EXTERIOR CHARACTERISTICS AND INTERNAL WOOD DECAY OF HAZARD TREES IN THUNDER BAY, ONTARIO.

By

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A Masters' Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Masters of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

Thunder Bay, Ontario

December 12 2013

A CAUTION TO THE READER

This M.ScF. thesis has been through a formal process of review and comment by three faculty members and an external examiner. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practise of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of either the thesis supervisor, the Faculty or Lakehead University.

ABSTRACT

Barker, K.J. 2013. Exterior characteristics and internal wood decay of hazard trees in Thunder Bay, Ontario. 305pp + xv pp.

Keywords: hazard trees, urban forest, street trees, decay fungi, resistograph, wood-strength, northwestern Ontario

One major component of urban forestry is the ability to recognize hazard trees and have them removed before they fail or cause damage to people or property. Thunder Bay's urban forest consists of approximately 20,000 street trees, many of which are at the end of their lifespan and becoming hazardous. Each year 200 or more street trees are removed by the city which provided an opportunity to undertake this research project to identify and possibly equate the relationship between exterior characteristics of trees deemed hazardous, with interior damages, *i.e.* wood decay. Secondary objectives of this project included measuring the occurrence and diversity of wood decay fungi on street trees in Thunder Bay, creating a resistograph measurement atlas, and determining if a relationship between resistograph measurements and wood strength values (density and MOE) is possible.

In total, exterior characteristics were measured on 177 hazard trees destined for removal, 65 in the summer of 2011 and 112 in the summer of 2012. Of the trees measured, 19 species were represented, with white birch (26%), silver maple (16%) , green ash (14%), and Manitoba maple (9%) being the most commonly occurring. White birch had the lowest health ratings, with crown die-back brought on by drought stress and bronze birch borer infestation. Damage by severe pruning on major limbs resulted in extensive decay observed among many of the white birch. Silver maple exhibited a decrease in trunk health and structure with increasing age. Large pruning wounds which facilitated invasion by decay fungi , and co-dominant forking were common problems encountered on silver maple. Green ash experienced damage to foliage and exhibited twig and branch die-back in the lower crowns of trees due to ash anthracnose.

Although discs should have been removed from all 177 street trees, only 26 tree discs from this pool of trees were collected by Parks crews. An additional 44 tree discs were collected by Parks crews that came from trees not on the original tree removal lists. Due to the small sample size for each tree species, it was not possible to find a correlation between exterior characteristics and internal defects. However, all tree discs (70) were photographed and drilled with a resistograph (IML Resistograph F-series) and are illustrated along with the resistograph charts in Appendix III. Cracks and advanced decay were readily recorded with the resistograph, but incipient decay was not detected as it had readings similar to sound wood. A significant source of error noted was drill bit deflection caused by knots in the wood, contours, and meandering growth rings.

One hundred and one trees were observed to be colonized by decay fungi, 22 of these trees were among the original 177, while the remaining trees were additional street trees observed in Thunder Bay. Twenty seven species of decay fungi were recorded, and among these, *Cerrena unicolor, Hypsizygus tessulatus, Pholiota aurivella, Chondrostereum purpureum, Pholiota squarrosa,* and *Ganoderma applanatum* were among the most commonly encountered. Particular attention needs to be paid to silver maple and white birch which were most heavily infected. Green ash exhibited the lowest infection by decay fungi.

Sixteen resistograph readings from two bolts from a silver maple were taken to compare the values on the y axis with actual wood density and MOE values. Results of a linear regression model suggest that a relationship exists. Although more trees would need to be tested in order to strengthen the interpretation of the relationship. This could provide for a methodology to be created which would give urban foresters measurements that could more accurately predict when a tree is likely to fail.

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ACKNOWLEDGMENTS

A special thanks to my advisor Dr. Hutchison who has been a role model as well as a source of guidance throughout this process. A large thanks to my committee members Dr. Mathew Leitch, Dr. Lense Meyer, Shelley Vescio. Dr. Richard Wilson is thanked for acting as the external examiner on this thesis. Scott Miller, Ben Ong and the City of Thunder Bay are thanked for their various roles in making this project a success.

A word of thanks to the Canadian Tree Fund, The Ontario Horticultural Association and Lakehead University for their financial support.

Credit and recognition to my friends (*i.e.* family) for their constant support, Josie Zussino, Mark and Janice Wilson, Justine Van Esbroeck, Steve Uchtenhagen , Amanda Lemay, the cousins (*i.e.* Jeff and Ally) Tyler Hubbard, Lee Salmon, Matt Levesque, Jacquie Glazier, the Tilley family and the Fairbairn family.

A large acknowledgement of thanks to my family Jim, Shrie, Kaitlyn and Rae Piggott, Aunt Lynn and Judy, Grandma (Norma Piggott) my brother John and family as well as those family members who are no longer with us (Jim Barker, Jamilyn Piggott, Evelyn and John Kemsley, Grandpa Rae and David Tilley).

Most importantly thanks to my mother Ann Tuplin, who without, I surely would have not succeeded and who is ever my rock. Finally thanks to my father who is forever with me and guiding me.

GENERAL INTRODUCTION

Urban shade trees suffer from injuries to roots, bark, and crown more intensely than their counterparts in natural forests due to the occurrence of human activities (*e.g.*, construction, soil compaction, lawnmower damage, vandalism *etc.*). As a consequence, urban shade trees are more susceptible to infection from insect pests and fungi. One such group of pathogens are decay fungi which enter trees through injuries to the roots and trunk. Subsequently, urban street trees suffer high rates of decay in the main stem and roots making them potential hazards which could cause injury to property and persons if toppled in strong winds. The extent and seriousness of decay depends upon many variables including host tree species, site, climate and fungi involved. Very little information exists for urban forests in Canada regarding stem-decay in urban street trees and potential risk hazards that they pose.

The objective of my research was to make an assessment of municipal street and park trees in Thunder Bay that were deemed hazardous and which were slated for removal in 2011 and 2012. External characteristics of each tree were examined, recorded and photographed (*e.g.*, health condition, external damages, presence of fruiting bodies of decay fungi, *etc.*) while the trees were still standing. Upon felling, internal symptoms were examined, measured and photographed (*e.g.*, extent of decay) from cross sections of the stems taken at breast height. In the laboratory, resistograph readings were made from each of the cross sections. Since fruiting bodies of decay fungi were frequently absent, attempts were also made to isolate possible decay fungi present in the decayed regions of each of the stem sections. The anticipated result of this research was to determine if a correlation exists between external symptoms and internal decay which could provide a useful tool for Thunder Bay and other municipalities in similar climatic zones to better manage older urban trees by improving the priority of removals of those deemed hazardous.

This thesis is divided into five chapters: 1) A literature review of existing research related to the assessment of hazard trees; 2) An examination of the exterior characteristics of the street and park trees slated for removal; 3) An examination of interior defects from sections taken from felled street and park trees including an atlas which illustrates the noise and abnormalities in the resistograph measurements taken; 4) An examination of the occurrence and frequency of wood-decay fungi on street trees in Thunder Bay; and 5) An examination of the relationship between wood strength measurements, specifically modulus of elasticity (MOE) & modulus of rupture (MOR) and resistograph measurements of a selected felled street tree (*Acer saccharinum* L.).

CHAPTER 1
LITERATURE REVIEW

1.1 WHAT IS URBAN FORESTRY?

Urban forestry is a multi-disciplinary science that deals with the management and utilization of trees and related vegetation in urban areas (Jorgensen 1970, McPherson 2006). The urban forest can be defined as all trees and related vegetation planted or protected to add value to urban communities (McPherson 2006). Trees and vegetation which grow in close proximity to humans can be divided into four distinct regions within the urban landscape; the urban zone, suburban zone, exurban zone and rural zone (Miller 1988). The urban zone encompasses all commercial districts, industrial sites and medium to high density residential areas (Miller 1988). The urban zone contains the lowest number of trees as the majority of free space is devoted to concrete structures with very little suitable growing space. The majority of trees in these areas will be planted trees, with few naturally occurring trees in existence. The suburban zone includes low density housing and shopping malls. Often these areas have a higher number of trees and more suitable growing locations than urban zones. Exurban zones are transition areas between suburban areas and the hinterland *i.e.*, rural forested areas or farmland. Exurban zones often have the highest density of trees. However, many of the trees in this area are naturally occurring and not planted. The final component of an urban forest is the rural zone, which contains all of the natural areas and farm land surrounding cities.

The urban forester is a professional who has responsibility for maintaining and enhancing the urban forest, often focusing on amenity-oriented forestry as opposed to an industry forester, who focuses on production and harvesting (Andresen & Williams 1975). Urban forests can be both publicly owned trees and privately owned trees within an urban environment. However, for the most part, only publically owned urban forests are managed by municipal urban foresters. Private trees are managed by their owner or an arborist hired by the owner.

All professional urban foresters require a post high school education, either college or university. Currently Canada has 21 universities and 18 colleges offering courses related to urban forestry (Andresen & Williams 1975, Canadian Forests website 2011). The United States has many more universities and community colleges that offer courses related to urban forestry (Bradley 1995).

1.2 BENEFITS OF AN URBAN FOREST

There are many benefits to an urban forest, some of which can easily go unnoticed by the public. However, when closely examined, a tree provides society with numerous measurable values such as aesthetic and economic benefits, decrease in air pollution, energy savings, relief from the urban heat island effects, benefits to human health and behaviour, improvements in urban hydrology, a decrease in noise pollution, and an increase in carbon sequestration (Miller 1988). To fully understand the values of an urban forest, all the positive characteristics of trees must be understood (Miller 1988), however, to achieve these benefits, there are significant costs associated with maintaining an urban forest.

1.2.1 AESTHETIC AND ECONOMIC BENEFITS OF AN URBAN FOREST

Humans naturally prefer areas that contain trees and other vegetation (Driver *et al.*, 1978, Getz *et al.* 1982, Herzog *et al.* 1982, Kaplan 1983, Nasar 1983, Ulrich 1984, Ulrich 1986, Jackson 2003). Despite the fact it cannot be quantitatively measured, there are ways to estimate the aesthetic value of trees. These values are based on what community members are willing to pay to preserve a park or pay for a property due to the presence of a street tree (Anderson & Cordell 1988, Tyrväinen & Vaananen 1998).

In many cases, people are willing to pay money to be in a park for a period of time (Tyrväinen & Vaananen 1998). Another statistic about the value of an urban forest is the willingness of residents to pay a monetary sum to keep a park or urban forest from being converted into another land use project (Tyrväinen 2001).

Street trees, like parks, are difficult to evaluate in terms of a monetary value. However, street trees have the potential to significantly raise the market value of a home, which makes them important economically in an urban setting. Studies in Athens, Georgia have shown that a large street tree located in front of a home increases the average resale value of a house by $2,412.00 (Anderson & Cordell 1988). The increase in value, as a result of the presence of a large urban tree, is based on tree species, tree health, tree size and age (Anderson & Cordell 1988). The aesthetic value of the publicly owned street trees in Thunder Bay is estimated to be approximately $37 million (Kurikka 2012).

1.2.2 AIR POLLUTION

Air pollution is a problem in many major cities around the world. One way to potentially combat air pollution is to have a large urban forest (McPherson 1998). Urban forests reduce air pollution by removing airborne pollutants such as dust, SO_2 and ozone. Chicago's urban forest, for example, removes over 6145 tonnes of air pollutants per year (McPherson 1998), which is estimated to have an economic value of over 9.2 million dollars. A similar situation can be found in Beijing where the urban forest annually removes approximately 1261.4 tonnes of air pollutants (Yang *et al.* 2005). Improvements in air quality by the publicly owned urban forest in Thunder Bay is estimated to be valued at approximately $77,308 per year (Davey Resource Group 2011).

1.2.3 ENERGY SAVINGS

Urban heat islands are areas with temperatures higher than surrounding rural areas (McPherson 1994). Urban structures such as pavement, buildings and cement absorb little heat and as a result reflect more heat back into the urban environment (McPherson 1994). The excess amount of heat in urban air can cause an increase in the concentration of smog, human discomfort, disease as well as an indirect increase in carbon dioxide as a result of a higher demand for electricity from power plants to supply power to air conditioners in summer months and heaters in winter months.

It has been shown that trees have an ability to save enormous amounts of energy in cities if trees are planted in the correct locations to maximize energy savings (Huang *et al.* 1987, Dwyer *et al.* 1992, McPherson & Rowntree 1993, McPherson & Simpson 1999, Akbari 2002). Energy savings are attributed to a reduction in the use of air conditioners in summers and heaters in homes in winter

(Huang *et al.*, 1987, McPherson 1994). Shade, evaporation and wind reduction provided by trees are the three factors which lead to energy savings (McPherson & Rowntree 1993). Coniferous trees are capable of blocking winds that would disperse heat from large buildings and private homes in winter (McPherson & Simpson 1999, Akbari 2002). Large deciduous trees planted close to homes lose their leaves in the winter allowing direct sunlight to help heat buildings in the winter. In the summer, large deciduous trees shade buildings and reduce evaporation keeping the area below tree canopies and under trees cooler as well as blocking warm dusty winds in hot climates which increase effectiveness of air conditioning, all leading to less energy use (McPherson & Simpson 1999, Akbari 2002).

It has been suggested that energy savings per tree can be as high as $200 for an individual tree per year (Akbari 2002). It was estimated that the urban forest in Sacramento saves up to $18.5 million per year in energy costs (Simpson 1998). The estimated average savings of a single tree in 12 major cities across the USA is provided in Figure 1 (McPherson & Rowntree 1993). Evapotranspiration accounts for one third to approximately two thirds of all energy savings from trees (McPherson and Simpson 1995). Wind reduction accounts for a much smaller percentage of energy savings of approximately 5-15% (Heisler 1986, Heisler 1990). Energy savings can at times be significantly higher than 15% as seen in cities such as Boston (Figure 1). The most challenging value to estimate is the energy savings as a result of shade due to meteorological factors (McPherson & Simpson 1999). Cities that experience the most benefits are those that have high average temperatures, are dry and experience heavy winds. Energy savings in Thunder Bay have been suggested to be approximately $455, 908.00 per year (Davey Resource Group 2011).

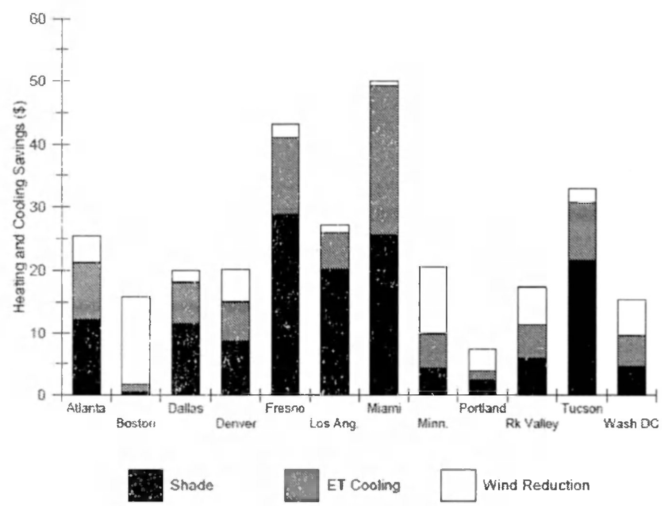

Figure 1: "Simulated total annual heating and cooling savings due to shade from one 7.6m (25-ft.) tall tree and ET(Evapotranspiration) cooling and wind reduction effects assumed to be associated with a 5 percent increase in local tree cover"(McPherson & Rowntree 1993)

All trees have the potential for energy savings, but if they are not placed in the correct spot in relation to buildings, that may not happen (McPherson & Simpson 1999). For example, conifers are planted around the perimeter of the house, approximately 15m away to act as a wind break on the house, but not to cast a shadow on the house reducing the effectiveness of warmth from the sun (Heisler 1984, Sand 1991). Deciduous trees are planted close to the house so they cast a shadow in summer to keep the house cool but not in the winter to allow the sun to warm it. Deciduous trees should be placed on the east, west and south side of houses to block morning and afternoon sun (Solecki *et al.* 2005). Deciduous trees should also be planted in front of windows to avoid direct sunlight heating the inside of the house in summer (Solecki *et al.* 2005). Conifer trees should not be planted on the south side of the house as they would block southern exposure to the sun in winter increasing heating costs by casting shadows on the house. The orientation of the trees in relation to the house is also important to consider. Wind break conifers should be planted to block the house in the direction of the prevailing winds. For example if the prevailing winds are coming from the east, a conifer wind block is most useful on the east side of the house.

1.2.4 HUMAN HEALTH AND BEHAVIOUR

Nature, specifically animals, plants, landscapes and wilderness have positive effects on the physical, mental and social well-being of humans (Frumkin 2001). Nature has restorative and tranquil properties that may aid in the physical and mental processes related to healing (Frumkin 2001). Residents in retirement homes have reported feeling more tranquil and calm when located closer to trees and related vegetation (Browne 1992). Similar results have also been found among employees in office buildings when plants are present in the office (Shoemaker *et al.* 2000). Gardens have been planted in prisons and it has been observed that there were less assaults as gardening seemed to have a soothing effect on the prisoners (Neese 1959, Lewis 1992). In a 1984 hospital study, patients in rooms with views of trees and natural settings had shorter recovery times than similar patients in rooms with views of only a brick wall (Ulrich 1984). In a separate study, natural light, ventilation, views of greenery and proximity to natural green areas are considered to be the most important characteristics of architecture in relation to increasing health (Jackson 2003).

