factory logs are present in condemned urban street trees than a previous study down by MacFarlane (2007) that suggested only 35% of condemned urban trees. However, his study looked at all urban trees, so a true comparison cannot be made. Presence of logs differs between tree species; *Quercus species.* had a much higher likelihood of logs. This generally follows trends similar to MacFarlane (2007) in which "hard maples" such as *A. saccharum* had the lowest log presence of 58%, while 95% of most oaks measured had suitable logs. Suitable logs included lower grades such as construction logs and local logs—not considered in our study—as well as factory grades. Therefore, we would expect our study to have less logs in comparison to MacFarlane (2007) because he included two extra classes for logs that we did not include. We chose not to include these classes because they are not as valuable and therefore, may not be worth the effort to recover

Non-condemned trees have a log presence of 74%, refuting the assumption that urban street trees are inferior in log quality in general. However, when the decision is made to remove these trees, it is likely they will be in the process of decaying, significantly reducing their log presence. Thus, an opportunity may exist in the future to harvest urban trees as they begin to decline in their service life and maximize their potential log quality.

Our study only considered factory logs because they are of higher value compared to construction and local logs. However, all logs including construction and local logs should have been considered since they can still be milled. Furthermore, grading techniques used by traditional forestry failed to include many trees that artisans and wood workers seek because of differences in quality and desirability. In order to include desirable traits of artisans and wood workers, a study could be conducted to survey what traits in wood are desired.

5.2 Characteristics of Trees with Logs

5.2.1 Log Grade Distribution

Of our sampled trees, 42% had a log in factory grades 1, 2, or 3 compared to that in the 2007 MacFarlane, study in which only 35% of trees sampled had these log grades. This could be explained by the prior study measuring all urban trees compared to our study measuring only the six most abundant street trees. Despite our results being higher for urban trees than they were in the MacFarlane study, they are lower than graded trees found in a forest setting where 59% of trees had a factory grade of 1, 2, or 3 (MacFarlane 2007). Further research could help us understand if this pattern exists throughout other metropolitan areas. It may even be possible that some urban regions may have tree qualities comparable to forest-grown trees.

Our discovery that the non-condemned trees were of an even higher quality (table 4.3) demonstrating that urban street trees have an abundance of quality. These trees, although not considered for harvest, have the potential to give higher quality logs. Of the trees we sampled, 74% had a log in factory grades 1, 2 or 3 demonstrating that these trees are of much higher quality. However, it is important to reiterate, only trees in “good condition” as denoted by DDOT arborists were measured and these trees were only sampled in the lowest residential zone. Compared to condemned trees, non-condemned trees were graded higher. Nearly half were a grade 1 or 2 compared to “condemned trees” in which only a quarter of trees were graded as grade 1 or 2 indicating not only are trees in “non-condemned” more likely to have logs but the quality is likely to be higher. We can argue, even though trees slated for removal may have low quality, the potential in urban trees exists if the trees are removed before they begin to decline or senesce or as a proactive harvest if an invasive pest were to decimate the street tree population.

Overall, the trends in the data suggest the prevalence of trees containing logs is higher among the lower-density residential zones. This supported our hypothesis that trees in low-density residential zones would be more likely to contain logs. This is further supported by other studies that conclude that population density has a negative correlation with timber quality (Top et al. 2008) and that hostile environments found in high density urban areas are not desirable for tree quality (DeBell et al. 1994, Uusitalo and Isotalo 2005). Thus, fewer trees in heavily developed areas with high populations contain logs. We were not able to detect a statistically significant effect of presence of logs in trees sampled or their quality for land-use zones. Therefore, further investigation is needed to validate these patterns.

In terms of species differentiation, the statistical difference between presence of tree species indicated that *Q. species* had more logs per tree than *A. species.* We thus determine that *Q. species* was more desirable in urban areas as they have the best form, which is consistent with MacFarlane (2007), who found, *Q. species* to be less prone to decay. Since the DBH distribution was generally similar amongst species, we can determine that there is a difference in tree type that goes well beyond confounding factors such as site type or size. Those interested in urban saw timber should therefore, direct their attention to *Q. species,* particularly *Q. phellos,* as it is more likely to provide a higher yield to the time invested.

Choosing non-condemned species in only the least populated zones showed the extreme variation in urban trees and likely the starkest difference from condemned trees. However, this may not have been the best form of comparison as there are many confounding factors that do not allow for us to make an exact comparison between condemned and non-condemned trees. Furthermore, as mentioned in the volume section, our results would greatly be improved if our sample size were to increase. This would be difficult as trees in certain zones were limited, thus zoning may not be the most appropriate stratifying variable when making statistical comparisons. An additional remedy would be to conduct a longitudinal study measuring the condemned trees yearly, thus gathering enough sample points over time.

5.2.2 Sampled Logs Diameter (DBH) Distribution

The DBH distribution for sampled trees with the presence of logs is very similar to that of the DBH distribution of all sampled trees. However, in general, the average diameter is roughly one to three inches larger across different land-use zones and species. Thus, one is more likely to find logs in trees that are of greater size.

5.2.3 Log Length Distribution

Log length followed similar patterns of the DBH distribution for trees that had a log length. We did not measure the potential log length if a log did not exist. Therefore, we could not compare the log lengths between trees containing logs and trees not containing logs. The absence of a difference between zones indicates that one can find a similar log length throughout the city. However, there was a statistical difference between species that followed a similar trend to the DBH distribution. Thus, for the maximum log length, one should consider searching for *Q. palustris* and *Q. phellos* because like DBH, these species had the greatest log length. However, the overall range of average log length between species only ranged four feet, or if one foot excluding *A. rubrum.* Therefore, without *A. rubrum*, the difference is not detectable.

5.2.4 Superficial Defects of Trees with Logs

The lack of statistical differences across species, zones, and tree grades comparing superficial defects indicate that trees across the district regardless of species or land-use zone have similar defect characteristics for all trees that contain a log. Therefore, species and land-use seem to have no effect on the amount of defects a tree will have. Tree defects are more likely a result of age, vitality, and environmental exposure.

5.2.5 Urban Timber Volume

Scaling the volume data per tree, the total volume of potentail timber generated is equivalent to 36,500 board feet. MacFarlane (2007) determined 16,000 cubic meters could be generated each year in potential timber. If we extrapolated our sample size to include all urban trees in an area of the same size with similar "urban classifications" we would have an estimation of 17,300 cubic meters of sawable timber (McFarlane 2007). Thus, our results are in line with MacFarlane's (2007) scaling. If we included all likely condemned trees in DC, it is likely there would be enough wood from all species to fulfill half the needs of a small mill, if the mill requires 3,000 cubic meters or 1.27 million board feet to run yearly (Falk 2002). There is not enough volume for a mill to operate solely on urban timber generated from felled trees in DC. Therefore, it would behoove those interested in timber reclamation to rely on portable sawmills. For traditional saw mills, certain amounts of board feet are expected usually ranging from 2,500 to 3,500 board feet which is the legal load for a truck load (Cesa 2003). *Q. phellos* had the largest average board feet per tree of 371. Therefore, at least seven removed trees would be needed to fill a truck load.

The belief that urban areas lack adequate volume of urban timber is partially accurate. Using only the top six condemned species will not generate enough timber for a sawmill and likely will not make this endeavor profitable. However, many wood workers have access to portable sawmills that can be used throughout the city that can help make even one tree worth sawing. Even with the amount of timber available, one must consider the species selection. The top most available species are *Q. palustris and Q. phellos, which* may not be in popular demand as current markets favor *Juglans* and *Acer* species. However, another top species *Acer platanoides*, although not popular in the states, has value in Germany (Jurek and Wihs 1998). Thus, opportunities for less desired species may have potential as people find creative use for them.

The volume results are hindered by low statistical power due to a small sample size. To better replicate this study, an increase in sample size would be needed. The confidence intervals increased drastically as the sample sizes decreased (Table 4.8). For example, the large confidence interval—over 100% in the 42 inch and above DBH class—demonstrated the large variance and uncertainty for the data estimation. The small sample size did not allow us to make the assumptions that the data followed normal distribution under the central limit theorem. A larger sample size could greatly reduce the confidence intervals. Furthermore, the stratification proved to be inadequate with the sample size. Increasing the sample size would help remedy this. It also may be more appropriate to look at fewer species and fewer land-use zones to fulfill all the assumptions with the statistical tests.

Another limitation of the study was the measurement techniques used to determine the log volume. Urban trees taper differently from forested trees. Thus, urban trees should have different taper equations to measure their volume from their forested counterparts. The methods used to account for urban taper were in the form of regression equations, which could be improved by increasing the sample size and could even be species and diameter size specific.

Comparing the average volume of board feet of each tree there was little difference detected between different land-use zones. However, the average board footage was significantly lower in the non-residential area. And in general, the lower density residential areas had higher average volume per tree. This is evident in other parts of our study in which the DBH averages were larger for low-density areas. The statistical difference in average volume per tree in different species also mirrored that of the log length and DBH, which also had significant difference between the volumes. *Q. phellos* had the second longest log length and close to the highest average DBH, further demonstrating the direct correlation between log volume and size which is what we would expect since DBH is input, a measurement used to determine volume. Therefore, DBH can be a good predictor of the amount of volume for good quality trees.

The higher volume trees tended to be more common among the *Quercus* species, aligning with their tendency to be higher quality. Thus, if urban forests are full of *Acer* species, it is likely the trees are going to be less viable for urban timber reclamation due to the low quality and subsequent low volume. If urban forests have a large abundance of *Quercus* species, urban timber is likely to be more available.

5.2.6 Feasibility of Removal

Trees were also ranked in a feasibility study that rated the likelihood and the ease logistically harvesting them. No trees were rated the lowest rating of "most difficult for removal" suggesting that the feasibility of harvesting all the trees with relative ease was likely. With a mean and median closer to the lowest possible score of 11 than the highest possible score of 44 proves that the majority of trees have less removal obstructions than what we—the researchers—had anticipated. This is explained by the fact that in most urban areas many impediments that may deter an urban logger from using and extracting the wood are often temporary, for example, pedestrian and vehicle traffic, which can be briefly rerouted at the time of removal. Often street trees are lined with infrastructure that could easily be damaged.

However, more infrastructure is found in higher density zones where there are less trees. Therefore, the trees that are found in the highest-dense zones also have the lowest volume and as feasibility scores increase (and thus difficulty in removal increases), volume decreases. Since more street trees are found in the lower density zones on average, one should look to the less dense zones first for timber harvesting. Street trees also have the benefit of being on the street, though there are logistic issues—mentioned in this study—the benefit of having vehicles next to the street and the ease of removal compared to “back yard” trees should be noted.

The results—concluding a difference between zones—supported our hypothesis. However, our hypothesis stating that there is no statistical difference between removal statuses, species, and log grades was refuted. Delving further, we find these results to be intuitive. Delineating the density of population and infrastructure with the zones, zones with more infrastructure are likely to have fewer trees and fewer trees slated for removal (table 4.9) because more infrastructure restricts room for tree growth (Sæbø et al. 2003). However, there was no difference among the feasibility scores, of different species. Our statistical analysis determined that species are not a factor in the feasibility scores meaning tree removal operations face the same challenges across species. The majority of the feasibility score was based on infrastructure surrounding the tree itself. Since we measured the same species throughout each land-use zone, it is logical that species had no effect on the feasibility score. Log grade quality also did not have an effect on feasibility, though trees in more constrained environments would seem to have a lower grade. However, the p-value indicated that it was near to being significant suggesting that the as log grade increased, the feasibility score decreased, making for a more feasible salvage. If the sample size were to increase, we would likely see more conclusive and definitive results show in is significant difference between different log grades. Thus in our study we can only conclude, it would be easier to remove a log from a less populated dense area.

MacFarlane (2007) produced the only other known study that attempted to assess the feasibility of urban timber. The study looked at all urban trees and they made an emphasis that street trees were relatively easy to remove, considering 90% are easily removed. However, this particular study had four categories with ambiguous language that made any means of comparison difficult to conduct. Future studies, need to focus on a standard methodology for measuring tree feasibility to understand true differences between the studies. Our categories had specific guidelines that could be *exactly* measured and easily replicated. However, this section of our research—tree removal feasibility—is an exploratory study. Modifications to the methods could be beneficial to increase the relevance of the feasibility scores. We attempted to understand the constraints felt by professionals in the field anecdotally, however did not have the time for a formal study. Further research should concentrate on the perceptions and concerns of arborist and what they perceive to be the major logistical constraints to urban log extraction. This could be done with surveys and interviews.

5.2.7 Superficial Metal Objects Observed in Street Trees

The majority of trees in the city displayed metal within their wood. We only found a statistical difference in metal between “condemned” and “non-condemned” trees. There was no difference in size between the two different removal statuses, which would give more time for people to abuse the tree, thus the difference can be attributed to a correlation between damaged or decaying trees and the presence of metal. Perhaps “condemned trees” are located in busier, harsher environments that cause them to be removed more frequently and attract more human interference. All other differentiating categories (land-use zone, species, and log grades) had no statistical difference between them.

Not having a difference between different land-use types proved unexpected and went against our hypothesis. With an increase in population density, one would expect trees to be more susceptible to metal insertion. Not surprising, is the lack of difference among species. There was no reason to believe that one species would matter to an individual placing a metal object in tree; most likely, most residents are unaware of tree species when embedding metal. We can conclude that trees are evenly regarded as posts and kiosks despite location or species. A further surprise was the lack of difference between different log grades. Grading was determined irrespective of metal presence. However, it would have been logical to expect lower quality logs to have a likelihood of metal objects. We can determine that quality or health of a tree has little effect as to whether a person will insert metal into it.

Our research on the presence of metal in trees was based on visual indicators such as protruding office staples or nails. We did not possess the means to accurately detect metal beneath the surface of the bark. Literature suggests standard metal detectors are sufficient for metal detection (Sherrill 2001). However, we would disagree as standard detectors may vary in quality and depend on good weather (avoiding wet wood). Cesa (2003) suggests only 9% of urban trees have nails which is far less than our findings of 38%. Further research delving into how much metal a portable sawmill can handle including office staples be valuable to understand the implications metal has on sawmill blades and sawyers.

5.2.8 Points of Interest

Our research suggests that for those who are interested in timber from trees condemned for removal, the best land use zone to explore first is the lowest density housing (R-1). Though this particular zone was not the highest in terms of percentage of sample trees containing logs or average volume per tree, it was close to the top in both number of logs and log volume. Furthermore, this zone had a low feasibility score (fewer removal obstacles), a high volume per tree and relative high presence of logs per trees sampled.