The urban forest is the largest contributor of large trees and vegetation in urban areas which can help increase the visual appeal and sense of wellness by being in a visually more appealing setting (Lynch & Rivkin 1959, Ulrich 1986). Forests in urban areas also support wildlife such as birds which also have been found to have a positive effect on human health and wellness (Frumkin 2001, Jackson 2003)

Humans are more likely to naturally congregate in areas that have trees and vegetation (Driver *et al.*, 1978, Herzog *et al.* 1982, Getz *et al.* 1982, Kaplan 1983, Nasar, 1983, Ulrich 1986, Jackson 2003). Trees not only increase the aesthetic value of an area, but they also increase the quality of the microclimate by reducing temperatures and improving air quality and thus improving comfort. It is a benefit to store owners to place trees near their shops as this will increase traffic and the number of pedestrians walking in front of their shops (Erwing 1999. Wolf 2005). The combination of street trees and other aesthetically pleasing features can actually increase the shopping experience. It has been suggested that customers are likely to spend more in stores with increased levels of comfort (Wolf 2005), and are also more likely to return to shop in these stores.

1.2.5 URBAN HYDROLOGY

Large trees intercept water from rainfall and retain water thus reducing flooding and runoff and decreasing costs of water treatment and flooding damage (Dwyer *et al.* 1992, Nowak & Dwyer 2007). In Dayton, Ohio, it was estimated that trees reduced water runoff by as much as 7%. The annual savings provided by publically owned street trees in Thunder Bay associated with storm water runoff and flooding reduction was estimated to be $552, 362.00 (Davey Resource Group 2011).

There are many positive benefits in arid dry areas from the presence of trees, however trees can also play a negative role as they can be a drain on water resources (Dwyer *et al.* 1992, Nowak & Dwyer 2007). In clay soils, water retention by trees can lead to decreases in soil quality leading to cracking, drying and shrinking of the soil (Dwyer *et al.* 1992, Nowak & Dwyer 2007). The loss in water resources and the damage to water quality has been found to be offset, however, by the energy savings provided by trees.

1.2.6 DECREASE IN NOISE POLLUTION

Trees strategically planted in urban areas associated with soft soil surfaces can reduce noise by as much as 50% (Dwyer *et al.* 1992). Large rows of dense foliage such as conifer trees or densely grown coniferous and deciduous shrubs are most effective at reducing noise (Dwyer *et al.* 1992). Areas where trees have the most effect on reducing noise is between residential neighbourhoods and major highways and roads, as well as loud downtown areas containing taverns and bars. Trees are more effective at reducing noise when they are planted closer to the noise source rather than the area where the noise is meant to be reduced (Nowak & Dwyer 2007). Trees can reduce the impact of noise levels by reducing the view of the areas causing the noise pollution. It has been found that individuals experience less impact from noise if they cannot view the source of the noise (Anderson *et al.* 1984). For these reasons, trees can increase the quality of living by reducing noise pollution in urban areas.

1.2.7 CARBON SEQUESTRATION

Carbon sequestration is the process of removing carbon from the atmosphere thus reducing the effects of climate change. In the process of photosynthesis, trees take in CO_2 and combine it with water to create carbohydrates and oxygen (Lorenz & Lal 2010). The carbohydrates are stored in all parts of the tree and the oxygen is released back into the atmosphere (Lorenz & Lal 2010).

There have been multiple estimates to the amount of carbon sequestered from an urban tree. One study suggests that an urban tree with a DBH of approximately 31-46cm and with a crown of approximately $50m^3$ can sequester carbon at a rate of approximately 19 Kg/year (McPherson 1994). Another study found that trees sequester carbon at a rate of approximately 4 kg/year until the tree has a crown of approximately $50m^3$. The average rose to approximately 11 Kg/ year when the urban tree crown surpasses $50m^3$ (Akbari 2002). Akbari (2002) calculated in combination with data from research by Rosenfeld *et al* (1998), that trees in Los Angeles can individually reduce carbon in the atmosphere by 18 kg/year. A city tree is 3 to 5 times more valuable than a forest tree at sequestering carbon due to canopy size (Rosenfeld *et al* 1998, Akbari 2002). It was also shown that the total value of all carbon sequestered in the five cities of Tucson, Chicago, Sacramento, Modesto and San Joaquin was approximately $67, 000, 000 per year (Brack 2002). The reduction in carbon for the City of Thunder Bay was estimated to hold an annual value of $67, 178.00(Davey Resource Group 2011).

1.3 COSTS OF MAINTAINING URBAN FORESTS

Although urban forests provide significant benefits there are also major costs associated with maintaining an urban forest such as planting, pruning, hazard tree removal, storm/ litter clean up, infrastructure/ liability and administrative and inspection costs (McPherson *et al.* 2005). Table 1 represents the costs and benefits of the urban forest in five cities (McPherson *et al.* 2005). The highest cost related to maintaining the urban forest varies by city and the individual situation that each city is in. For example the highest expense for the city of Berkeley is infrastructure and liability, however the opposite is true for Cheyenne where it is at 0 dollars.

As shown in all cases, the benefits always outweigh the costs of maintaining the urban forest. The benefits of trees are best shown by the benefit cost ratio (BCRs). Benefit cost ratios are the return on every dollar spent on maintaining a street tree. For example, for every dollar spent on maintaining a street tree in Ft Collins, Colorado you receive $2.18 in return from the benefits of that tree. In all five cities there are significant positive returns on the money spent maintaining street trees. The lowest BCR value is in Berkeley where only $1.37 is returned for every dollar spent, however every dollar spent still returns more to the city than the cost.

Table 1: Annual costs and benefits of street trees in five USA cities (McPherson *et al.* 2005).

			Cities		
Total Benefits	Ft. Collins	Cheyenne	Bismarck	Berkeley	Glendale
Energy	112,025	186,967	84,348	553,061	116,735
CO_2	40,454	29134	27,268	49,588	12,039
Air Quality	18,477	11,907	3,715	-20,635	32,571
Storm water	403,597	55,297	496,227	215,648	37,298
Property Increase	1,596,247	402,723	367,536	2,449,884	467,213
Total Benefits	2,170,799	688,029	979,094	3,247,545	665,856
Total Costs					
Planting	11,052	45,913	5,880	95,000	21,100
Pruning	405,344	84,677	94,850	770,000	88,412
Removed/disposed	130,487	23,337	50,061	70,000	12,710
Lm/liter/gm waste	94,394	97,840	38,241	195,000	65,813
Infrastructure and liability	72,200	0	21,490	1,062,000	3,000
Amin/inspect/other	184,161	76,103	106,118	180,000	85,401
Total costs	997,638	327,897	316,640	2,372,000	276,436
net benefits	1,173,161	358,133	662,454	875,545	389,421
Benefit to Cost Ratios	2.18	2.09	3.09	1.37	2.41

1.4 FACTORS AFFECTING TREE HEALTH IN AN URBAN FOREST

1.4.1 ABIOTIC PROBLEMS

There are many abiotic factors that can greatly affect the health of a tree including soil condition, air quality, chemical injuries, from human sources and dogs, construction, vandalism, severe weather and mineral deficiencies. All of these abiotic conditions, except for severe weather, have a greater potential to occur in urban areas.

Soils are one of the most important factors for how successful a tree will be on a site. Soils can greatly affect tree growth, health development and overall success. A tree grown on a poor site with heavy compaction and few nutrients has little chance of success even if it is grown within its species range in a favourable macroclimate (Manion 1981, Sinclair & Lyon 2005). There are many factors that can affect the quality of soil in a specific site; they include pH, density, soil structure, pore space and arrangement, chemical properties, physical properties and biological properties.

Trees encounter problems with air quality often near industrial areas and in cities with heavy traffic. Major contributors to air pollution include ozone, sulphur dioxide, fluorides, and other gases associated with large industrial areas (Manion 1981, Sinclair & Lyon 2005). Pollutants enter through stomata on the surface of the leaf and supress photosynthesis as well as other physiological processes (Sinclair & Lyon 2005). Symptoms differ depending on whether symptoms are acute or chronic, but often appear as stunted chlorotic or necrotic leaves.

Chemical injuries are often a problem in urban areas and are a result of acute or chronic exposure to salt and herbicide sprays. Salinity damage is often associated with salt used on roads to reduce ice in the winter or it can also be associated with salt spray from the ocean. Herbicides also have the potential to cause major damages to trees in urban areas however these damages are often associated with the misuse of herbicide sprays when targeting other invasive or unwanted species.

Damage as a result of construction, lawn maintenance, snow removal and vandalism are types of damages that occur very often within a city. All result in similar types of physical damage to the tree where scrapes occur on the stem of the tree or in extreme cases if the main stem or branches are small enough, severed or broken. Construction also has the potential to significantly damage the roots of trees as heavy equipment can compact the soil while digging can physically sever roots.

Severe weather like many of the other abiotic factors has the potential to significantly affect the health of trees through several means including water stress (water loss exceeds supply), flooding, sunburn, sunscald, frost damage and lightning (Manion 1981, Sinclair & Lyon 2005). Each form of severe weather results in different types of damages, some more significant than others, however each can play a crucial role in the life of a tree.

Mineral deficiencies can be a major problem for urban trees. Although trees grown in forest situations seldom ever have problems with mineral deficiencies, urban soils can often be lacking in one of the 16 elements considered to be essential for tree heath (Manion 1981, Sinclair & Lyon 2005). Urban soils often lack nutrients as a result of reduced organic matter, proper soil mixing and bio activity in soils (*e.g.,* Mycorrhizal fungi *etc.*). The pH of the soil in urban landscapes also tend to be higher than in natural forests, resulting in reducing availability of some elements such as iron and manganese. Injuries include cholorotic and necrotic leaves as well as stunted leaf growth and leaf deformities (*i.e.*, curling).

Although not considered often as an issue, dogs may cause chemical injury to trees in the urban forest. As their urine can raise the pH in the soil around the bases of trees; however this only occurs in situations where individual trees are near paths where dogs are common and dogs often stop to urinate at the base of the same tree (Tattar 1978).

1.4.2 BIOTIC DISEASE

There are many biotic diseases that can cause serious problems to trees in urban areas. Organisms that cause biotic diseases include viruses, mycoplasmas, bacteria, nematodes, parasitic flowering plants, insects and fungi. Each affects the health of trees in different ways and thus need to be understood and mitigated for differently.

Generally viruses and mycoplasmas can be transmitted by either humans through pruning and handling, or else by sap sucking insects such as aphids. While diseases caused by these causal agents, as well as nematodes, can be problematic in warmer areas of the world they don't pose a problem in more temperate urban forests.

However, bacteria can be a major problem in the urban forest. Bacteria are single celled organisms that can cause serious damages to trees. Bacteria enter trees through some opening such as a wound or a plant openings such as stomata or lenticels (Manion 1981, Sinclair & Lyon 2005). Once inside bacteria can divide and create colonies consisting of millions of cells. They then excrete enzymes which can damage cell walls of the host tree (Sinclair & Lyon 2005). An example of a common bacterial disease which is occurring with greater frequency in Thunder Bay is fire blight caused by the bacterium *Erwinia amylovora* (Burrill) Winslow (Hutchison pers. comm.). It is one of the most common and destructive bacterial diseases, however, it only occurs on woody species in the Rosaceae.

Parasitic flowering plants rely on a host for nutrients, water and photosynthate (Manion 1981). Although mostly occurring in warmer climates there are species which occur in Thunder Bay such as eastern dwarf mistletoe (*Arceuthobium pusillum* Peck.) which causes witches brooms in spruce and larch.

Insects are considered to be one of the most destructive forces in the urban forest (Johnson & Lyon 1991). Insects commonly act as vectors for disease which will ultimately kill trees such as the smaller European elm bark beetle (*Scolytus multistiratus* Eichh) vectoring the fungus responsible for Dutch elm disease (*Ophiostoma novo-ulmi* Brasier.) and the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) vectoring blue stain fungi which cause vascular wilts. Insects can also directly damage the health of trees by their tunneling and life cycles such as the emerald ash borer (*Agrilus* *planipennis* Fairmaire), bronze birch borer (*Agrilus anxius* Gory) and the Asian long horn beetle (*Anoplophora glabripennis* Motschulsky) whose galleries disrupt the flow of sap in a tree (Johnson & Lyon 1991). Insects also commonly cause damage to the foliage of trees in urban areas. Examples of common defoliators in Thunder Bay's urban forest are Sawflies (Order Hymenoptera, Genus *Arge*), forest tent caterpillars (*Malacosoma disstria* Hübner), morningcloak butterfly larvae (*Nymphalis antiopa* Linnaeus), and canker worm larvae (Genus *Geometra*) (Johnson & Lyon 1991). Insects and other organisms in the Class Arachnida are also responsible for damages such as galls and other deformities on trees. Examples in Thunder bay include spider mites (Genus *Acari*), spruce gall adelgids (Subclass *Adelges*), ash flower gall mite (*Aceria fraxinivora* Nalepa) and oak apple gall wasp (*Amphibolips confluenta* Harris) (Vescio, City Forester, pers. comm.). Insects and members of the class Arachnida that cause galls often don't play a major role on the health of the tree unless they occur in high enough quantity to completely disrupt the normal processes of the tree.

Fungi that affect tree health, are one of the largest contributors to tree mortality in natural and urban forests. Fungi affect the health of trees in differing ways. Examples include foliar diseases, branch and stem cankers, vascular wilts, root rots and stem decay.

Foliar fungi affect the foliage of trees. Examples in Thunder Bay include *Gnomoniella fraxini* Redlin & Stack (ash anthracnose), *Stegophora ulmea* (Fr.) Syd. & P. Syd. (black spot of elm, elm anthracnose), *Rhytisma americanum* Hudler & Banik (Tar spot of maple), *Melampsora occidentalis* H.S. Jacks. (poplar leaf rust) and *Apiosporina collinsii* (Schwein.) Höhn. (black leaf of saskatoon). A secondary group of fungi which effect foliage are called powdery mildews, some common examples from this group of fungi include *Uncinula adunca* (Wallr.) Lév. (powdery mildew of balsam poplar and willow) and *Erysiphe syringae* Schwein. (Powdery mildew of lilac) (L.J. Hutchison pers. comm.).

Canker causing fungi infect a tree through wounds in the bark of branches and stems and cause a characteristic damage often in the shape of a target or a simple round split in the wood or else elongate girdlings of the branch and stem. On occasion these damages are covered with sap as the tree attempts to seal the wound and heal over. Common examples of canker causing fungi which occur in Thunder Bay include *Leucostoma kunzei* (Kunze) Munk (Cytospora canker of spruce), *Nectria cinnabarina* (Tode) Fr. (coral spot disease) and *Hypoxylon mammatum* (Wahlenb.) P. Karst. (hypoxylon canker of Aspen) (L.J. Hutchison pers. comm.).

Vascular wilt fungi are fungi that don't degrade the wood, however, they clog up the vascular system in trees causing symptoms similar to a tree wilting from drought due to the flow of water being cut off. Commonly occurring and destructive examples of these types of diseases include *Ophiostoma novo-ulmi*. (Dutch elm disease), *Verticillium albo-atrum* Reinke & Berthold (Verticillium wilt) and conifer wilt or blue stain (*Ophiostoma* spp.) (Sinclair & Lyon 2005).

Wood decay fungi are the last group and one of the most significant when examining hazard trees. These will be discussed in detail later. Wood decay fungi are able to produce enzymes which can break down the lignin, cellulose and hemicellulose in wood. Although most wood decay fungi are saprophytic, growing on dead logs and downed woody debris , some wood decay fungi can include facultative necrotrophs which can decay the roots and occasionally the lower stem of a tree (root and butt rots) or infect the stem (heart rot). Examples of common root rot fungi which occur in Thunder Bay include *Onnia tomentosa* (Fr.) P. Karst. (Stand opening disease) and *Armillaria* spp. (Honey mushroom)(Sinclair & Lyon 2005). Examples of stem decay fungi which commonly occur in Thunder Bay include *Ganoderma applanatum* (Pers.) Pat. (artist conk), *Pholiota* spp , *Fomes fomentarius* (L.) Fr. (tinder conk), *Cerrena unicolor* (Bull.) Murrill (Mossy maze polypore) and *Chondrostereum purpureum* (Pers.) Pouzar (Silver leaf disease) (Davis & Meyer 1997, Sinclair & Lyon 2005).

1.5 HAZARD TREES

A hazard tree is a tree that has lost its structural strength and thus has the potential to fail and cause physical damage to a person or property (Matheny & Clark 1994). Other than pathogens, there are only a few factors that can cause structural degradation of trees, including physical damage and chemical changes in wood strength (Lonsdale 1999). Some potential growth characteristics that can lead to hazard trees are large tree height to small trunk diameter ratio and trees with high crown ratios *i.e.*, tree sails (Poukos & Camp 2010). Hazard trees are a major issue within cities if they are not properly dealt with early. Hazard trees have the potential to cause serious damage and harm to people and property during windstorms or other serious weather events if they fail. Hazard trees failing can account for up to 20-50% of all power outages, making them a serious problem in many cities (Poukos & Camp 2010). An example of this issue was the power outage which occurred Thursday August 14, 2003. This power outage was the result of a tree failing and falling on a power line in Ohio resulting in a cascading effect of power outages across the eastern seaboard which had lasting effects over the next five days and was one of the largest power outages in decades (CBC 2003).

A major aspect of hazard tree identification and detection is assessing the potential damage a tree could cause if it were to fail. Some factors that are included in this assessment include the amount of foot traffic in the area of the tree, presence of homes and cars as well as other high value objects that could be damaged (Albers & Hayes 1993, Schwarze 2008). For the purposes of this thesis, these factors were not considered, as health and structure of the tree were felt to be of greater concern than the potential damages a tree could cause by failing. In addition, since most trees included in this thesis are considered street trees, it is expected that all trees have the potential to cause similar levels of damage if they were to fail (*i.e.*, falling on parked cars, hydro lines, people or homes).

1.5.1 HAZARD TREE IDENTIFICATION

Hazard tree identification and evaluation of tree health is an important function of urban forestry that requires training and experience. Currently there are a few methods used to determine if a tree is a hazard tree. One method commonly employed in North America explains that, for a tree to be considered a hazard tree, it has to have less than 1cm of sound wood for every 6cm of stem diameter

(Pokorny, 2003, Schwarze 2008). This is the case if no cavities are present. If cavities are present on less than 30% of the circumference of the stem then there must be 2cm of sound wood for every 6cm of stem diameter (Pokorny, 2003, Schwarze 2008). If a cavity is greater than 30% of the diameter of the stem then the tree is considered to be a hazard (Pokorny, 2003, Schwarze 2008). No attempt has been made to discriminate differences between species in terms of wood strength. This is an area where research needs to be conducted as poplar has very different strength values than an oak and will thus likely fail under different conditions although they are still measured under the same standards. A second method is used in Germany where a crown to diameter ratio is used to help in the decision process of whether a tree is a hazard (Matheny & Clark 1993, Schwarze 2008). To identify precisely the crown to stem ratio percentage, tree pulling techniques have been employed. The tree pulling method is a simple method where a load is placed on a tree and measurements are made on the stem for strain and root lift (Schwarze 2008). This method is largely controversial though, as certain types of decay, such as selective delignification and brittle decay, can have misleading results. A third method is the trunk failure hazard assessment technique (Lonsdale 2003). Lonsdale proposed a series of formulas to predict failure based on the size of the decay column and the amount of solid wood (Lonsdale 2003). Lonsdale's method of assessing trunk failure states that the t/R ratio or radial thickness of solid wood/radius of the stem has to be >0.3-0.35 for trees with full crowns (Schwarze 2008). Although this method is backed by a significantly large data set, there are concerns with the data set. These concerns include species, trees larger than DBH 80cm and other confounding factors such as wind exposure and tree height (Schwarze 2008).

Due to the number of problems a tree encounters in its life time, it is important to look at individual parts of the tree and evaluate them separately to create a better picture of the tree's health as a whole (Albers & Hayes 1993, Matheny & Clark 1994). The parts of the tree that need to be evaluated are health and structure of roots, stem/trunk and of major scaffold branches. The health of small branches and buds/ foliage also need to be evaluated as part of the tree evaluation. Properties that the City forester will be looking for can be broken down into seven categories including decayed wood, cracks, root problems, weak branch unions, cankers, poor tree architecture and dead tree tops and branches. Urban foresters will also take into account the location of the tree in proximity to street lights, hydro poles and other urban structures such as underground utilities that the tree could potentially damage (Matheny & Clark 1994, Pokorny 2003).

1.5.2 WOOD DECAY

Wood decaying pathogens are particularly destructive as they may not only potentially weaken the health of the tree, they also destroy the structural strength of the tree (Lonsdale 1999). Understanding the extent of the decay within the tree and factors promoting the decay of wood is crucial in understanding if the tree is a hazard, because not all trees that contain decay are hazards (Terho 2009). When assessing whether a tree should be felled because of decay, it is important to determine the rate at which the decay is advancing within the tree (Terho 2009). If the decay within the tree is advancing rapidly and not maintaining a steady growth rate, it is a more significant hazard. Also, the location of decay is important. If the decay is restricted to heart wood, then the decay fungi are less detrimental to the overall strength of the tree than if the decay is also found in the sapwood.

There are multiple types of wood decay, but they all can be divided into three large categories, brown rot, white rot and soft rot (Schwarze *et al* 2000). Brown rotters break down the cellulose and hemicellulose of trees leaving only lignin in the wood (Schwarze *et al* 2000). The brown rotter group is made up of only fungi of the Division Basidiomycota which includes mushrooms and bracket fungi. Unlike the brown rotters, the white rot decay group is more diverse. White rotters are made up of not only members of the Basidiomycota, but also members of the Ascomycota. Like the diversity of species that cause white rots, the speed of decay of the cellulose, hemicellulose, and lignin also varies greatly between species. White rotters can generally be broken into two further classes, those responsible for selective delignification (*e.g.*, pocket rot) and those responsible for simultaneous rot. The final group of wood decayers are the soft rotters. This group is quite different than the first two groups, with their distinctive feature being that the hyphae of these species grows within the secondary wall of the wood. This type of rot often forms recognizable cavities orientated longitudinally to the cell axis. The group of fungi that form this type of rot are found within the Ascomycota.

1.5.3 CRACKS

Cracks are defects in trees that occur when the load on a tree exceeds the ability of the tree to hold the load (Pokorny 2003). Cracks are defined as separations in wood resulting in splits through solid wood and bark (Pokorny 2003). The most common type of cracks are vertical cracks which run vertically along the stem of the tree. Vertical cracks can further be broken down into three types of cracks. Shear cracks which is the most common, simply a split in the stem (Figure 2). Shear cracks have a high risk of leading to tree failure as the structure of the tree is compromised (Pokorny 2003). In-rolled cracks are where the margins of the cracks roll inside the stem. In-rolled cracks are detrimental to the health of the tree as wood decay fungi are always associated with in-rolled cracks (Figure 2) (Pokorny 2003). Finally, ribbed cracks result in a raised rib of wood formed when the tree tries to seal a wound. The crack is a result of cold temperatures and the expansion and contraction of wood (Pokorny 2003). Frost cracks are often the reason for the formation of this type of wound. Frost cracks occur when water enters the wood in some pre-existing damage and freezes causing an expansion of the wood and a crack. The process of healing over this type of wound in the summer and re-cracking in the winter causes the characteristic ribbing pattern in the wood. Frost cracks are a common sight and one of the largest damages occurring on street trees in Thunder Bay. Horizontal cracks are the least frequently occurring type of crack. Horizontal cracks, are cracks, runs horizontally across the grain of the tree. Horizontal cracks occur when the load on the tree is significant and the downward force of the crown tears fibers in the stem of the tree (Figure 2). These cracks always result in tree failure (Pokorny 2003). All cracks on trees should be assessed as many can lead to failure of the stem of the tree causing the tree to fall and potentially cause damage.

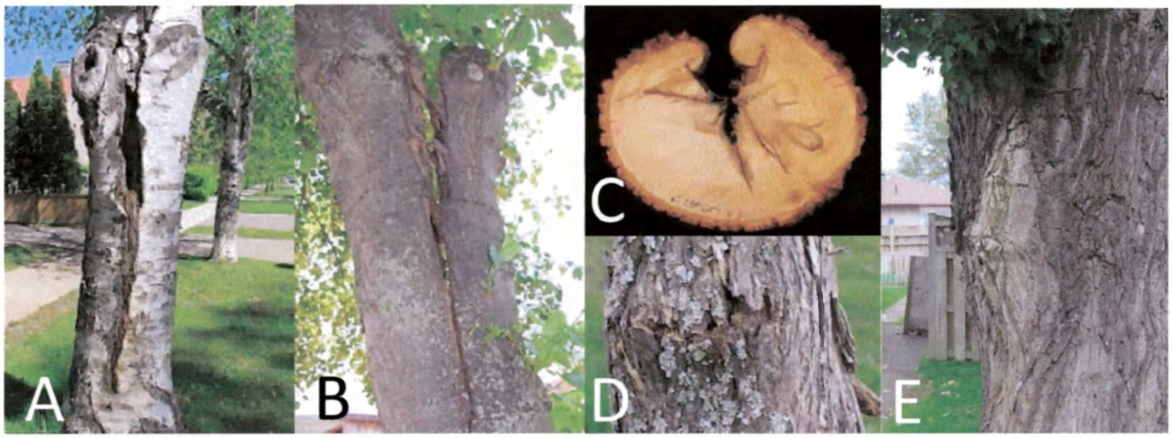

Figure 2: Examples of cracks seen in an urban forest. A. Vertical Crack, B. Sheer Crack, C. In Rolled Crack, D. Horizontal Crack E. Ribbed Crack.

1.5.4 ROOT FAILURE

Root failure is without question a major hazard and occurs when the roots are no longer structurally sound enough to hold the weight of the trunk and crown of the tree (Pokorny 2003). Root failure occurs as a result of physical damage from construction, soil compaction, grading, trenching, paving, fungal decay, drought, flooding and other environmental factors (Pokorny 2003). Roots can also create hazard trees if roots are bunched up and crisscrossed when planted. The bunched up roots can eventually grow large enough to girdle themselves killing large supporting roots. This problem can be solved by proper root pruning when the tree is initially planted. Root failure is a major problem because if the roots of a tree are not strong enough to hold the weight of the tree, it is likely the tree will fail in heavy wind events. Two significant wind events in Thunder Bay within the past few years resulted in many trees falling over due to root rot, especially in and around Boulevard Lake (Hutchison pers. comm.).

1.5.5 WEAK BRANCH UNIONS

Weak branch unions occur as a result of two factors: included bark and epicormic branching (Pokorny 2003). Included bark occurs over a period of time when two branches closely spaced grow together slowly over time (Pokorny 2003). As the two branches come into contact with each other, the bark of the two branches get enclosed creating a weak area as bark does not adhere to wood. Included bark can also occur between a single branch and the main trunk of the tree creating a weak union. Branches supported by included bark will eventually all become hazards as the tree will not be able to structurally support the weight of the branch over time. Epicormic branches and water sprouts are also hazards, because they grow quickly and are not deeply attached to the stem of the tree like normal branches are. Weak branch unions are a major hazard as they can lead to large scaffold branches falling and potentially causing serious damage.

1.5.6 CANKERS

Cankers are areas of dead wood and cambium on the stem or branches of a tree (Pokorny 2003). Cankers can be caused by fungi, insects, lightning and mechanical damage (Pokorny 2003). Cankers create hazards as the tree continues to add layers of wood to the entire tree except to the dead area with the canker. This creates a weak area in the stem or branches of the tree. Cankers caused by fungi can also lead to girdling and death of the branch or stem. Trees are considered to be high hazards when cankers cover more than 40% of the stem.

1.5.7 POOR ARCHITECTURE

Poor architecture is a growth pattern exhibiting a structural imbalance and an associated structural defect such as decay, cracks, weakened roots or cankers (Pokorny 2003). The most common and most noticeable defect is a leaning tree or an overloaded branch such as a branch pruned into a lion tail shape (Pokorny 2003). Trees are considered to be hazardous when the lean of the tree is greater than 40^0 or there is a defect associated with the lean of the tree. Poor architecture is a problem as it produces stress and loads on a tree which are unnatural and when any other structural defect is associated with it, the tree is unable to respond properly.

1.5.8 DEAD TREE TOP OR BRANCHES

Dead top or branches are easily defined as dead branches in the crown of the tree. Dead branches can be a hazard as normally they are already structurally compromised by whatever caused the death of that branch (Pokorny 2003). Even if the branch is not structurally compromised, it is likely that decay fungi will quickly enter the branch and cause decline in the structure of that branch (Pokorny 2003). Structurally compromised branches can quickly fail and fall on people or property and cause damage.

1.6 TREE PROBLEMS SPECIFIC TO TREE SPECIES

The characteristics listed previously are general problems that can occur with many tree species; however, there are issues that seem to occur more often to particular tree species than others. The major street trees in Thunder Bay include *Acer saccharinum* L, *Betula papyrifera* Marsh, *Fraxinus pennsylvanica* Marsh, and *Tilia* spp. and some of the problems specific to them are listed below.

1.6.1 ACER SPECIES

The largest problem occurring for species of *Acer* is forking of the main stem and scaffold branches (Gibbs & Greig 1990, Pokorny 2003, Terho 2009). The resulting included bark of a fork is a potential entry point for decay fungi and a very weak structural point on a tree (Gibbs & Greig 1990 Pokorny 2003, Terho 2009). It has been found that *Acer* does have the ability to efficiently compartmentalize decay, however, the methods it employs are not as effective as other street tree species such as *Tilia* (Terho & Hallaksela 2008). In a study done of street trees in New Jersey, *Acer saccharinum* had the highest occurrence of disease (Tate 1986). Maples, and specifically silver maple, have been found to be susceptible to ice and storm damage (Hauer *et al* 1994). Common pathogenic fungi that attack *Acer saccharinum* L. include *Verticillium albo-atrum* (Verticillium wilt), the canker causing fungi *Nectria galligena* Bres. (Nectria Canker), *Nectria cinnabarina* (Coral spot disease), *Eutypella parasitica* R.W. Davidson & R.C. Lorenz (Eutypella canker), the root rot fungus *Armillaria mellea* and species of fungi that attack the trunk such as *Fomes fomentarius*, *Climacodon septentrionale* Fries. and *Ganoderma applanatum* (Burns et, al. 1990, Sinclair & Lyon 2005).

1.6.2 BETULA SPECIES

One of the largest problems with *Betula* in terms of tree decline in urban areas is crown dieback (Pokorny 2003, Terho *et al.* 2008). Crown dieback is a general discoloration of leaves and dead branches in the crown (Pokorny 2003, Terho *et al.* 2008). *Betula* species generally have problems containing vertical spread of disease and rot up the stem of the tree into scaffold branches (Main Branches). In general, *Betula* is also not drought stress tolerant which often leads to its general decline in cities. White birch (*B. papyrifera* Marsh.) specifically is also very sensitive to soil compaction and flooding around its roots (Johnson 1999, Pokorny 2003). Some very common decay fungi found in studies have been species of *Pholiota*, *Cerrena unicolor*, *Fomes fomentarius* and *Inonotus obliquus* (Ach. Ex Pers.) Pilát (Erkkilä & Niemelä 1986, Johnson 1999, Sinclair & Lyon 2005). Birch is also attacked by many insects, but one specific opportunistic insect that is a major problem in Thunder Bay is bronze birch borer (*Agrilus anxius*) which preferentially attacks drought stressed trees (Burns & Honkala. 1990).

1.6.3 FRAXINUS SPECIES

There are relatively few studies that have examined green ash (*Fraxinus pennsylvanica* Marsh.) in urban environments and the common problems and diseases associated with it. A few of the problems reported to be associated with ash are weak branch unions, poor architecture and branch breakage (Pokorny 2003). Green ash is susceptible to storm and ice damage (Hauer *et al* 1994, Johnson 1999, Pokorny 2003). The main problem now associated with ash is the emerald ash borer (*Agrilus planipennis*). The ash borer has not yet reached Thunder Bay, but it will likely reach the area at some point in the future. Secondary problems that occur often in urban areas associated with ash are ash anthracnose (*Gnomoniella fraxini*) and ash flower gall mite (*Aceria fraxinivora* Felt)(Sinclair & Lyon 2005). There are only a few major wood decay fungi that are closely associated with green ash, such as *Perenniporia fraxinophila* (Peck) Ryvarden; and *Dendrothele macrodens* (Coker) P.A.Lemke. Most of the closely related species only cause minor wood decay (Farr et al. 1989, Burns & Honkala 1990). There is, however, a root rot fungus *Phymatotrichum omnivorum* Duggar. commonly associated with green ash that can cause major damage but, Thunder Bay is outside the natural range of this fungus (Percy 1983, Burns & Honkala 1990).

1.6.4 TILIA SPECIES

Tilia spp. are generally very good compartmentalizers of rot with the majority of rot only occurring in heartwood (Terho & Hallaksela 2008). *Tilia* have been reported to have a problem with double leaders and included bark which leads to potential for splitting. Branch breakage is common on ageing trees as well as roots sensitive to soil (Johnson 1999, Pokorny 2003). American linden (*Tilia americana* L.) has been found to be more sensitive to storm and ice damage than littleleaf lindens (*Tilia cordata* Miller)(Hauer *et al.* 1994). Commonly occurring decay fungi on *Tilia* spp are *Pholiota* and *Hypholoma* (Alden 1995). The exact species of many of the *Tilia* in Thunder Bay are hard to determine as all are cultivars and do not occur naturally. However, their closest relative that occurs naturally would be *Tilia americana*. It has been reported that little decay naturally occurs in *Tilia*, until past the age of 120, which makes it a very useful urban street tree species (Burns & Honkala 1990).