In terms of specific species exploration, *Q. phellos* would likely give the most volume per tree but since the majority of condemned trees are q. palustris, there is an abundent amount of logs in the district of this species. Of our top six species measured *Q. rubra* and *A. saccharum* have higher values but lower quantites. Removal should include these species, even if they are not available to contribute to the overall cause. Even as feasibility differs among various land-use zones, each tree should be saved for higher uses if possible as it is one of the new standards laid out in the ANSI A300.

5.3 Urban Timber Grading Usefulness

The USFS system for grading trees (Rast et al. 1973) is the best way to quantify and qualify the available timber creating empirical data. Once the timber is qualified and quantified the empirical data can be used for comparisons across time, species, and geographic location. However, if there is not a protocol for enumerating the timber, then comparisons become meaningless. Therefore, a standardized method is necessary for meaningful results to be spread throughout the country.

The methods used in this research were derived from the United States Forest Service for hardwood timber (Rast et al. 1973). Though this method is effective and widely acceptable throughout the United States (Leatherberry 1993, Miles and Chen 1990, MacFarlane 2007, Perkins et al. 2008), it may not be the most appropriate protocol for grading urban timber though it has been used in a previous study characterizing urban timber (MacFarlane 2007). As mentioned in the literature review, urban trees grow and function differently from their forested counterparts, thus are likely not to suffice for the needed qualities for urban timber. Furthermore, interest in urban timber is often centered around the sentimental value of the tree or features unique to the tree that artisans desire (Sherrill 2003). The latter is often the cause for log disqualification using traditional methods of grading.

However, there is currently no grading system for urban timber. Much of the timber that could have been used for specialty items was left out using this protocol. Even more surprising is the notion people may not want high-quality wood. Numerous anecdotal accounts have suggested markets driven by people's desire are focused more on misfit wood that incorporates knots often creating Adirondack style furniture and products unique for the artisan and customer. For these reasons, need for a grading system in the urban area is needed and should be further researched.

5.4 Recommendations

Since this study was exploratory in nature, there are many opportunities for research in characterizing urban timber and beyond. Many studies could continue the work based on this study studying a variety of issues associated with urban timber. Others could quantify and qualify urban park timber as well as compare cities with suburbs. These could be used for comparisons to which setting produce higher quality timber and more volume. Furthermore, studies should quantify the different desired wood. No study to our knowledge exist, not even ours, quantifying wood that is desired by artisans. This study focuses urban timber based on standards set but the USFS forty years ago. Therefore, we neglect niche markets that may be most interested in distressed urban wood, something future researchers could explore. Surveys conducted with urban timber artisans and wood worker enthusiasts could help clarify the wood traits seen as desirable and valuable and which trees and species are best to use and sell.

Other significant concerns still needing to be addressed include an economic study on urban timber use. Though our study does not include all possible timber, it includes a base in which an economist could put value on the logs being extracted and cost associated with extraction and transportation determining if urban timber is a cost saving. Finally, a study could be conducted on where to store this waste. We developed maps for our sample frame and could easily use Geographic Information Systems to determine specifically where high valued logs are located, where they can be stored, and the distance associated with log transportation.

CHAPTER 6 – CONCLUSION

Urban timber products from condemned trees are an environmental and economical alternative to mulching and landfill disposal. According to anecdotal data, concerns over the quality and quantity of urban timber prevents further exploration into this lightly tapped resource. The results from this study of characterizing condemned street trees in Washington, DC validate these concerns to the extent that the majority of trees studied were not deemed quality grade timber using the USFS hardwood grading techniques (Rast et al. 1973). However, a significant number of the trees were graded as factory logs, indicating a substantial amount of quality timber is generated each year with the removal of these trees. Furthermore, contrary to anecdotal data, these trees are more easily feasible for removal than originally thought because our research shows few interferences to log extraction. However, metal presence in the form of office staples and to a lesser extent nails is prevalent throughout all trees regardless of quality, species, or location. Arborists, urban foresters, and contractors should maintain constant vigilance—when marking trees for condemnation or in the act of removal—for high quality timber that may be used for higher-valued wood products.

We estimated 36,500 board feet are generated in the District from street tree removals in a typical year for the top six species being removed. The high-density residential zone R-5 generated the most volume per tree followed closely by the low-density residential zone R-1. R-1 has the most volume by zone due to its larger tree population. Of all species studied, *Q. phellos* has the most volume per species. However, the highest volume would be found in *Q. palustris* because it has the highest population of trees condemned for removal.

The volume of urban trees in the district is not large compared to rural forested land. However, our data provides an estimate of the quantity of urban timber that will be removed regardless of whether it is used for timber or sent to a landfill. Cities should maintain detailed records of the quality of timber being removed especially cities with a large urban street tree population. Further studies should focus on the availability in park trees and other trees on public and private land. No timber should be wasted regardless of which jurisdiction owns it or the logistical challenges facing it. These trees are not going to add any value by not being used, unlike forests trees that can offer ecosystem services even after death.

The majority of the “condemned” trees did not have any timber with gradable logs where as in contrast the “non-condemned” trees had a majority of timber that qualified as gradable logs. There was no significant difference between the zoning although the R-1 zone had the most logs per tree. The species of trees found to contain the highest percentage of logs were *Q. phellos* followed by closely *Q. palustris*. *Q. palustris* has the highest number of logs because it had an abundant number of trees.

The lack of difference in grade distribution among removal statuses, land-use zones, and species denotes that trees throughout the city barely differ in quality. Overall, there are very few trees containing the highest grades of timber as determined by the USFS hardwood grading protocol. The majority of trees were a grade 3. This is important because the higher the grade log the more valuable the log. However, this grading scale was developed specifically for forest timber, and it should be remembered that any log has value, it may just need a different metric to measure that value. There is evidence to suggest that urban timber has value that rural timber does not have, such as local artisanship and sustainability. These values that are not considered when grading rural timber because it exists to fulfill a different role. Therefore, all logs should be considered for reclamation because the current grading system may be giving an artificially low grade because the situation is different.

Log presence is significantly low but that should not be a deterrent for use. Some species are more likely to provide a log and can be targeted for utilization. However, these species are not always the most desired by mills, thus having low market value. Similar to the volume, municipalities should take action to track the log grade available in their cities. After data is collected over years, more informed decisions could be made about the quality of logs annually removed.

There were no statistical differences on tree feasibility between tree removal status, and species. Thus, removing trees across different species could be removed with relative ease. However, there was a difference between land use zones that generally follows a pattern: as building density increases, the feasibility score increases denoting the difficulty of tree removal.

This exploratory study has the ability to be the basis for further studies. Much of the conversation involving urban timber utilization discusses many assumptions and logistical issues including market structure and log storage space. However, the feasibility of removal is often ignored even though it is a pivotal cog in urban timber utilization: without the ability for feasibility, urban timber will not be used regardless of the quality of timber. The low feasibility scores from this study in which no tree was ranked on the most difficult side, should convince municipalities that urban timber is relatively accessible furthering its availability. Street trees have incredible access to roads giving them their namesake “street trees.” Thus in some way they should be more accessible than forested trees which need road built. Furthermore, street trees are going to be removed regardless of whether or not they have value. Felling a trunk at eight to twelve feet is not likely going to be an added expense or cause of concern.

The majority of trees had metal embedded in the wood. The majority of metal in the wood was in the form office of staples, which would range from a few to hundreds. “Non-condemned” trees had significantly less metal in all forms metal including office staples and forms of metal excluding office staples. However, all land-use zones and office species are relatively similar.