1.7 PREVENTION OF HAZARD TREES AND MITIGATION

The first step to reducing and preventing hazard trees and tree failure in a city is to implement a tree risk management program. A tree risk management program is designed to assess and remove or mitigate the potential for hazard tree failures in a community (Pokorny 2003). A tree risk management program can be broken down into ten steps, seen below, which cover the process of evaluating and reducing the number of hazard trees (Pokorny 2003):

Assess the tree resource*: The completion of a tree inventory which can provide the value of the urban forest as well as future associated costs such as planting, pruning, removal and maintenance. The tree inventory should also assess needs across the city i.e., more plantings.*

Review current tree management practises*: This process will familiarize the urban forester with current urban forest goals, potential areas for improvement as well as a review of programs already in place.*

Assess fiscal and human resources available to manage the tree resource*: Create a better understanding of resources available to the urban forester as well as areas where manpower or resources may be lacking to accomplish certain goals.*

Identify program goals*: This process will assist in identifying new goals as well as affirming past goals related to the urban forest. In this stage individuals should be consulted from differing areas that are involved or should be involved in the urban forest.*

Formulate a tree risk management strategy*: This step involves producing a method to inspecting, preventing and correcting hazardous defects and situations in the urban forest.*

Prioritize inspection and corrective action needs*: To complete this section a city must be divided into zones based on risk factors for tree failure. Minimum inspection methods should be determined based on risk zone where trees are located and corrective measures should be prioritized based on level of importance.*

Select a tree risk rating system: *A rating system should be established and standardized for the city to help prioritize level of importance for tree corrective programs.*

Write a comprehensive tree risk management program policy: *This is a written document that states the responsibilities of the municipality as well as its citizens and all the standards and practises being implemented by the City in terms of managing hazard trees.*

Implement a tree risk management strategy: *This step involves the hiring and training of staff as well as proceeding to implement the strategy in the urban forest.*

Evaluate and revise: *To ensure that all goals are being fulfilled, the impact of this program on the urban environment should be evaluated and altered to ensure the highest levels of efficiency.* (Pokorny 2003).

To attain the best results with a tree risk management program it should be closely tied to all other aspects of the urban forest including tree pruning and maintenance, tree planting and emergency response programs (Pokorny 2003). These programs need to closely work together to make the best use of resources available (Pokorny 2003). For example, if these programs are not closely aligned, tree planting programs may plant trees in areas determined to be high risk which may be counterproductive as more maintenance is required for trees in high risk zones.

Once a tree is designated as a hazard, there are a relatively few options to repair or resolve the problem. The options that are available include moving an object which could be potentially damaged, (*e.g.,* benches); correcting the tree using pruning, cabling and bracing; converting the tree to a wildlife tree; closing the area around the tree and, finally, removing the tree (Pokorny 2003). In most cases removal of the tree is the best option as all the other options simply delay the final solution or mitigate damages if the tree were to fall (Pokorny 2003). The first option is to remove anything that can be damaged by the tree's fall. This option is only useful in areas with little foot traffic and where objects are easily moved from the danger area. This option is not used in high traffic areas as the tree could potentially fall on a person (Pokorny 2003). The second step to mitigating damages is pruning of the tree. This is a common method used as it removes dead branches, decay cracks, weak branch unions and other features of a tree that are dangerous or potentially interfere with other objects such as utility lines. This is a relatively short term solution. Depending on the size of the pruning the tree may be unable to heal over the wound properly leading to decay and other problems in the tree. Trees pruned at a young age may receive benefits that will lead to a tree with a longer and safer life span (Pokorny 2003). The third option is cabling and bracing. This is an expensive option that requires a high level of skill and expertise. Improper cabling and bracing can actually lead to the failure of a tree as it can create a load on an area of a tree unable to support and respond fast enough to the new load. It is an option however for high value trees with cultural significance or landmark trees (Pokorny 2003). The fourth option is to convert a tree to a wildlife tree. This is a good option for trees in wooded areas with little foot traffic near the tree. Wildlife trees can include standing dead trees, trees standing with advanced rot or a tree already down with only a stump remaining. Each provide different benefits to wildlife and the area around the wildlife tree. To attain the most benefit from a wildlife tree, the tree should be of a large size. The final option is complete removal of the tree. This is the best option when the tree is a high to medium risk tree in an area with high foot traffic and the tree has potential to fail and cause serious damages. This is a good option also for a variety of situations where a tree can potentially fail even if the tree will not cause significant damage from falling but still poses a small threat.

1.8 TREE DEFENCES

Unlike animals, trees are unable to repair damaged tissue themselves when they are wounded (Shigo 1985). As trees cannot repair their cells, they require a system to respond to wounds and control the advancement of decay within the rest of the tree. This system is called CODIT or Compartmentalization Of Decay In Trees (Shigo & Marx 1977). CODIT is a complicated response of the tree to reduce the movement of decay fungi throughout the rest of the tree (Figure 3). CODIT does this by first blocking all the vertical vascular cells; tracheids in conifers and vessels in hardwoods, above and below the wound with tylosis, gum deposits, pit asperations *etc.* (Figure 4) (Shigo 1979, Shigo 1984). Tangential walls in the wood are created at the end of each growth ring and are continuous around each growth ring (Shigo 1979, Shigo 1984). This tangential wall stops the outward movement of decay on the horizontal axis of the tree. Ray cells make up the radial walls restricting the movement of decay in the same direction as growth rings around the tree. A tree is able to form a new wall around the wound in the form of cambium which will separate the wound within the tree from healthy wood growing around the wound (Shigo 1979, Shigo 1985). CODIT is not only a strong physical barrier to the movement of decay fungi within a tree but it is also a chemical barrier as well. When a tree is wounded, it is capable of producing chemicals in the wounded area restricting the ability of decay fungi to infect the rest of the tree (Schwarze 2008). This is partially the reason for the discoloration in wounded areas (Schwarze 2008). To account for their weakened structure, trees compensate by producing thicker annual rings. Where the thicker annual rings are located depends on not only the location of the wound but also whether the tree is deciduous or coniferous (Pokorny 2003).

Figure 3: Stem showing a wound and the location of the CODIT response (Shigo 1979 Images by Carol 1979).

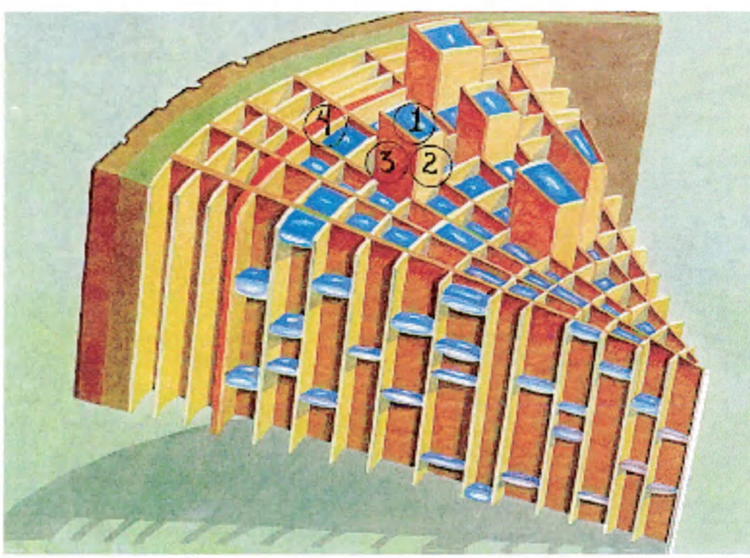

Figure 4: A section of a tree where the CODIT response is taking place. The numbers refer to CODIT's response to limit movement of decay fungi in the 1.vertical axis 2. tangential axis 3. radial axis, and 4. the restrictive zone between wound and new growth of wood (Shigo 1979, Images by Carol 1979).

1.9 DETECTION OF WOOD DECAY USING A RESISTOGRAPH

There are many methods to detect wood decay in trees without cutting them down. Some of these methods include using an electrical conductivity meter such as a shigometer, constant feed drills, single pulse sonic and ultrasonic measurements, breaking core samples and computerized tomography. Each of these methods have positive and negative aspects. Core sampling, use of an electrical conductivity meter and drilling are very intrusive, but in some cases provide more reliable data. On the other hand, computerized tomography and single pulse sonic and ultrasonic measurements are less invasive, but require more training, cost more and have the potential to produce incorrect readings due to noise. Of the methods presented above, drilling, or more specifically resistographs, offers a inexpensive, minimally non-invasive and relatively accurate measurement of the amount of decay present in a tree (Nicolotti & Miglietta 1998, Costello & Quarles 1999, Johnstone *et al.* 2010). A resistograph is a device that measures the density of wood based on the resistance a portable drill encounters when drilling into the tree. The resulting densities are graphed on a chart. To determine when decay is hit, the operator watches the graphed densities until there is a significant drop in density meaning the drill has hit weaker decayed wood. Multiple authors have agreed that the resistograph is a reliable and accurate choice (Nicolotti & Miglietta 1998, Costello & Quarles 1999, Johnstone *et al.* 2010). Although the resistograph is relatively non-invasive, it has been shown in some cases to lead to an increase in the spread and rate of decay within a live tree (Kersten & Schwarze 2005). However, the resistograph is unlikely to spread material from an infected tree to a healthy tree due to the shape of the resistograph drill bit (Kersten & Schwarze 2005). The flared tip of the resistograph drill bit is difficult for spores to be transferred on, opposed to bores in standard drill bits which allow easy transportation of spores and fungal material (Kersten & Schwarze 2005).

1.9.1 FACTORS LEADING TO RESISTOGRAPH ERRORS

Some of the factors that can greatly influence the accuracy of the resistograph readings are temperature, moisture content, drill bit angle, drill bit deflection and operator error (Rinn *et. al.* 1996, Chantre & Rozenberg 1997, Lin *et al.* 2003, Ukrainetz & O'Neil 2010). Moisture content has been shown to alter densities between dead trees with low moisture contents and live trees with high moisture contents (Ukrainetz & O'Neil 2010). As moisture content drops in wood, resistograph resistance increases (Lin, *et al.* 2003) Moisture content within live trees may vary enough to alter resistograph readings. Drill bit angle has been shown to be highly significant with differences seen between a drill bit alignment at 0^{0} and 20^{0}. Drill bit deflection has also been shown to negatively affect resistograph readings (Ukrainetz & O'Neil 2010). It has been shown that readings of a drill bit passing within 3cm of a knot were found to have errors; however, past 3cm the changes in resistograph readings were negligible (Ukrainetz & O'Neil 2010). Curved and meandering contours in wood as well as distortion of the drilling profile can lead to resistograph reading errors. Operator error was the final factor found to affect resistograph readings. Operator movements can cause spikes and valleys in resistograph readings leading to misinterpretation of results or other errors (Ukrainetz & O'Neil 2010).

1.9.2 RESISTOGRAPH USES

Resistographs have been shown in the literature to be effective tools for detecting wood decay and abnormalities in wood which can cause failure in hazard trees (Nicolotti & Miglietta 1998, Costello & Quarles 1999, Johnstone *et al.* 2010). Some research has also been done to understand whether a resistograph can be used as a tool for other tree measurements. Other uses of the resistograph include the detection of fire calluses, tree ring detection and densities and density measurements to use in tree selection programs (Rinn 1996, Isik & Li 2003, Stambaugh *et al* 2008). To detect fire calluses, trees in previously burned sites were felled and tree discs were removed from the tree (Stambaugh *et al.* 2008). The tree discs were then brought back to the lab and resistograph readings were drilled within three days of the tree being felled (Stambaugh *et al.* 2008). The study found that the resistograph was a useful tool for detecting fire calluses; however it was very difficult to differentiate between fire scars and other damages found in a tree such as lightning damage, cracks and other agents causing damages in wood. Newer resistographs can make a numerical measure of amplitude which has been found to be closely related to density in wood (Isik & Li 2003). By using amplitude measurements, trees can be selected which contain high densities and used in tree improvement programs (Isik & Li 2003). The use of a resistograph to identify trees with high densities for tree improvement is accurate, quick and only minutely invasive in comparison to older methods of tree selection. Resistographs have been useful in determining tree ring density measurements (Rinn 1996, Rinn *et al.* 1996). The change in resistance between early wood and late wood is recorded on resistograph readings and has been generally reliable with the assumption that none of the factors listed above which can affect resistograph readings are present.

1.10 WOOD STRENGTH TESTING AND CORRELATION WITH RESISTOGRAPH READINGS

Currently in the literature there is little science to relate wood strength values to resistograph resistance measurements. If resistograph measurements could be related to wood strength measurements, then resistograph measurements would more accurately measure the chances of failure in hazard street trees. Minimum wood strength values could be determined for trees based on species, moisture content (MC) and DBH. The resistograph could be used as a tool to quickly measure wood strength values in trees once tree species, MC and DBH have been factored into the equation. One study suggests that a relationship does exist and presents an equation for calculating modulus of elasticity (MOE) based on resistograph values; however it has yet to be further tested (Tsai 2003). The wood strength values that will be examined and compared to the resistograph readings include MOE and wood density/specific gravity. These wood strength measurements have been selected based on their common use in wood strength testing research. There are many factors which affect wood strength that need to be accounted for to relate wood strength measurements to resistograph readings. These factors include MOE, density, variability of wood strength within a tree, moisture content and tree size.

1.10.1 MODULUS OF ELASTICITY

The modulus of elasticity is a measure of wood's ability to recover or the resilience of the material to return to its previous state after a load or strain is placed on the wood. An example of the modulus of elasticity is shown in Figure 5. The straight line on the graph represents the ability of the wood to withstand a load and recover (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). Once the wood sample reaches the limit of proportionality, the load is too great to recover causing the wood sample to curve and permanently setting the wood (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). The load continues to increase until the wood reaches the maximum load it is capable of supporting causing a rupture. Modulus of elasticity is measured to determine the loads that wood is capable of supporting until it permanently sets and eventually ruptures. This knowledge could potentially be important when evaluating whether a tree is a hazard as it can give an exact value as to when the wood may rupture and no longer be able to support the weight of the tree based on the extent of decay and loads on the crown of the tree from wind, *etc.*

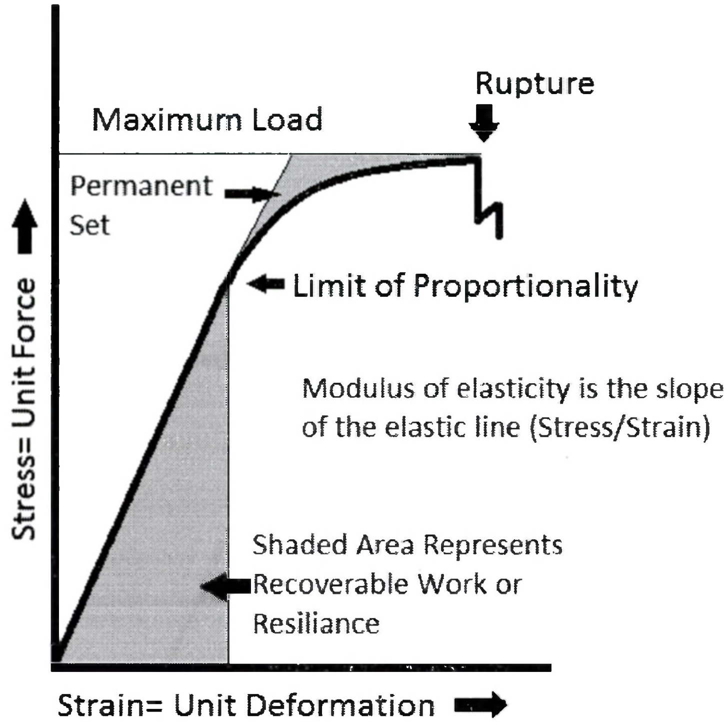

Figure 5: Diagram of idealized modulus of elasticity until failure (Panshin & Zeeuw 1980).

1.10.2 WOOD DENSITY AND SPECIFIC GRAVITY

Wood density is the combination of the specific gravity of wood and moisture content (Simpson 1993). Specific gravity is the relative amount of solid cell wall material making it the best measurement for predicting wood strength (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). Density is closely correlated to the resistograph readings making it a useful value to apply to resistograph readings but they are not perfectly correlated suggesting some error could occur (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007).

1.10.3 WOOD STRENGTH VARIABILITY

Wood strength is variable and a result of many factors. Wood strength can differ within a single tree, between trees of the same species and between trees of different species (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). Juvenile wood, transition wood, mature wood and reaction wood all greatly vary in strength and properties (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). A single tree has the potential to contain all of these variables making wood strength vary between different sections of the tree. Environmental conditions can also play a role in wood strength, which can cause variability of wood strength within species in different environmental situations. Tree species also plays a major role in the strength of wood as differing tree species contain different properties altering overall use and wood strength elasticity and hardness values. Due to the large potential for variability of wood strength within trees, predicting whether a tree will fail based on wood strength is a difficult task.

1.10.4 MOISTURE CONTENT

Moisture content is a major factor affecting wood strength of trees and lumber products (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). As moisture content in wood increases the relative wood strength decreases. The relationship between moisture content and wood strength can be seen in Figure 6. Moisture content is an important variable to measure as live trees have high moisture contents and wood testing is done on wood dried to approximately 12% (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). The loss of wood strength as a result of the increase in moisture content of a live tree should be accounted for if the resistograph becomes a viable tool for measuring wood strength in live trees.

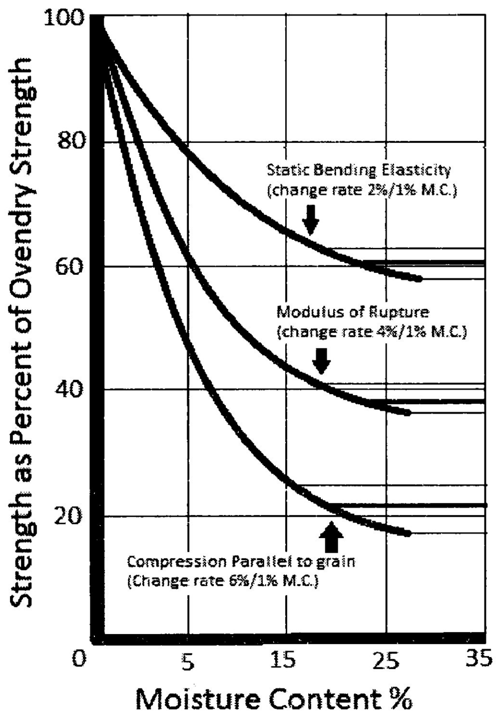

Figure 6: Effect of change in moisture content by strength as percent of oven dry strength. (Panshin, Zeeuw 1980).

1.10.5 DBH AND SIZE OF TREE AS A FACTOR AFFFECTING TREE STRENGTH

Diameter and size are important factors when determining if a tree is a hazard tree as larger trees have more factors affecting wood strength than smaller trees. Larger tree strength values are more difficult to predict as large trees will contain heartwood, sapwood, juvenile wood and mature wood which all affect wood strength (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). Larger trees also have more biomass associated with them creating more weight to bear for the stem and roots of the tree. As a result, larger trees should be more closely examined to determine wood strength. Larger trees also have a greater chance to cause more damage if they should fail.

1.11 STATE OF THE URBAN FOREST IN THUNDER BAY

1.11.1 THUNDER BAY

The study area for this research is the City of Thunder Bay, Ontario, Canada, located approximately 48°23' 50. 82"N and 89°15' 40. 52"W with an elevation of approximately 194m. Thunder

Bay is surrounded by the Boreal forest to the North and West of the city and Lake Superior to the South and East. Thunder Bay is situated in a unique climate area as there is a strong lake effect from Lake Superior that changes the micro climate of the city. Thunder Bay is located in the plant hardiness zone 3a due to the warming effect of Lake Superior, but directly on the edge of zone 2b (Natural Resource Canada 2012) (Figure 7). Plant hardiness zones designate where trees of certain species are capable of living due to climate restrictions (Natural Resource Canada 2012).

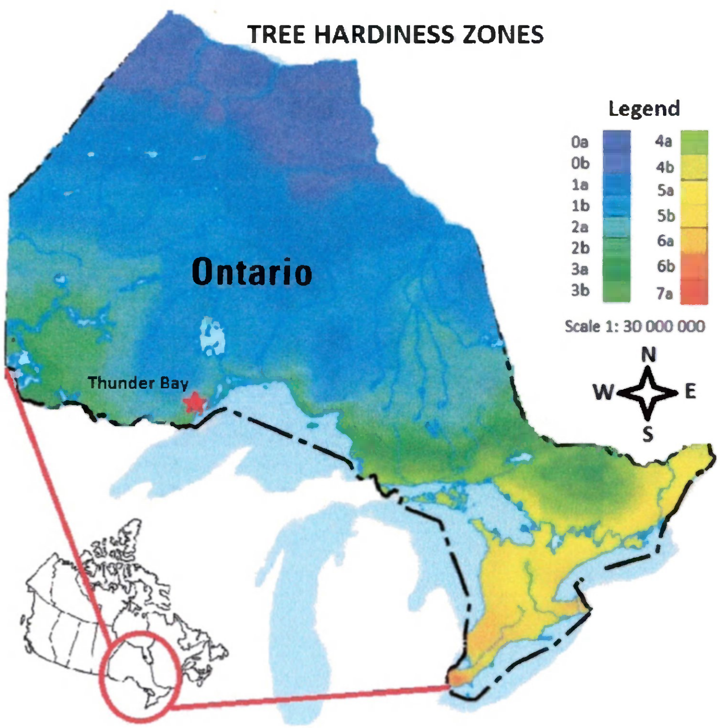

Figure 7: Tree Hardiness zones of Ontario with the location of Thunder Bay, Ontario Identified (Natural Resource Canada 2012).

1.11.2 HISTORY OF THE URBAN FOREST IN THUNDER BAY

Urban forestry in Thunder Bay, formerly Port Arthur and Fort William prior to 1970, started as early as 1886 with large plantings of poplar in Waverley Park and subsequent pruning of park trees in Waverley, Vickers and Dease parks in the 1930's (Davey Resource Group 2011). Eventually the City moved to planting boulevards in the latter half of the 20th century, however these plantings were sparse, sporadic and done without an overall vision or plan for the urban forest (Davey Resource Group

2011). There was no direct management or planning of the urban forest until 1995 when the City employed a consultant forester to advise and oversee operations of urban forest projects. A year later an advisory committee was established to further advise the consultant forester and Parks Division as well as establishing a connection with the community. The first advocacy group for the protection and future protection of the urban forest was Trees Thunder Bay. The group started in 2000, and at the height of its membership, contained as many as 2000 members. In 2001 the City also acknowledged for the first time the need for direct management of the urban forest. From the years 1999 until 2001 an inventory was conducted in the City of all boulevard trees and available planting spots for trees in the city (Wilson 2006). This inventory concluded there were 20 000 municipal street trees currently in the City of Thunder Bay, however there were an additional 10 000 planting spots which were yet to be utilized (Davey Resource Group 2011, Wilson 2006). These street trees have been estimated to be valued at $37 million (Kurikka 2012). The city did not reach its next major milestone until 2005 when the first public tree bylaw in Thunder Bay was implemented (Vescio 2005). In the following years, a tree stewardship program was undertaken to increase the number of trees planted, a citizen pruner program created, and an urban forestry website created to increase public knowledge and awareness (Wilson 2006). Currently it is estimated that in the last five years more trees have been removed than planted which suggests a negative trend towards the total number of street trees in Thunder Bay (Dunick 2012).

1.11.3 PRESENT STATE OF THE PUBLICALLY OWNED URBAN FOREST IN THUNDER BAY

Currently the most commonly occurring street tree species in Thunder Bay is *Fraxinus pennsylvanica* (green ash) comprising approximately 26% of street trees (Table 2) (Davey Resource Group 2011). Green ash is followed by *Acer saccharinum* (silver maple), *Tilia* spp (Basswood/ Linden) and *Betula papyrifera* (white birch) as the next most commonly occurring species with each representing 18%, 8% and 8% respectively (Table 2) (Davey Resource Group 2011).

Table 2: Percent of the 20 000 publically owned street trees by species (Davey Resource Group 2011).

Species	Number	Percent
Green Ash	4,661	26%
Silver Maple	3,245	18%
Linden/ American Basswood	1,440	8%
Paper Birch	1,406	8%
White Spruce	772	4%
Crab Apple Hybrids	732	4%
Black Ash	537	3%
Manitoba Maple	502	3%
American Elm	383	2%

In the 2001 inventory approximately 85% of the city street trees were rated as good, 8% rated as fair, and 1% rated in the poor condition (Table 3) (Davey Resource Group 2011). However, since 2001, the condition of the urban forest has decreased as is natural over time and it is more likely that there are significantly more trees appearing in the moderate, fair and poor categories. Currently in the city the oldest cohort of trees are white birch and silver maples. These two species represent the majority of old declining trees within the City of Thunder Bay. Their decline is generally due to age although the bronze birch borer has been found to be a major factor currently affecting the decline of white birch in the city.

Table 3: Condition of publically owned street trees (Davey Resource Group 2011).

Condition	Percent of Trees (%)
Perfect	0.2
Good	84.9
Fair	7.4
Poor	0.9
Dead	0
N/A	6.5

The majority of publically owned street trees in Thunder Bay are generally smaller trees in the size class distributions of 1-15, 16-30 and 31-45 cm DBH (Figure 8)(Davey Resource Group 2011). There are significantly fewer trees in the larger size distributions with significant drops in the percentages of trees occurring in the size class 45-60cm DBH and significantly less trees past the size of 60cm DBH (Figure 8) (Davey Resource Group 2011). Figure 8, below shows the change in the percentage of trees across the eight size class distributions.

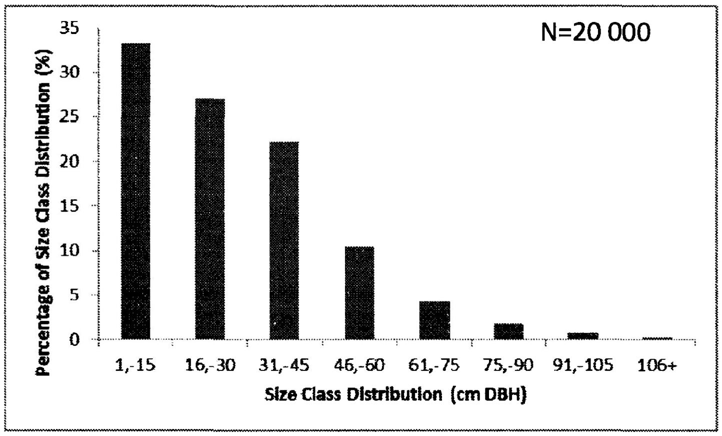

Figure 8: Percent of trees present by size class distribution of publically owned street trees (Davey Resource Group 2011).

1.12 CONCLUSION

The value of the urban forest in Thunder Bay is estimated to be worth as much as $37 million (Kurikka 2012). Due to the value and the many benefits gained, the urban forest needs to be maintained and protected (Miller 1988). Both the abiotic factors (*e.g.*, soils, air quality, chemical injuries, construction, vandalism, weather and mineral deficiencies) and biotic pests (*e.g.,* bacteria, insects and fungi) which occur often in urban areas can lead to stressful growing conditions for trees. Stressful growing conditions can potentially lead to street trees becoming hazards and dangerous to the citizens who live near them. It is the responsibility of the urban forester to address hazardous trees and remove or mitigate damages to the best of their ability.

Although there has been research into assessing hazard trees there are limitations to this research which include the fact that cities such as Thunder Bay are located in northern climates where unique tree health issues occur (*e.g.* Frost cracks). The most commonly used techniques in assessing hazard trees have been shown to potentially contain areas of weakness (*i.e.* differences in wood strength between Oak and Poplar, yet same rule is used) such as not taking into account differences between wood strength of differing species (Schwarze 2008). Assessing hazard street trees is an area where more research needs to be conducted to further assist urban foresters.

By further understanding the relationship between exterior characteristics of trees and interior stem decay the urban forester will have greater potential to more accurately evaluate trees and assess how dangerous they may be. Knowledge of the decay fungi present can also assist the urban forester in creating a hierarchy of tree removal. The use of tools such as the resistograph can further assist with this problem; however it is only a useful tool if reading noise and inaccuracies can be weeded out and we fully understand the abilities of the resistograph.

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CHAPTER 2:
Examining exterior characteristics of hazard street trees in Thunder Bay, Ontario, for the management of urban forests.

2.1 INTRODUCTION

When selecting tree species for planting along boulevards, urban foresters often select species based on climate, soil conditions, specific needs of that planting site (*i.e.,* a shorter tree under hydro lines, large shade trees for parks *etc.*) and species availability. Some things that should also be considered are the types of problems a tree may encounter and develop over the course of its lifetime. However, for an urban forester to include this decision in the tree selection process there must be research which can be applied based on the problems certain species have encountered in similar growing conditions. In a city such as Thunder Bay, which is situated in a harsh climate (hardiness zone 3a), there is little research to base decisions on. Since many of the street trees planted in Thunder Bay are located at the edge of their hardiness zones they may react and develop damage and characteristics unique to their particular location. Similarly, when evaluating a tree's health, unique characteristics and external symptoms may be more detrimental to some tree species than others. The original purpose was to evaluate external damages and characteristics of hazard trees slated for removal to search for any correlations with unseen internal defects in the stem. However, as it will be pointed out in Chapter 3, this did not happen, and thus this chapter will attempt instead to catalogue external damages and characteristics and see if any correlations exist, with age class, tree species, *etc.*

2.2 MATERIALS AND METHODS

To determine if there were common or unique exterior characteristics associated with tree species or age class, a list of hazard street trees selected for felling was provided in 2011 and 2012 by the City of Thunder Bay (Appendix I, II). Each tree on the list was visited and their key external characteristics measured (Terho 2009, Terho & Hallaksela 2005). In addition, the following information was provided: tree species, DBH, location, and date of sampling. Photographs of each tree were taken, as well as close ups of external tree characteristics. General health and structure of each tree was measured by dividing the tree into five sections for evaluation; the roots, trunk, scaffold branches, small branches and buds and foliage (Table 4)(Council of Tree and Landscape Appraisers 2000). Roots, trunk and scaffold branches were given one value for health from 1-5 (one being dead and five being healthy) and one value for structure from 1-5. Small branches and buds/foliage were only given a value for health (Council of Tree and Landscape Appraisers 2000). The rating system can be seen below in Table 4 and Table 5. A rating system is also provided for detrimental exterior characteristics *i.e.,* pruning damage, co-dominant leaders/forks/weak branch unions, frost cracks, physical scrapes as well as other damage encountered (Schein 1993, Matheny & Clark 1994). The rating system for external tree characteristics is a simple scale with 4 pertaining to minor damage ranging down to 1 as major damage. An example of a filled in data collection sheet can be seen in Figure 9. Comments and observations about the exterior characteristics of the tree were also collected and written on the street tree tally sheet as seen in Figure 9.

Table 4: Modified Weicherdings table for establishing condition value for health and structure of hazard street trees (Schein 1993).

Rating	Description
5 Excellent:	Perfect specimen. Excellent form and vigour for species. No pest, disease or mechanical damages present. No corrective work required.
4 Good:	Healthy and vigorous. No apparent signs of disease, insect or mechanical injury. Little corrective work required. Representative of species
3 Fair:	Average condition and vigour. May need corrective pruning or repair. Undesirable characteristics present *i.e.* form, insect or disease.
2 Poor:	General state of decline. Severe problems present, *i.e.* severe mechanical, insect or disease damage present. Death not imminent
1 Dead or dying:	Dead, or imminent death within up coming years. Due to age or mechanical, insect or disease damage.

Table 5: Guide to judging plant condition (Council of Tree & Landscape Appraisers 2000).

Tree Component	Factors Considered in Health Value
Roots	Root anchorage, Collar/ Flare Soundness, Mechanical Injury, Girdling/Kinked Roots, Compaction/Water Logged, Chemical Symptoms, Presence of Insects and Disease. Structure(1-5)+Health(1-5)= Subtotal(2-10)
Trunk	Sound Bark and Wood, Cavities, Mechanical or Fire Damage, Cracks(Frost, Mechanical and Other) Swollen or Sunken Areas, Presence of Insects or Disease. Structure(1-5)+Health(1-5)= Subtotal(2-10)
Scaffold Branches	Strong Attachments, Well Pruned, Well Proportioned, Wound Closed, Presence of Deadwood and Fire Injury, Presence of Insects and Disease. Structure(1-5)+Health(1-5)= Subtotal(2-10)
Small Branches and Twigs	Vigour, Distribution, Appearance, presence of Insects and Disease, Presence of Weak and Dead Twigs. Health(1-5)= Subtotal(1-5)
Foliage and/or Buds	Size of Foliage/Buds, Colouration, Nutrient Deficiencies, Chemical Injuries, Wilted or Dead Leaves, Presence of Insects and Disease. Health(1-5)= Subtotal(1-5)
Total Health Score	Structure(15)+Health(25)= Total Health(8-40)

As shown in Figure 9 there is both a percent value for the total health of the tree and an adjusted health value for the tree. As the scale is a rating from 1 to 5, dead trees received a value of one for areas of the tree that were dead. As a result, a completely dead tree could have a health score of eight out of a possible forty or a health percentage of 20. To account for this, eight was subtracted from the total health score of each tree and given a value out of 32. This allowed for a tree that is completely dead to receive a health rating of 0 out of 100. This is why certain trees were given a negative value such as the tree at 1735 McGregor Ave where parts of the tree were missing upon arrival so it received a negative health percentage.