The findings of this study confirm the beliefs that metal is prevalent among street trees. However, most metal appears to be on the bark; thumbtacks and office staples are too small to penetrate the wood. As the log is debarked there is less metal present. When non-staple metal objects are characterized, roughly a third of logs have the presence of metal. These larger metal objects are of concern as they can do more damage to the mill. This should not deter urban timber usage. Though there is an included step in the process, if the log has value, the miller could deem cutting the metal out worth the time.

The volume of wood may not meet the demands of even a single mill. However, the stream is steady and only likely to increase as DC tries to increase its tree canopy cover, and although a traditional mill may not be the answer to the problem, this does not exclude the fact that a mill specific to urban areas could be profitable. The frequency of quality timber, though the minority of trees, is worth exploring and the feasibility favors resource extraction. Thus, this study has mixed results for urban timber exploration. Presently, urban timber should be left to those who use urban timber for reasons beyond profitability such as sentimental value and environmental responsibility. Quality timber exists in the urban setting for those willing to invest the time and effort to find it (Sherrill 2003).

Urban timber use has been in limbo for the last two decades; part of this is caused by the lack of empirical data has made it difficult for municipalities to establish well planned strategies to utilize urban timber. This study both helps and hurts the argument supporting the fruition of urban timber depending on which facet interests the reader; however, taken in its entirety we, believe that there is a place for urban timber utilization that has not been fully explored and would involve a paradigm shift in how we think about utilizing timber in different settings. There were limitations to this study such as this study was on a relatively small area (61 square miles), and if addressed by expanding to the metropolitan area and thus increasing the log count and subsequently the volume, could offer information that would improve the prospects of urban timber utilization. To improve the accuracy of the results we suggest the sample size should be increased by a factor of three or four. We had high variability with our results leading to less conclusive results and conclusions, which we allocate to our small sample size.

Urban trees, specifically street trees, are known for their multiple functions. However, trees have the opportunity to have an additional added value. Urban trees have the opportunity to serve a finale function to the public and will not be just a hindrance and cost burden to the cities. Economic gains are likely to be limited in the production, but the cost avoidance associated with disposal could be greatly mitigated and the sentimental value people hold to their neighborhood trees could be captured: building a sense of place.

Using traditional forest grading methods fail to capture all the timber that has value. As we need to think about these trees as unique forms of timber found in urban areas and not as ordinary timber. This is a paradigm shift away from what we had originally proposed: quantifying high quality timber. Knots and other visible defects, which often decrease the value of conventional timber may actually increase the value for artisans and wood workers. Therefore, a new protocol should be used for urban timber evaluation. To understand the characteristics going into this protocol, studies should be conducted to understand which trees characteristics are important and valuable. This could be done through surveys and interviews conducted by social scientists.

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APPENDIX A
Field Data Collection Sheet for Quantity and Quality of Urban Timber

(Front)

Tree ID	DBH (inches)	Log Length (feet)	Log Location (butt/upper)	Starting Height (feet)	Total # Knots (Worst Face)	Knots (2nd – Worst Face)	% Cull	% Sweep	Surface Defect	Grade	Volume (feet^3)

(Back)

Tree ID	Zone Land Use	Tree Crown Height	Total Tree Height (feet)	Presence of Metal			Time and Date I Took a Picture	Species
				Office staples	nails	other		

APPENDIX B
Tree Variables Measured

Variable Name	**Variable Type**
DBH (in)	Continuous
Log length (feet, in)	Continuous
Log location (on tree)	Categorical
Starting height (inches)	Continuous
Total number of knots	Continuous
Total knots on the second worst face	Continuous
Percent cull	Continuous
Percent sweep	Continuous
Surface defect	Continuous
Grade (Grade 1, 2, 3, or cull)	Ordinal/categorical
Volume (board feet)	Continuous (derived from log length and DBH)
Zone land use	Categorical
Tree height live top (feet, in)	Continuous
Total tree height (feet, in)	Continuous
Presence of Metal (office staples, nails, and other)	Continuous
Percent crown missing	Continuous
Crown height exposure (1-5)	Categorical
Species	Categorical

APPENDIX C

Field Data Collection Sheet for Logistical Site Feasibility of Salvaging Timber

Criteria	Timber Salvage Site Feasibility Ratings				Rating Score
Site Use	(4)	(3)	(2)	(1)	
Vehicular traffic (1–4) (expressed in daily average)	very heavy (20k+)	heavy (10–20K)	moderate (0–10K)	low (not reported)	
Pedestrian traffic (1–4)	very heavy	heavy	moderate	low	
Overhead utilities (1–4)	directly over	present in felling zone	within same distance as tree height	none	
Underground utilities (1–4)	directly under	present in felling zone	within same distance as tree height	none	
Presence of above-ground infrastructure (1–4)	directly under	present in felling zone	within same distance as tree height	none	
Amount of above ground infrastructure on the block in (number of items)	much (>20)	moderate (10–20)	few (>10)	none	
Type of infrastructure (1–4)	removable	durable	protectable	fragile	
Physical Structure of Tree					
Trunk decay/openings or defect Percent of circumference of trunk (1–4)	severe (>33%)	moderate (17-32%)	minor (<-16%)	none	
Site Access					
Amount of on-ground infrastructure	much (>20)	moderate (10–20)	few (>10)	none	
Felling obstacles at ground level within felling zone	many (>10)	few (5-10)	very few (>5)	none	
Space to fell log (1–4)	none (within 8 feet)	very restricted (within 16 feet)	restricted (within 32 feet)	unrestricted	
Space to maneuver machinery (1–4)	none (single lane)	very restricted (two lanes)	restricted (multiple lanes)	unrestricted multiple lanes and intersection	

APPENDIX D

Appendix D: Summary of Zone Land Use Zones

The Summary of Zone Districts provides up to date general zoning information about each zone district. For specific information about each zone district, please consult the Zoning Regulations that were the basis for the sample scheme used in this study.

Districts		Summary
CR		Permits matter-of-right residential, commercial, recreational and light industrial development to a maximum lot occupancy of 75% for residential use, 20% for public recreation and community center use (up to 40% with Board of Zoning Adjustment approval), and 100% for all other structures, a maximum FAR of 6.0 for all buildings and structures, of which not more than three (3.0) may be used for other than residential purposes, a maximum height of ninety (90) feet for all buildings and structures and forty-five (45) feet for public recreation and community centers. An area equivalent to 10% of the total lot area shall be required at ground level for all new development, and rear yards shall be provided for each residential building or structure.
C-1		Permits matter-of-right neighborhood retail and personal service establishments and certain youth residential care homes and community residence facilities to a maximum lot occupancy of 60% for residential use and 100% for all other uses, a maximum FAR of 1.0, and a maximum height of three (3) stories/forty (40) feet. Rear yard requirements are twenty (20) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-2-A		Permits matter-of-right low density development, including office employment centers, shopping centers, medium-bulk mixed use centers, and housing to a maximum lot occupancy of 60% for residential use and 100% for all other uses, a maximum FAR of 2.5 for residential use and 1.5 FAR for other permitted uses, and a maximum height of fifty (50) feet. Rear yard requirements are fifteen (15) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-2-B		Permits matter-of-right medium density development, including office, retail, housing, and mixed uses to a maximum lot occupancy of 80% for residential use and 100% for all other uses, a maximum FAR of 3.5 for residential use and 1.5 FAR for other permitted uses, and a maximum height of sixty-five (65) feet. Rear yard requirements are fifteen (15) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-2-C		Permits matter-of-right higher density development, including office, retail, housing, and mixed uses to a maximum lot occupancy of 80% for residential use and 100% for all other uses, a maximum FAR of 6.0 for residential and 2.0 FAR for other permitted uses, and a maximum height of ninety (90) feet. Rear yard