Tree Condition Tally Sheet

Kurtis Barker			
Date: August 3 2012	Tree#:	Tree Species: Ms	
Location: 123 Arthur St.			
DBH: 65.3			

Tree Condition

Root Condition

Structure(1-5)	Health (1-5)	Subtotal	Observations
3	2	5	Good location for roots lots of room. Lawn mower and weed wacker damage to large roots.

Trunk Condition

Structure(1-5)	Health (1-5)	Subtotal	Observations
2	2	4	Large fruiting body of *Ganoderma applanatum* found. Extensive decay. Small frost crack

Scaffold Branches Condition

Structure(1-5)	Health (1-5)	Subtotal	Observations
3	3	6	believed to be structurally sound. Large pruning wound healing.

Small Branches Condition

Health(1-5)	Subtotal	Observations
4	4	Few dead branches. Generally healthy looking.

Foliage/Bud Condition

Health(1-5)	Subtotal	Observations
4	4	Healthy vigourous foliage thinning in some areas.

Tree Condition Value:	23	**(Value/40)x 100:**	57.5
Tree Condition Adjusted Value:	23	**((Value -8)/32) x 100:**	39.47368

Disease Sample : 123 Arthur St

Disease species /Observations /Decay location:	Photograph # 1324-1335, *Ganoderma applanatum* on stem of tree observed. Hazard as a result of decay in stem. Pruning wound on scaffold branches healing. Small frost crack

Hazard Tree Y/N:	Y				
	1	2	3	4	4 minor- 1 significant
Pruning damage			X		
Fork					
frost crack				X	
Physical scrape					
other					

Figure 9: Example of a filled in street tree tally sheet.

2.3 RESULTS

As shown by Figure 10 the majority of felled street trees were located in what was formerly the residential areas of Port Arthur and Fort William. Few trees were removed from the intercity area of the city or from residential areas located outside the interior of the city *i.e.*, in more exurban type areas. In total, only 11 hazardous trees on the list were located in these exurban type neighbourhoods. All the trees located and sampled in the exurban type neighborhoods were located in front or beside a home and in close proximity to a road. These trees were still designated as street trees and not forest trees grown in a natural setting.

Figure 10: Locations of measured, felled street trees. (Google Earth)

Table 6: Tree species by size classes and their average health condition.

Tree Species by Size Class (DBH)	Count of Species	Average of Root (Damage)/10	Average of Trunk (Damage)/10	Average of Scaffold (Damage)/10	Average of Small Branch (Damage)/5	Average of Foliage (Damage)/5	Health Average (% /100)	[1] Average of Pruning Damage	Count of Pruning Damage	[1] Average of Fork Damage	Count of Fork Damage	[1] Average of Frost Crack Damage.	Count of Frost Crack Damage	[1] Average of Physical Scrape Damage.	Count of Physical Scrape Damage
White Birch	**46**	**5.96**	**4.13**	**3.11**	**2.04**	**2.11**	**29.21**	**2.40**	**15**	**3.21**	**14**	**2.47**	**19**	**2.33**	**6**
0-25	2	6.00	2.00	2.00	1.00	1.00	12.50			1.00	1			2.00	1
26-50	23	5.70	3.83	3.04	1.87	1.96	26.22	2.56	9	3.20	10	2.20	10	1.67	3
51-75	20	6.25	4.75	3.30	2.30	2.35	34.22	2.20	5	4.00	3	2.88	8	3.50	2
No DBH	1	6.00	3.00	3.00	3.00	3.00	31.25	2.00	1			2.00	1		
Silver Maple	**28**	**5.93**	**4.04**	**4.96**	**3.19**	**3.38**	**38.50**	**1.89**	**9**	**1.78**	**9**	**2.00**	**1**	**2.80**	**5**
0-25	2	8.00	5.50	6.00	3.00	3.50	56.25							4.00	1
26-50	1	6.00	4.00	5.00	4.00	4.00	46.88	2.00	1	3.00	1				
51-75	4	6.50	4.75	4.25	2.50	2.50	39.06	2.00	1	2.00	1			1.00	1
76-100	10	6.00	3.70	5.30	3.30	3.50	43.13	1.50	2	1.40	5	2.00		3.00	2
101-126	9	5.11	3.67	4.67	3.33	3.56	38.54	2.00	4	2.00	2				
No DBH	2	6.00	5.00				-7.81	2.00	1					3.00	1
Green Ash	**24**	**6.33**	**4.54**	**3.00**	**1.58**	**1.63**	**28.39**	**2.67**	**9**	**3.29**	**7**	**2.20**	**5**	**2.20**	**5**
0-25	11	5.64	4.18	2.36	1.55	1.27	21.88	2.00	3	3.00	2	2.00	3	2.00	2
26-50	9	7.33	5.33	3.44	1.44	1.89	35.76	4.00	2	3.33	3	2.50	2	3.00	2
51-75	3	6.67	4.33	4.33	2.33	2.33	37.50	2.67	3	3.50	2			1.00	1
No DBH	1	4.00	2.00	2.00	1.00	1.00	6.25	2.00	1						
Manitoba Maple	**16**	**4.88**	**4.87**	**4.47**	**2.33**	**2.60**	**32.03**	**2.25**	**4**	**2.00**	**4**	**3.00**		**2.40**	**5**
0-25	3	4.00	8.50	8.00	3.00	3.00	34.38	3.00	1					2.00	1
26-50	1	6.00	4.00	3.00	1.00	1.00	21.88								
51-75	9	4.89	4.89	4.22	2.56	2.89	35.76	1.00	1	2.00		3.00		2.50	4
76-100	1	6.00	4.00	4.00	2.00	3.00	34.38								
101-125	2	5.00	2.00	3.00	1.50	1.50	15.63	2.50	2	2.00	2				
Trembling Aspen	**10**	**5.00**	**3.70**	**3.30**	**2.00**	**2.00**	**25.00**	**4.00**	**1**	**4.00**	**1**	**1.00**		**1.00**	**1**
0-25	3	6.00	3.33	2.00	0.67	0.67	14.58			4.00	1				
26-50	4	5.25	3.50	4.25	2.75	3.00	33.59					1.00		1.00	1
51-75	3	3.67	4.33	3.33	2.33	2.00	23.96	4.00							
Red Pine	**8**	**10.00**	**9.75**	**5.25**	**1.88**	**1.63**	**64.06**								
0-25	7	10.00	9.71	4.71	1.86	1.57	62.05								
26-50	1	10.00	10.00	9.00	2.00	2.00	78.13								

[1] Pruning damage, fork damage, frost crack damage and physical damage were rated on a scale from 1-4 with 1 being the most severe damage likely causing death to 4 being only minor damage healing properly.

Table 6: Tree species by size classes and their average health condition (Continued).

Tree Species by Size Class (DBH)	Count of Species	Average of Root (Damage)/10	Average of Trunk (Damage)/10	Average of Scaffold (Damage)/10	Average of Small Branch (Damage)/5	Average of Foliage (Damage)/5	Health Average (% /100)	[1] Average of Pruning Damage	Count of Pruning Damage	[1] Average of Fork Damage	Count of Fork Damage	[1] Average of Frost Crack Damage.	Count of Frost Crack Damage	[1] Average of Physical Scrape Damage.	Count of Physical Scrape Damage
Little Leaf Linden	**6**	**6.33**	**3.17**	**6.33**	**3.67**	**3.83**	**47.92**	**3.20**	**5**	**1.75**	**4**	**2.50**	**2**		
0-25	2	7.00	4.00	6.50	3.00	3.00	48.44	3.00	2	1.00	1	1.00	1		
26-50	2	6.00	3.00	7.00	5.00	5.00	56.25	3.00	1	1.00	1	4.00	1		
51-75	2	6.00	2.50	5.50	3.00	3.50	39.06	3.50	2	2.50	2				
Balsam Poplar	**6**	**5.50**	**4.17**	**4.17**	**2.17**	**2.17**	**31.77**			**1.00**	**1**	**2.50**	**2**	**2.00**	**4**
0-25	1	2.00	2.00	2.00	1.00	1.00	0.00			1.00	1			2.00	1
26-50	5	6.20	4.60	4.60	2.40	2.40	38.13					2.50	2	2.00	3
Chokecherry	**6**	**5.17**	**3.33**	**3.83**	**1.67**	**2.67**	**27.08**	**3.67**	**3**	**3.33**	**3**	**2.50**	**2**	**1.00**	**1**
0-25	6	5.17	3.33	3.83	1.67	2.67	27.08	3.67	3	3.33	3	2.50	2	1.00	1
Jack Pine	**5**	**3.80**	**3.00**	**2.00**	**1.00**	**1.00**	**8.75**	**3.50**	**2**					**3.00**	**1**
0-25	1	10.00	6.00	0.00	0.00	0.00	25.00							3.00	1
26-50	4	2.25	2.25	2.50	1.25	1.25	4.69	3.50	[illegible]						
Hawthorn	**4**	**3.25**	**2.50**	**2.25**	**1.25**	**1.25**	**7.81**								
0-25	4	3.25	2.50	2.25	1.25	1.25	7.81								
White Spruce	**4**	**3.00**	**2.75**	**2.75**	**1.50**	**1.50**	**10.94**	**2.00**	**2**	**4.00**	**2**	**3.00**		**1.50**	**2**
0-25	1	2.00	2.00	2.00	1.00	1.00	0.00	1.00	1	4.00	1				
26-50	3	3.33	3.00	3.00	1.67	1.67	14.58	3.00	1	4.00	1	3.00		1.50	[illegible]
American Elm	**3**	**8.67**	**7.33**	**2.67**	**1.33**	**1.67**	**42.71**			**2.50**	**2**				
26-50	2	10.00	8.00	3.00	1.50	1.50	50.00			3.00	1				
51-75	1	6.00	6.00	2.00	1.00	2.00	28.13			2.00	1				
Flowering Crab Apple	**3**	**5.67**	**4.33**	**4.67**	**2.33**	**2.67**	**36.46**	**3.00**	**2**	**3.50**	**2**				
0-25	3	5.67	4.33	4.67	2.33	2.67	36.46	3.00	2	3.50	2				
Schubert Chokecherry	**2**	**5.00**	**4.50**	**4.50**	**1.50**	**3.00**	**32.81**	**3.00**	**1**	**2.00**	**1**				
0-25	2	5.00	4.50	4.50	1.50	3.00	32.81	3.00	1	2.00	1				
Lombardy Poplar	**2**	**6.00**	**6.00**	**5.00**	**2.00**	**2.00**	**40.63**								
26-50	2	6.00	6.00	5.00	2.00	2.00	40.63								
Balsam Fir	**2**	**4.50**	**3.50**	**4.00**	**2.00**	**2.00**	**25.00**								
26-50	2	4.50	3.50	4.00	2.00	2.00	25.00								
Mountain Ash	**1**	**8.00**	**4.00**	**4.00**	**3.00**	**3.00**	**43.75**							**2.00**	**1**
51-75	1	8.00	4.00	4.00	3.00	3.00	43.75							2.00	1
Lilac	**1**	**4.00**	**4.00**	**6.00**	**3.00**	**3.00**	**37.50**			**4.00**	**1**				
0-25	1	4.00	4.00	6.00	3.00	3.00	37.50			4.00	1				
Grand Total	**177**	**5.83**	**4.38**	**3.80**	**2.15**	**2.28**	**31.94**	**2.87**	**53**	**2.80**	**51**	**17.91**	**37**	**2.02**	**32**

[1] Pruning damage, fork damage, frost crack damage and physical damage were rated on a scale from 1-4 with 1 being the most severe damage likely causing death to 4 being only minor damage healing properly.

The 177 trees are arranged by species and size class in Table 6. The average health of each tree *i.e.*, the health values for roots, trunk, scaffold branches, small branches and foliage are also provided (Table 6). Additional damages to each tree are also listed including pruning damage, co-dominant fork damage, frost crack damage, and physical scrapes (Table 6). Nineteen tree species are represented among the hazard street trees assessed. The frequency count of each tree species as well as the count of trees occurring in each size class is presented in Figure 11, Figure 12 and Table 6. Also shown in Table 6 are the values for external damages as well as the severity of the damages.

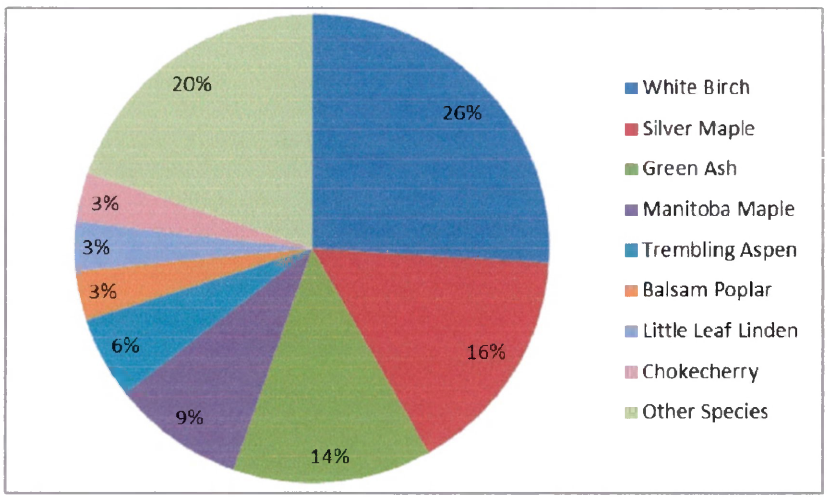

Figure 11: Pie chart of species occurrence and percent.

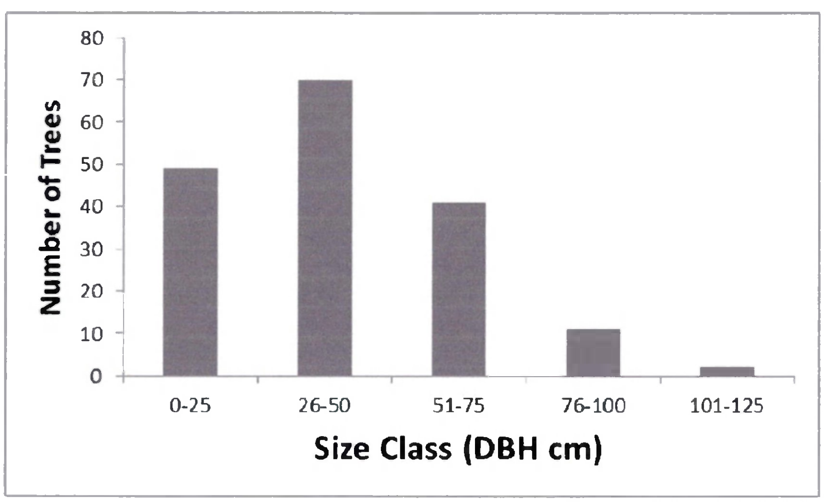

Figure 12: Number of trees per diameter size class.

The most trees examined of any species was white birch. Among the 43 trees in the size classes 26-50 and 51-75cm DBH, there did seem to be a relationship with poor foliage and small branch health (Figure 13 A), which was a major factor in the removal of the trees (Table 6). In the 26-50cm DBH size range, the average foliage health rating was 1.96 and the average small branch health was 1.87 which is very low (Table 6). Cracks were the largest occurring problem for white birch on 19 of the 46 trees externally examined (Table 6). Scaffold branch health was also shown to be a problem among birch. This is due to the combined high occurrence of pruning damage and forking damage which occurred 15 and 14 times respectively (Table 6). Generally, the severity of pruning damage and forking damage was found to be moderately significant to the health of the tree with averages being 2.40 and 3.21 respectively (Table 6, Figure 13 B, C, D). However, examples were found where extensive decay was associated with a past pruning damage resulting in a major cavity in the tree (Figure 13 C). One of the only areas where the trees seemed to be healthy was in their roots. However, this is only based on a visual inspection for damage and not based on any values of soil compaction or other issues associated with urban soils. Overall, the health conditions of the white birch examined were very low, with the average health of the tree only equalling 29.21% (Table 6).

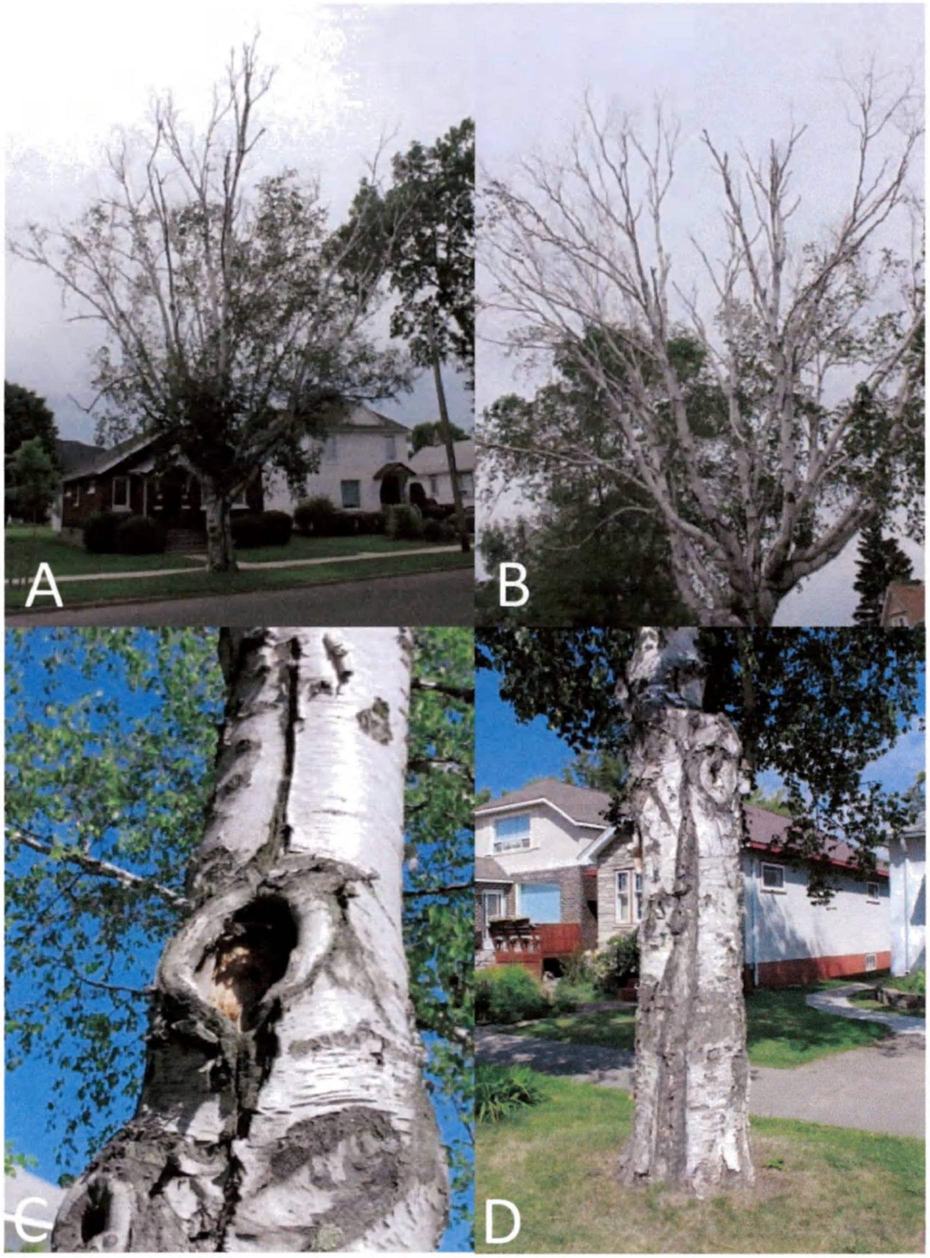

Figure 13: Common examples of exterior white birch damages. Declining crown and foliage (244 Francis St W) B: Co-dominant forking damage (220 Francis St). C: Pruning damage and extensive decay (415 Norah St). D: Large crack on the stem of the tree (1465 Moodie).

The lowest health ratings for silver maple were found in the average trunk and scaffold branch health sections (Table 6) (Figure 14). Unlike the white birch, size class did play a role in the trunk health condition of the trees, with the trunk condition rating decreasing with increase in class size (Table 6). Similar trends of health decreasing with size increases were not visible in other health ratings, including the average total health of the tree. Scaffold branches were the second lowest rated area of tree health for silver maple. There did not seem to be a relationship between scaffold branch health and size class of the tree. In general, the average health of the roots, foliage and small branches were rated as close to average health for trees of that species (Table 6).

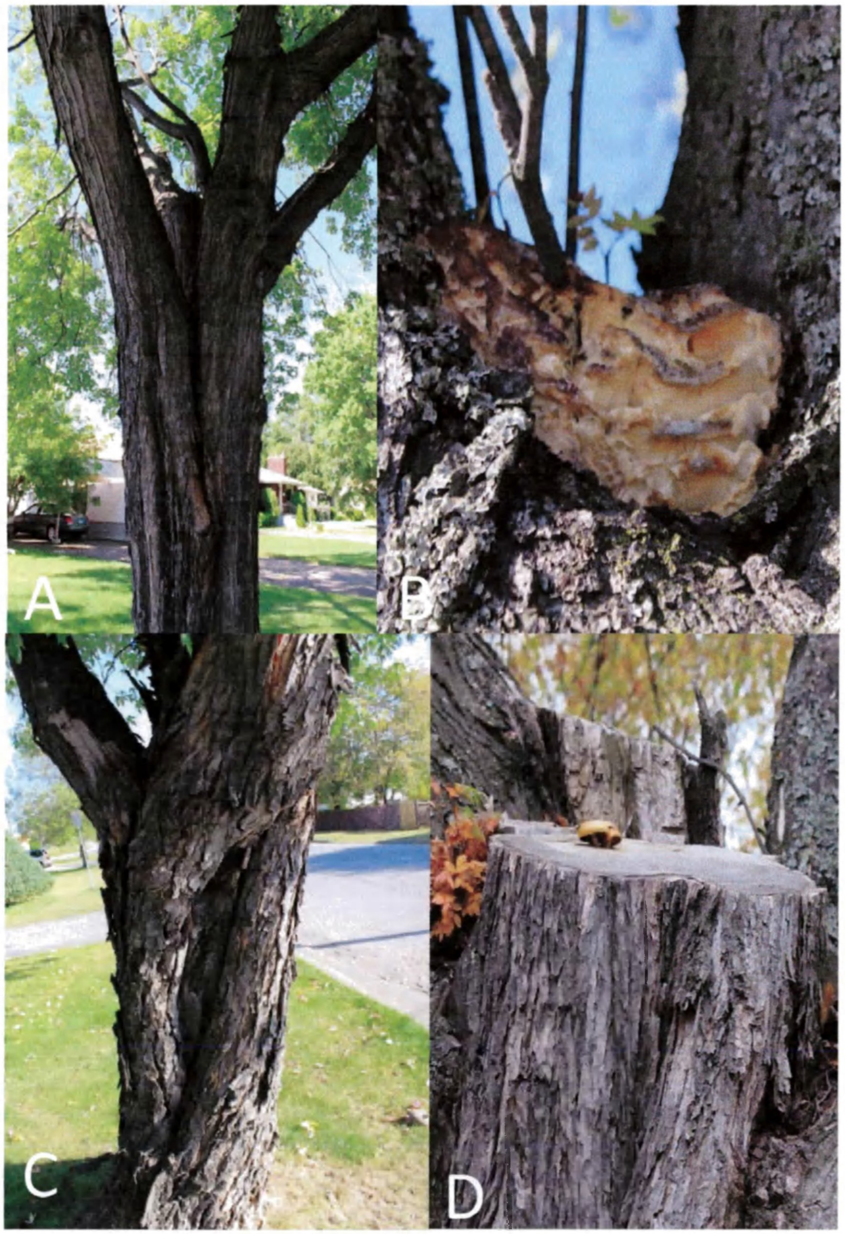

Figure 14: Example of common exterior damages associated with silver maple. A: Co-dominant fork (2704 Willow Pl) B: Co-dominant forking damage and associated decay fungus (*Climacodon septentrionalis*) (Prospect Ave) C: Large wound or crack on the stem of a silver maple(188 Madeline St 1) D: A large pruning wound and associated wood decay fungus (*Pholiota aurivella*) (2604 Chestnut St).

The overall health condition rating of silver maples felled was below average at 38.5% (Table 6). A condition rating of 38.5% would indicate that many of the removed silver maples were below what would be considered a standard healthy street tree. The health rating was significantly higher than the health rating for the white birch removed.

The third species examined, green ash, was found to have low health values for scaffold branches, small branches and foliage (Table 6).There is a foliar pathogen in Thunder Bay, *Gnomoniella fraxini*, which has had a major effect on the health of ash foliage. *Gnomoniella fraxini* causes an anthracnose disease of ash that damages foliage and leads to characteristic necrotic dead areas near the borders of leaves and also causes a characteristic curling of the leaf (Figure 15 A, Figure 16). *Gnomoniella fraxini* also results in twig dieback, and in severe cases characteristic dead branches in the lower crown of the tree (Figure 15 B).

Figure 15: (A): Image of ash leaves infected by *Gnomoniella fraxini* from 582 Dalhousie Dr. (B): Photo of an ash tree at 526 Dalhousie Dr. showing characteristic die back of twigs and branches in lower crown from infection of *Gnomoniella fraxini*.

Average health values for the trunks of green ash were not high, with a total average of 4.54 out of 10 (Table 6). Although there were relatively few exterior damages associated with green ash, there were examples where frost crack damage and pruning damage significantly affected health. However, they occurred only on a relatively small number of trees (Table 6 Figure 16). The total health average for ash slated for removal was 28.39 out of 100 which is low in comparison to other tree species being removed (Table 6).

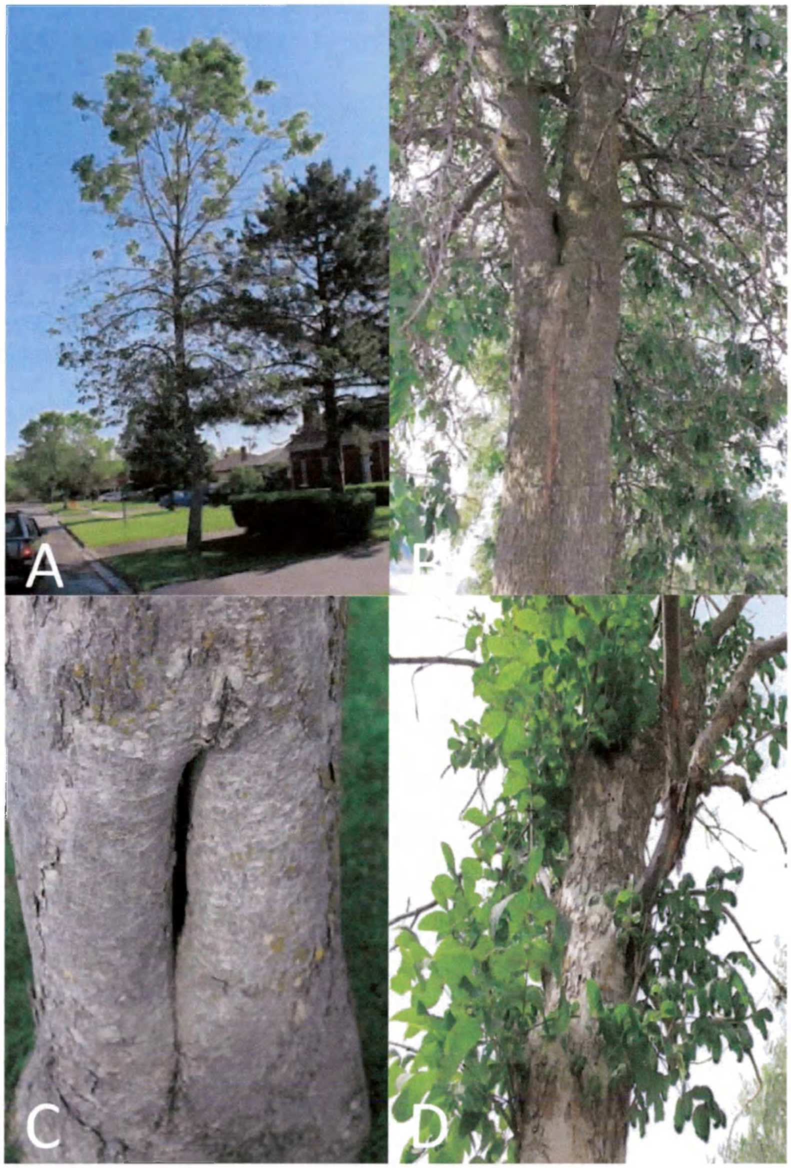

Figure 16: Examples of common exterior damages of ash. A: An example of a tree infected with *Gnomoniella fraxini* (183 Windemere Ave N). B: Example of a co-dominant fork and an associated crack (550 Luci Ct) C: A physical damage partially healed over(361 McKellar St N) D: Example of a tree in decline and associated water sprouts(61 McKellar St N).

Manitoba maple contained low values of health for roots, trunk, scaffold branches, small branches and foliage with 4.89, 4.89, 4.22, 2.56 and 2.89 respectively (Table 6, Figure 17).

Figure 17: Examples of common exterior damages of Manitoba maples. A: A tree in general decline (183 Windemere Ave N). B: A large fruiting body of *Hypsizygus tessulatus* originating from a pruning wound on the stem of a tree (550 Luci Ct) C: A large frost crack on the stem of a tree (1023 Victoria Ave E) D: Declining branches in the crown of a Manitoba maple(2612 Isabella St E).

It is important to remember when comparing the health values for all areas of the tree that roots, trunk and scaffold branches are measured out of 10 while small branches and foliage are measured out of 5 meaning the values for small branches and foliage are comparable for health. There were also no damages that occurred often enough to account for the low health averages of the Manitoba maples.

Specimens of *Prunus virginiana* L. cv Schubert (Schubert Chokecherry) all experienced the same commonly occurring problem, infection of the branches and stems by black knot (*Apiosporina morbosa*) (Figure 18). This is what eventually lead to their designation as hazard trees and their eventual removal. Many trees were very heavily infected with some possessing large cankers in the main stem resulting in a reduction of vigour and health (Figure 18).

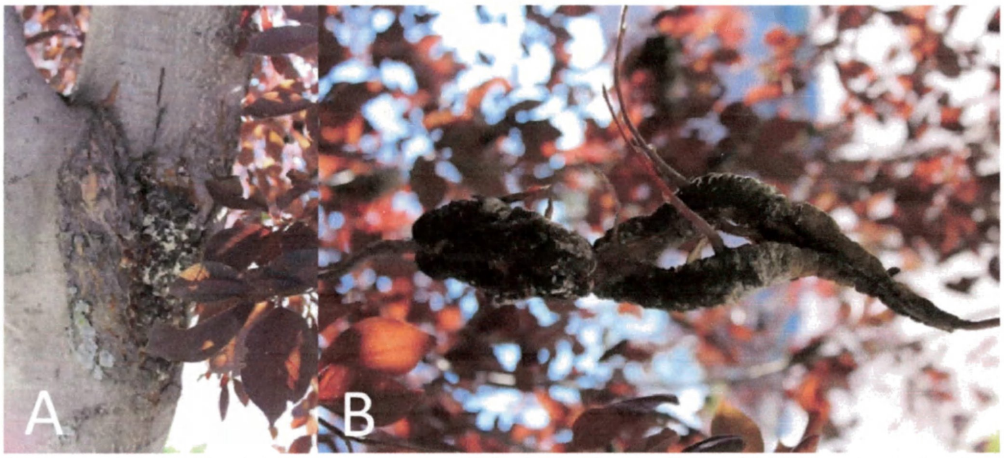

Figure 18: A: Example of a black knot canker on a Schubert chokecherry (96 Secord St). B: Black knot on the branch of a Schubert chokecherry (96 Secord St).

The remaining tree species only occurred in small numbers. The small sample sizes in combination with being divided into size groups meant no definite conclusions could be drawn about these other species. Many of the trembling aspen slated for felling were located near the exterior edges of the city making them less useful for conclusions about hazard street trees. Eight red pine were examined but all were occurring in the same location. They cannot be compared as health issues, could be completely related to site problems as opposed to other potential problems associated with red pine growing in city conditions.

A wide array of hazard street trees contained exterior damages not mentioned in Table 6 and were labeled as other damages (Figure 19). The description of the other damages found as well as their occurrence and average damage severity can be seen in Table 6 and Table 7.