		requirements are fifteen (15) feet; one family detached dwellings one family semi-detached dwellings side yard requirements are eight (8) feet.
C-3-A		Permits matter-of-right medium density development, with a density incentive for residential development within a general pattern of mixed-use development to a maximum lot occupancy of 75% for residential use and 100% for all other uses, a maximum FAR of 4.0 for residential and 2.5 FAR for other permitted uses and a maximum height of sixty-five (65) feet. Rear yard requirements are twelve (12) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-3-B		Permits matter-of-right medium density development, including office-retail, housing, and mixed uses. It is intended for uptown locations, where the largest component of development will be office-retail and other nonresidential uses to a maximum lot occupancy of 100%, a maximum FAR of 5.0 for residential and 4.0 FAR for other permitted uses, and a maximum height of six (6) stories/seventy (70) feet. Rear yard requirements are twelve (12) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-3-C		Permits matter-of-right development for major business and employment centers of medium/high density development, including office, retail, housing, and mixed uses to a maximum lot occupancy of 100%, a maximum FAR of 6.5 for residential and for other permitted uses, and a maximum height of ninety (90) feet. Rear yard requirements are twelve (12) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-4		The downtown core comprising the retail and office centers for the District of Columbia and the metropolitan area, and allows office, retail, housing and mixed uses to a maximum lot occupancy of 100%, a maximum FAR of 8.5 (or 10.0 if permitted height is in excess of one hundred-ten (110) feet), a maximum height of 110 feet and 130 on 110-foot adjoining streets. (Maximum height and FAR depend on width of adjoining streets.) Rear yard requirements are not less than twelve (12) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.
C-5		Pennsylvania Avenue Development (PAD) permits retail and office, housing and mixed development in the area on the north side of Pennsylvania Avenue, NW between Tenth Street and 15th Street, NW to a maximum lot occupancy of 100%, a maximum FAR of 10.0 to 12.0, and a maximum height of 130 to 160 feet. (Maximum height and FAR depend upon approval of bonus incentives.) Rear yard requirements are not less than twelve (12) feet; one family detached dwellings and one family semi-detached dwellings side yard requirements are eight (8) feet.

C-M-1		Permits development of low bulk commercial and light manufacturing uses to a maximum FAR of 3.0, and a maximum height of three (3) stories/forty (40) feet with standards of external effects and new residential prohibited. A rear yard of not less than twelve (12) feet shall be provided for each structure located in an Industrial District. No side yard shall be required on a lot in an Industrial District, except where a side lot line of the lot abuts a Residence District. Such side yard shall be no less than eight (8) feet.
C-M-2		Permits development of medium bulk commercial and light manufacturing uses to a maximum FAR of 4.0, and a maximum height of sixty (60) feet with standards of external effects and new residential prohibited. A rear yard of not less than twelve (12) feet shall be provided for each structure located in an Industrial District. No side yard shall be required on a lot in an Industrial District, except where a side lot line of the lot abuts a Residence District. Such side yard shall be no less than eight (8) feet.
C-M-3		Permits development of high bulk commercial and light manufacturing uses to a maximum FAR of 6.0, and a maximum height of ninety (90) feet with standards of external effects and new residential prohibited. A rear yard of not less than twelve (12) feet shall be provided for each structure located in an Industrial District. No side yard shall be required on a lot in an Industrial District, except where a side lot line of the lot abuts a Residence District. Such side yard shall be no less than eight (8) feet.
HE-1		Hill East Subdistrict 1 (19th Street) includes squares with frontage onto 19th Street, between Independence Avenue and Massachusetts Avenue. Allows a maximum lot occupancy of 80%, minimum and maximum building heights of 26 and 50 feet respectively, a maximum of 4 stories, and a maximum floor area ratio (FAR) of 3.0. New buildings, or additions to existing buildings must be reviewed by the Zoning Commission for consistency with established design guidelines.
HE-2		Hill East Subdistrict 2 (20th Street) includes squares with frontage on 20th Street. The maximum lot occupancy is 75%, the minimum and maximum building heights are 40 and 80 feet respectively. The maximum number of stories is 7, and the maximum floor area ratio is 4.8. New buildings, or additions to existing buildings must be reviewed by the Zoning Commission for consistency with established design guidelines.
HE-3		Hill East Subdistrict 3 (Water Street) includes squares with frontage on Water Street. Allows a maximum lot occupancy of 80%, minimum and maximum building heights of 80 and 110 feet respectively, a maximum of 10 stories, and a maximum floor area ratio (FAR) of 7.2. New buildings, or additions to existing buildings must be reviewed by the Zoning Commission for consistency with established design guidelines.
HE-4		Hill East Subdistrict 4 (Corrections) includes squares N and O. The maximum lot occupancy is 75%, the maximum building height is 90 feet. The maximum number of stories is 8, and the maximum floor area ratio is

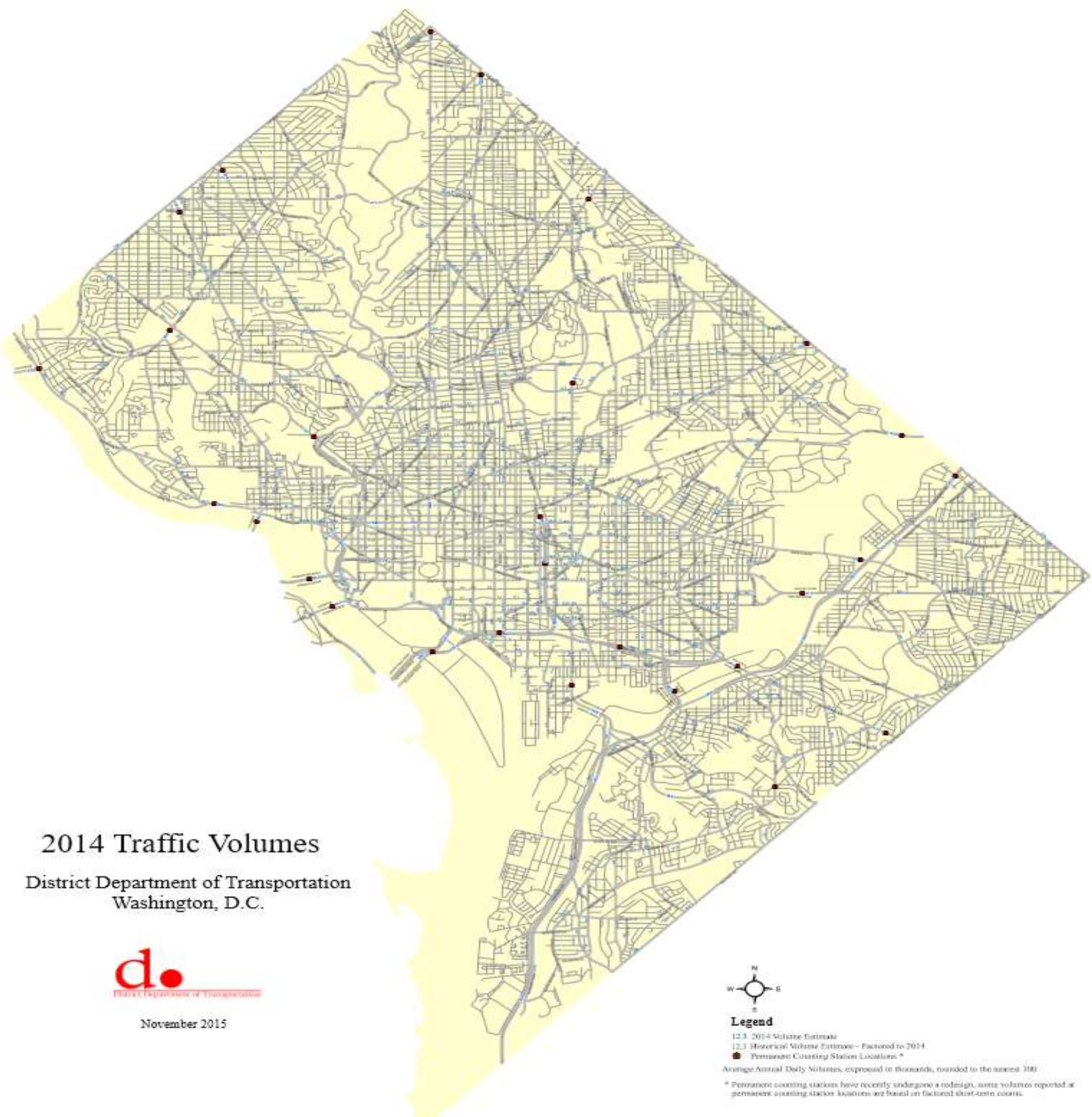
		6.0. New buildings, or additions to existing buildings must be reviewed by the Zoning Commission for consistency with established design guidelines.
M		Permits general industrial uses to a maximum FAR of 6.0, and a maximum height of ninety (90) feet with standards of external effects and new residential prohibited. A rear yard of not less than twelve (12) feet shall be provided for each structure located in an Industrial District. No side yard shall be required on a lot in an Industrial District, except where a side lot line of the lot abuts a Residence District. Such side yard shall be no less than eight (8) feet.
R-1-A		Permits matter-of-right development of single-family residential uses for detached dwellings with a minimum lot width of 75 feet for residential, churches, and public recreation and community centers and 120 feet for schools, a minimum lot area of 7,500 square feet for residential, churches, and public recreation and community centers and 15,000 square feet for schools, a maximum lot occupancy of 40% for residential, 60% for church and public school use, and 20% for public recreation and community centers and a maximum height of three (3) stories/forty (40) feet (60 feet for churches and schools and 45 feet for public recreation and community centers). Rear yard requirements are twenty-five (25) feet, side yard requirements are eight (8) feet.
R-1-B		Permits matter-of-right development of single-family residential uses for detached dwellings with a minimum lot width of 50 feet for residential, churches, and public recreation and community centers and 120 feet for schools, a minimum lot area of 5,000 square feet for residential, churches, and public recreation and community centers and 15,000 square feet for schools, a maximum lot occupancy of 60% for a church or public school use, 20% for public recreation and community centers, and 40% for all other structures; and a maximum height of three (3) stories/forty (40) feet (60 feet for churches and schools and 45 feet for public recreation and community centers). Rear yard requirements are twenty-five (25) feet, side yard requirements are eight (8) feet.
R-2		Permits matter-of-right development of single-family residential uses for detached and semi-detached structures, with a minimum lot width of 40 feet and lot area of 4,000 square feet for detached structures, churches, and public recreation and community centers, 30 feet and 3,000 square feet for semi-detached structures and 120 feet and 9,000 square feet for schools; a maximum lot occupancy of 60% for church and public school use, 20% for public recreation and community centers, and 40% for all other structures, and a maximum height of three (3) stories/forty (40) feet (60 feet for churches and schools and 45 feet for public recreation and community centers). Rear yard requirements are twenty (20) feet, side yard requirements are eight (8) feet.
R-3		Permits matter-of-right development of single-family residential uses (including detached, semi-detached, and row dwellings), churches and public schools with a minimum lot width of 20 feet and a minimum lot area of 2,000 square feet for row dwellings, 30 feet and 3,000 square feet for single-family semi-detached dwellings, 40

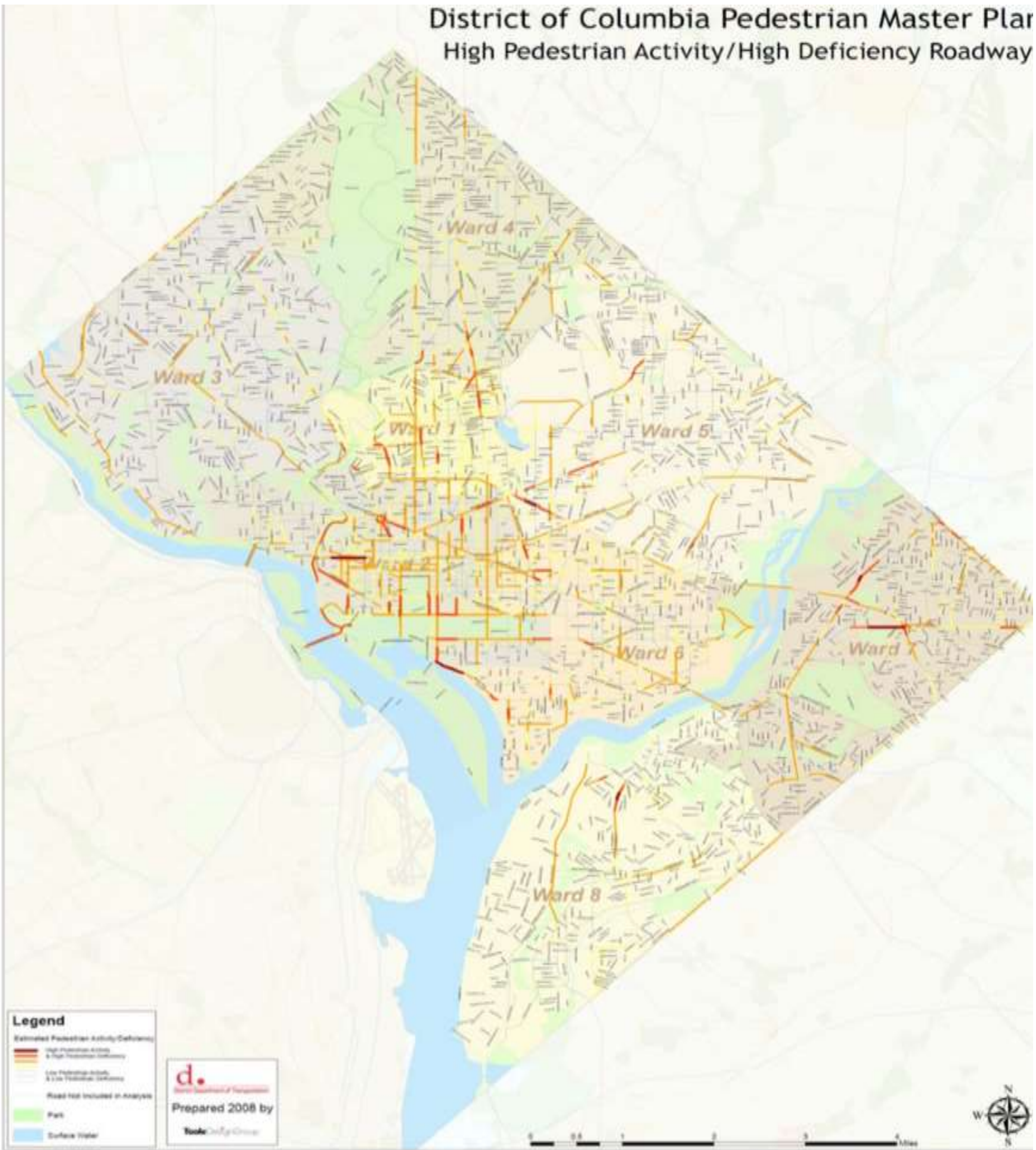
		feet and 4,000 square feet for all other structures and 120 feet and 9,000 square feet for schools, a maximum lot occupancy of 60% for row dwellings, churches and schools, 20% for public recreation and community centers, and 40% for all other structures, and a maximum height of three (3) stories/forty (40) feet (60 feet for churches and schools and 45 feet for public recreation and community centers). Rear yard requirement is twenty (20) feet.
R-4		Permits matter-of-right development of single-family residential uses (including detached, semi-detached, row dwellings, and flats), churches and public schools with a minimum lot width of 18 feet, a minimum lot area of 1,800 square feet and a maximum lot occupancy of 60% for row dwellings, churches and flats, a minimum lot width of 30 feet and a minimum lot area of 3,000 square feet for semi-detached structures, a minimum lot width of 40 feet and a minimum lot area of 4,000 square feet and 40% lot occupancy for all other structures (20% lot occupancy for public recreation and community centers); and a maximum height of three (3) stories/forty (40) feet (60 feet for churches and schools and 45 feet for public recreation and community centers). Conversions of existing buildings to apartments are permitted for lots with a minimum lot area of 900 square feet per dwelling unit. Rear yard requirement is twenty (20) feet.
R-5-A		Permits matter-of-right development of single-family residential uses for detached and semi-detached dwellings and, with the approval of the Board of Zoning Adjustment, new residential development of low density residential uses including row houses, flats, and apartments to a maximum lot occupancy of 40%, 60% for churches and public schools, and 20% for public recreation and community centers; a maximum floor area ratio (FAR) of 0.9, and a maximum height of three (3) stories/forty (40) feet (90 feet for schools, 60 feet for churches, and 45 feet for public recreation and community centers). Rear yard requirements are twenty (20) feet, side yard requirements are not less than eight (8) feet. If all other provisions of the zoning regulations are complied with, conversion of existing buildings to flat or apartment use is permitted as a matter-of-right.
R-5-B		Permits matter-of-right moderate development of general residential uses, including single-family dwellings, flats, and apartment buildings, to a maximum lot occupancy of 60% (20% for public recreation and community centers), a maximum FAR of 1.8, and a maximum height of fifty (50) feet (90 feet for schools and 45 feet for public recreation and community centers). Rear yard requirements are not less than fifteen (15) feet.
R-5-C		Permits matter-of-right medium density development of general residential uses, including single-family dwellings, flats, and apartment buildings, to a maximum lot occupancy of 75% (20% for public recreation and community centers), a maximum FAR of 3.0 and a maximum height of sixty (60) feet (90 feet for schools and 45 feet for public recreation and community centers). Rear yard requirements are not less than fifteen (15) feet.
R-5-D		Permits matter-of-right medium/high density development of general residential uses, including single-family dwellings, flats, and apartment buildings, to a maximum lot occupancy of 75% (20% for public recreation and

		community centers), a maximum FAR of 3.5 and a maximum height of ninety (90) feet (45 feet for public recreation and community centers). Rear yard requirements are not less than fifteen (15) feet.
R-5-E		Permits matter-of-right high density development of general residential uses, including single-family dwellings, flats, and apartment buildings, to a maximum lot occupancy of 75% (20% for public recreation and community centers), a maximum FAR of 6.0 for apartment houses and hotels, and 5.0 for other structures, and a maximum height of ninety (90) feet (45 feet for public recreation and community centers). Rear yard requirements are not less than twelve (12) feet.
SP-1		Permits matter-of-right medium density development including all kinds of residential uses, and limited offices for non-profit organizations, trade associations and professionals if approved as a special exception by the Board of Zoning Adjustment. Maximum lot occupancy is 80% for residential use except a hotel, 20% for public recreation and community centers and 40% with special exception approval from the BZA. Maximum FAR is 4.0 for residential and 2.5 for other permitted uses, and a maximum height of sixty-five (65) feet. Rear yard requirements are not less than twelve (12) feet, one-family detached dwellings and one-family semi-detached dwellings side yard requirements are eight (8) feet.
SP-2		Permits matter-of-right medium/high density development including all kinds of residential uses, and limited offices for non-profit organizations, trade associations and professionals if approved as a special exception by the Board of Zoning Adjustment. Maximum lot occupancy of 80% for residential use except a hotel, 20% for public recreation and community centers and 40% with special exception approved from the BZA. Maximum FAR is 6.0 for residential and 3.5 for other permitted uses, and a maximum height of ninety (90) feet. Rear yard requirements are not less than twelve (12) feet, one-family detached dwellings and one-family semi-detached dwellings side yard requirements are eight (8) feet.
StE		The Saint Elizabeth’s East (StE) District was established to provide for a broad mix of uses, including residential, commercial, hospitality, educational and civic uses consistent with the Saint Elizabeths East Master Plan and Design Guidelines. The purposes of the StE District are to reinvigorate the campus as an important neighborhood center, preserve and adaptively reuse historic resources, and enhance the unique and historic identity of the campus through new development. The new Saint Elizabeths East (StE) District will have nineteen (19) subdistricts, StE-1 through StE-19. Each StE subdistrict will have its own bulk and design provisions, including height, density, lot occupancy, and street frontage requirements for unique conditions associated with the historic nature and architecture of the campus. New parking spaces on the campus will be limited to four thousand eight hundred (4,800) spaces, which will be monitored through each building permit granted. Most of the uses within the StE District will be as a matter-of-right except for a few which will be

		permitted by special exception or are prohibited. Building heights range from zero (0) to ninety (90) feet with the tallest buildings away from the historic buildings. The proposed building heights address the context of existing to new buildings and allow heights to transition down to adjacent historic buildings. To ensure that the overall development maintains the mix of uses envisioned across the campus, a portion of the overall FAR within seven (7) of the subdistricts is required to be dedicated to residential use. To provide further flexibility, residential use can be transferred to properties located in other specified subdistricts through a combined lot mechanism, provided the maximum total density and height for the receiving subdistrict remains as specified for that subdistrict. Within the StE-7, 15, and 17 subdistricts, additional FAR for above-grade structured parking is provided.
W-0		Permits open space, park and low-density and low-height waterfront-oriented retail and arts uses with a maximum height of 40 feet and a maximum FAR of 0.5 (.75 for a lot that is used exclusively for recreational use, marina, yacht club, or boathouse building or structure), and a maximum lot occupancy of 25% (50% for a lot that is used exclusively for recreational use, marina, yacht club, or boathouse building or structure). Maximum height is forty (40) feet (25 feet for a structure located on, in, or over the water, including a floating home). There is also a 100-foot waterfront setback requirement.
W-1		Permits matter-of-right low density residential, commercial, and certain light industrial development in waterfront areas to a maximum lot occupancy of 80% for residential use, a maximum FAR of 2.5 for residential and 1.0 for other permitted uses and a maximum height of forty-five (45) feet. Rear yard requirements are not less than twelve (12) feet.
W-2		Permits matter-of-right medium density residential, commercial, and certain light industrial development in waterfront areas to a maximum lot occupancy of 75% for residential use and public recreation and community centers, a maximum FAR of 4.0 for residential and 2.0 for other permitted uses and a maximum height of sixty (60) feet. Rear yard requirements are not less than twelve (12) feet.
W-3		Permits matter-of-right high density residential, commercial, and certain light industrial development in waterfront areas to a maximum lot occupancy of 75% for residential use and public recreation and community centers, a maximum FAR of 6.0 for residential and 5.0 for other permitted uses and a maximum height of ninety (90) feet. Rear yard requirements are not less than twelve (12) feet.

APPENDIX E
Maps Used for Vehicle and Pedestrian Traffic Counts




District of Columbia Pedestrian Master Plar
High Pedestrian Activity/High Deficiency Roadway
Ward 4
Ward 3
Ward 1
Ward 5
Ward 6
Ward 7
Ward 8
Legend
Prepared 2008 by

APPENDIX F
Grading Diagrams Taken from the United States Forest Service Hardwood Grading Protocol

Figure 6.—Selecting the grading face.

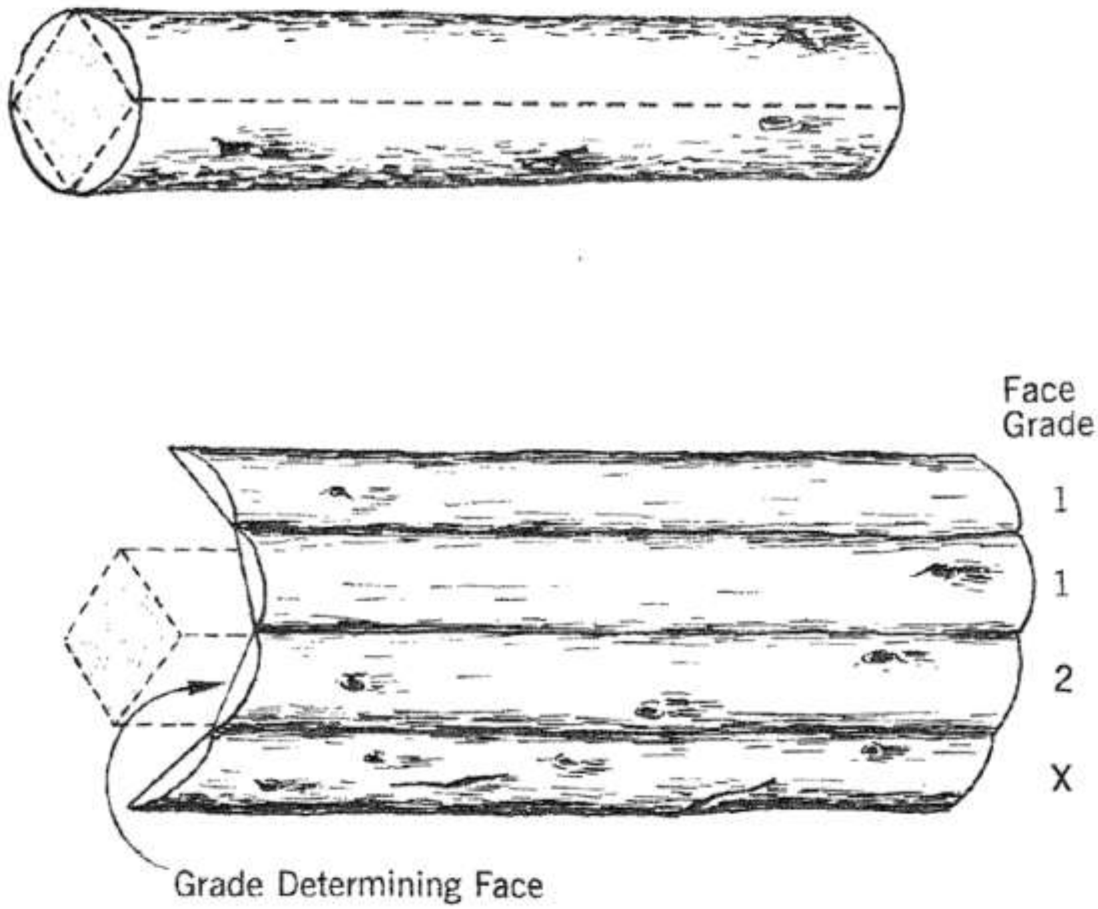


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Figure 5.—Forest Service standard grades for hardwood factory lumber logs.[a]

Grading Factors		Log grades							
		F1			F2				F3
Position in tree		Butts only	Butts & uppers		Butts & uppers				Butts & uppers
Scaling diameter, inches		13-15[b]	16-19	20+	11+[c]	12+			8+
Length without trim, feet		10+			10+	8-9	10-11	12+	8+
Required clear cuttings[d] of each of 3 best faces[e]	Min. length, feet	7	5	3	3	3	3	3	2
	Max. number	2	2	2	2	2	2	3	No limit
	Min. proportion of log length required in clear cutting	5/6	5/6	5/6	2/3	3/4	2/3	2/3	1/2
Maximum sweep & crook allowance	For logs with less than 1/4 of end in sound defects	15%			30%				50%
	For logs with more than 1/4 of end in sound defects	10%			20%				35%
Maximum scaling deduction		40%[f]			50%[g]				50%
End defect:		See special instructions (page 18)							

Table 4.—International 1/4-inch log rule[a]

Diameter (inches)	Volume (board feet) according to length, in feet—												
	8	9	10	11	12	13	14	15	16	17	18	19	20
8	15	20	20	25	25	30	35	35	40	40	45	50	50
9	20	25	30	30	35	40	45	45	50	55	60	65	70
10	30	35	35	40	45	50	55	60	65	70	75	80	85
11	35	40	45	50	55	65	70	75	80	85	95	100	105
12	45	50	55	65	70	75	85	90	95	105	110	120	125
13	55	60	70	75	85	90	100	105	115	125	135	140	150
14	65	70	80	90	100	105	115	125	135	145	155	165	175
15	75	85	95	105	115	125	135	145	160	170	180	195	205
16	85	95	110	120	130	145	155	170	180	195	205	220	235
17	95	110	125	135	150	165	180	190	205	220	235	250	265
18	110	125	140	155	170	185	200	215	230	250	265	280	300
19	125	140	155	175	190	205	225	245	260	280	300	315	335
20	135	155	175	195	210	230	250	270	290	310	330	350	370
21	155	175	195	215	235	255	280	300	320	345	365	390	410
22	170	190	215	235	260	285	305	330	355	380	405	430	455
23	185	210	235	260	285	310	335	360	390	415	445	470	495
24	205	230	255	285	310	340	370	395	425	455	485	515	545
25	220	250	280	310	340	370	400	430	460	495	525	560	590
26	240	275	305	335	370	400	435	470	500	535	570	605	640
27	260	295	330	365	400	435	470	505	540	580	615	655	690
28	280	320	355	395	430	470	510	545	585	625	665	705	745
29	305	345	385	425	465	505	545	590	630	670	715	755	800
30	325	370	410	455	495	540	585	630	675	720	765	810	860
31	350	395	440	485	530	580	625	675	720	770	820	870	915
32	375	420	470	520	570	620	670	720	770	825	875	925	980
33	400	450	500	555	605	660	715	765	820	875	930	985	1,045
34	425	480	535	590	645	700	760	815	875	930	990	1,050	1,110
35	450	510	565	625	685	745	805	865	925	990	1,050	1,115	1,175

[a] Values as published by H. H. Chapman, extended by formula: $V = (0.22D^2 - 0.71D) \times .905$ for 4-foot section. Taper allowance: ½ inch per 4 feet lineal.