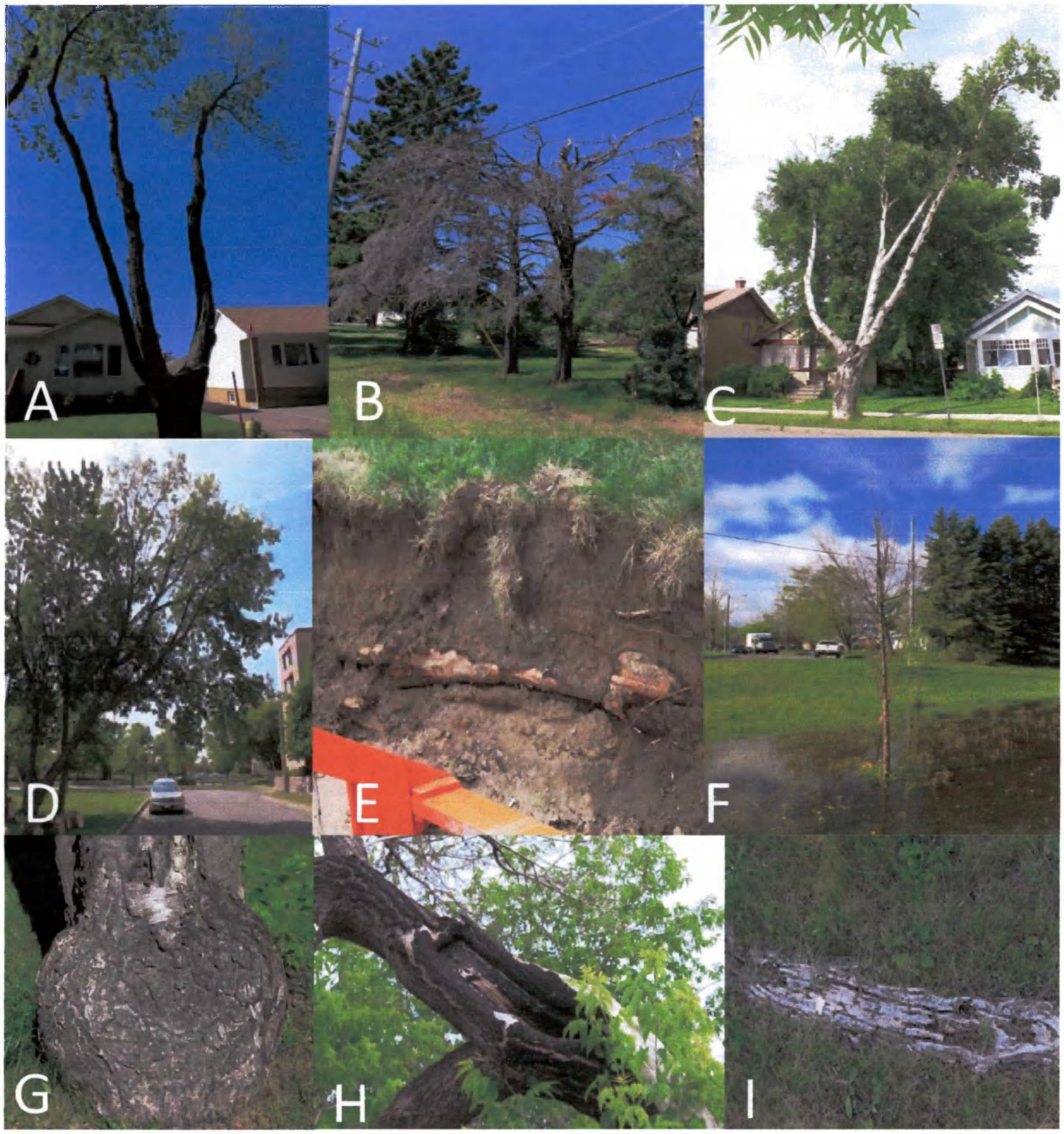

Figure 19: Examples of other damages. A: Lion tail pruning (220 Hamilton Ave). B: Topping (1615 Arthur St W-2). C: Bad pruning (323 Archibald St N). D: Structural lean (210 Ross St). E: Construction damage (220 Francis St). F: Flooding Damage (184 Theresa St 2). G: Burl (1417 Hamilton Ave). H: Lightning Damage (McKenzie St) I: Lawn mower/ weed whacker damage (4061 Vanguard Ave-1).

Poor pruning, lion tail pruning and topping were not included in pruning damage as proper pruning of scaffold branches can create large wounds allowing the entry of decay fungi after the pruning (Table 7). Poor pruning occurred in trees which had more than 50% of the crown removed leading to the eventual removal of the tree (Figure 19 C). This type of damage occurred once and had a severity level of 2 (Table 7).

Lion tail pruning refers to a pruning practise where the crown is significantly raised and only a small tuft of branches and foliage remains at the top of the tree (Figure 19 A). This type of damage was also recorded once and had a severity level of 1 on the trees health (Table 7).

Table 7: Description of other damage types observed, as well as occurrence and average damage severity.

Description of Damage	Occurrence of Damage	Average of Damage Severity (1= Severe - 4=Minor)
Poor Pruning	1	2
Significant Structural Lean	1	1
Construction Damage	3	2
Flooded Site	1	1
Large Burl at Base	1	2
Lightning	2	1
Lion Tail Pruning	1	1
Topped	1	1
Lawn Mower/ Weed Whacker Damage	14	2
Total	25	1.44

Topping/(Pollarding) is the act of removing the top of the tree (Figure 19 B). This has a significant negative effect on both the health and structure of the tree. This type of damage can lead to infection by decay fungi as well as a huge drop in vigour and health of the tree. Over pruning, lion tail pruning and topping have the potential to induce water sprouts (Figure 19 D), which can crowd around the cut stubs resulting in breaking and eventual colonization by decay fungi. Topping occurred once on the hazard street trees assessed and had a severity level of 1 (Table 7).

Significant structural lean refers to a lean in the trunk of a tree greater than 40^0 (Figure 19 D) (Pokorny 2003). This structural lean is dangerous and can lead to a failure in the trunk of the tree. This problem is likely more common than reported in this thesis as many structural leans can be related to co-dominant forking at the base of the tree and during the data collection process these problems were only labelled as co-dominant forks. Many trees occurring in this situation are a result of asymmetric pruning to shape the tree around power lines. This practise results in lop sided weights in crowns of trees. One tree was found to have a significant structural lean with a severity level of 1 (Table 7).

Construction damages were also found on three occasions in the City with a severity level of 3 (Table 7). Construction damage is mostly physical damage to the roots or stem of a tree from a large piece of equipment making physical contact with the tree or roots (Figure 19 E). Construction can also result in compaction of the soil, although, this factor is impossible to measure with a visual inspection.

Flooded sites were also recorded in the summer of 2012 as it was an unseasonably wet summer in Thunder Bay where flooding was common (Figure 19 F). Flooding was only observed for one Manitoba maple (184 Theresa St), a hazard tree that was removed, however, it is likely other trees were affected (Table 7).

Burls are a common occurrence in trees and are generally not detrimental to their health (Sinclair & Lyon 2005). Burls can cause damage to the structural integrity of a tree if the burl is very large in size and greater than 33% of the diameter of the trunk of the tree (Figure 19 G)(Pokorny 2003). Large burls create a weak spot in the strength of a trunk which can eventually lead to the failure of the tree (Pokorny 2003). One burl was found on a white birch city tree and was greater than 33% of the stem giving the severity level of 1 (Table 7).

A form of major damage observed in Thunder Bay has been caused by lightning. Lightning can cause massive wounds in trees and if the tree is fortunate enough to survive, it will likely become infected by decay fungi which can lead to degradation of both the structure and health of the tree (Figure 19 H)(Sinclair & Lyon 2005). Two trees were damaged by lightning, a white birch located at 420 Vickers St S and a Manitoba maple located on McKenzie St and in both cases the severity rating was 1 (Table 7).

The final and most common form of other damage observed in Thunder Bay was lawn mower and weed whacker damage (Figure 19 I). It was the most commonly occurring damage with an average severity rating of 2 (Table 7). Weed whacker damage and lawn mower damage was initially recorded as minor damages when root structure and health were evaluated. Only later in the data collection process were they measured as their own separate damage type.

As summarized in Table 7, these damages occurred far less often than the four main damages recorded *i.e.*, pruning damage, co-dominant forking, frost crack and physical scrape with the exception of lawn mower/ weed whacker damage. However, these lesser encountered damages did have more of a severe effect on the overall health of the individual trees affected being a major factor leading to the trees removal. The average severity of the damages for all 25 was 1.44 with the least severe damage being classified as 4 and the most severe damage classified as 1.

2.4 DISCUSSION

By examining hazard street trees prior to felling it was possible to draw conclusions about specific exterior characteristics associated with certain tree species.

White Birch was one of the most common street tree's assessed and one of the species which had the lowest value in terms of health. The low values for foliage and small branch health can likely be attributed to the dry conditions in 2011 and 2012. In most cases, the decline in foliage health is not related to a foliage pathogen or disease, but is likely related to drought stress damage and various deformities on the small stems which would lead to crown dieback (Figure 13 A). Other studies also conclude that birch is susceptible to drought stress damage (Pokorny 2003, Terho *et al.* 2007, Terho 2009), suggesting that white birch is not a suitable species for urban environments. This is due to the fact that most trees in urban environments will suffer from drought. Cracks were found to be an issue among birch due to their frequency. A study of urban street birch (mostly *B. pendula* Roth and *B. pubescens* Ehrh) in Helsinki, Finland found stem cracks to be common (Terho 2009) suggesting cracks are a wide spread problem for birch species in harsh northern climates. A low value for tree health is expected when assessing the health of trees selected for removal but such a low value means the majority of white birch removed are in very poor condition. Due to high rates of infection by the bronze birch borer on the already stressed street trees and the reasons previously mentioned birch is no longer planted as a street tree in Thunder Bay.

Damages associated with co-dominant forking and large pruning wounds on silver maple were a major factor for the entrance of decay pathogens and a reason for the removal of a significant number of silver maples (Figure 14). Similarly, co-dominant forking was found to be the largest structural defect for *Acer* spp. in a similar study in Helsinki, Finland (Terho 2009). The high occurrence of these two damage types can also help to explain why average trunk health condition and the average scaffold branch health conditions were so low. Although silver maple is a suitable tree species for planting in urban environments, trees need to be pruned at a young age to reduce occurrence of co-dominant leaders, forks and weak branch unions that significantly impact the health of the tree later in life. The large pruning wounds received in order to remove branches which could potentially fail are unnecessary if potential problem branches are removed earlier in the trees life. Fortunately the citizen pruner program initiated by the city of Thunder Bay will be a major step to alleviate this problem, as citizen pruners are assigned to prune young trees that otherwise would not be touched by city workers.

Various studies have found green ash to have weaker branch unions, poor architecture as well as the potential to become damaged by ice and wind events (Pokorny 2003, Hauer *et al.* 1994). Many of these symptoms were not directly observed in Thunder Bay, likely due to a high number of trees removed having smaller trunk diameters in comparison with other tree species. The smaller trunk diameters suggest many ash have not reached maturity and that the older ages required for some of these commonly occurring symptoms found in other studies have not occurred in Thunder Bay. The most seriously occurring problem at present in Thunder Bay for ash is infection by *Gnomoniella fraxini.*

However, despite ash being a healthy street tree species with few major issues they are also no longer planted in Thunder Bay due to the imminent threat of the Emerald ash borer which has yet to reach Thunder Bay.

Manitoba maples are generally considered to be weak wooded tree species that are fast growing and can quickly lose their structural integrity and become weak and brittle (Farrar 1995). Due to the nature of the species it is not suitable to be planted as a street tree and remaining Manitoba maples in the city should be closely monitored to ensure they are removed promptly when they become a hazard. Manitoba maples do have a place in the city and can play an important role if they are planted in low traffic areas such as certain wooded parks or areas being reclamated and returned to a natural setting.

Potential sources of error for the data collection may have occurred during the evaluation of the health of small branches. These errors may have occurred as general health of small branches is somewhat based on the health of the foliage attached to it. If a small branch has lost all its foliage the health of the small branch will reflect the lack of foliage on the branch. Similarly, foliage health is somewhat based on the health of the small branches. If many of the small branches are dead and lose their foliage, the foliage health measurement will reflect this. In certain cases however, such as branches infected with black knot (*Apiosporina morbosa*), health of the foliage is not affected by the health of the branch. If the fungus is in such a high quantity that it kills the small branches, foliage health can be affected. This means that small branch health and foliage health are closely linked, potentially not reflecting the true source of the problem.

A secondary source of error occurred when observing the health and structure of roots, as no destructive sampling was done to observe root condition. Observations are based on site location as well as overall health of the crown of the tree. In certain situations where leaves appeared chlorotic and stressed and roots are growing in a poor site, health and structure values reflect the poor growing condition and general health of the tree. Root health and structure is also based on the presence of root decay fungi such as *Inonotus tomentosus* (Fr.) Teng where the presence of fruiting bodies would suggest decay and degradation of the structure and health of the roots. Where roots were exposed on the surface and lawnmower or weed whacker damage was observed, health and structure values were given accordingly.

A potential third source of error found in the data collection process was the recording of other damages present. This was not included in the data collection until later, as other damages were simply recorded in the comments section of the data sheet and the effect of the damage was recorded in the health and structure of the five tree components measured. Other damages originally missed were recalculated for some trees based on photographs taken of these damage types. Basing health values on photographs is not as accurate as observations in the field and may have resulted in a source of error.

2.5 CONCLUSION

White birch was generally found to have problems with crown dieback and drought stress (*i.e.* low small branch and foliage health) similar to what has been observed in the literature (Terho & Hallaksela 2008, Pokorny 2003). The total average health condition of the removed hazardous white birch was found to be very low suggesting all parts of the tree were found to be in poor health. Although frost cracks were found to be an often occurring problem with white birch, they were found to be a major contributor for the overall negative health of the tree. Silver maples had lower health values for their trunks and scaffold branches. The overall health of silver maples declined as the size class increased. Co-dominant forking and pruning damages were found to significantly affect the health of silver maples with these problems. Weak branch unions were shown to have played a role in the health of scaffold branches and small branches. Infection by *Gnomoniella fraxini* lead to a general low health average for the foliage of ash. Manitoba maples were found to contain low values for all parts of the tree and in general the overall health averages of the trees were found to be low. The remaining tree species did not occur in high enough quantities to allow for conclusions to be drawn about them.

Other damages found to affect trees in the city (*i.e.,* poor pruning, significant structural lean, flooded site, large burl at base, lightning, lion tail pruning and topped trees) did not occur in high quantities. However, many of these damages significantly affected the overall health of individual trees affected, and in most cases lead to the removal of the tree.

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CHAPTER 3:
Analysis of interior tree characteristics in relation to resistograph readings and a reading atlas on discs of felled hazard street trees

3.1 INTRODUCTION

The first step in evaluating whether a tree might be a hazard or not, is through an examination of exterior tree characteristics (Schwarze 2008, Pokorny 2003, Matheny & Clark 1994). Once external characteristics are recorded, it still may be difficult to relate them to interior decay, as decay is often not visible from the exterior of the tree. If a relationship between certain exterior characteristics and interior decay existed, this would greatly simplify the process of evaluating potentially hazard trees.

There are several available instruments that allow the user to determine the interior state of the living tree without removing or significantly damaging the tree. Most important among these is a device called a resistograph (Mattheck *et al.* 1997, Costello & Quarles 1999). A resistograph is a drill which can be used to determine the amount of interior rot in the roots, stem or scaffold branches of a tree, and is commonly used by urban foresters throughout the world including Thunder Bay. Reading and interpreting the results of the device can be a difficult task as there are multiple factors that can lead to error in resistograph readings (Ukrainetz & O'Neil 2010, Lin *et al.* 2003, Chantre & Rozenberg 1997, Rinn *et. al.* 1996). If exterior tree characteristics were combined with information provided by the resistograph, including a resistograph atlas, an urban forester would have the tools needed to more efficiently and accurately evaluate the interior health of a tree. A resistograph atlas is a photographic reference section which compares resistograph readings to the discs, which were drilled with the resistograph, as well as features in the disc. To accomplish this goal, it is necessary to determine whether a relationship does exist between specific exterior tree characteristics and interior characteristics *i.e.* decay, in addition to creating a resistograph atlas and an analysis of resistograph readings for common resistograph errors.

3.2 MATERIALS AND METHODS

Once all of the external characteristics were measured on the street trees designated for removal by the City of Thunder Bay, stem discs were collected at DBH from the felled street trees by the

City of Thunder Bay works crews. The discs were collected between the months of April to October in 2011 and 2012 and were all approximately 5-15cm thick. The discs were brought back to either the Parks North or Parks South yards where they were temporarily stored until collected and brought to Lakehead University. The discs were stored in plastic bags, in a freezer (-6^{0}C) to keep them fresh, as well as stopping the advancement of decay fungi. From the time of the felling of the street trees until the discs reached the freezer at Lakehead University, the discs were left for no more than one week. When the time came to evaluate the tree discs, they were removed from the freezer and left to thaw for two days. Once thawed, diameter, age at DBH and species identity were recorded on a tree disc measurement sheet (Figure 20). Measurements (in cm) were also made of the size of the pocket of rot (if present) by measuring from the cambium of the tree to the edge of the rot. The tree disc was photographed, comments were recorded about the disc, and a diagram of the disc was drawn in addition to the comments.

Tree Disc Measurements

Kurtis Barker

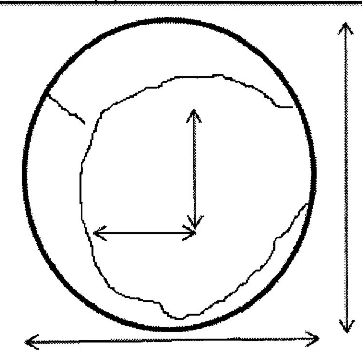
Date:August 20 2012	Age: 80	Tree#:	Tree ID	Photo: 1380-1388
Address: 123 Arthur St		Diameter: 65.3	Species Ms	
Sample #	Rot present Y / N	Diagram of rot		
Comments: Extensive decay small frost crack		Dist. To Rot Measur. (cm) N: 15 S: 2 E:0 W:10		

Figure 20: Example of a filled in tree disc measurement sheet.

The tree discs were drilled with a resistograph (IML Resistograph F-Series) borrowed from the City of Thunder Bay. The tree discs were drilled from four arbitrarily chosen directions similar to what an urban forester would do when determining the amount of rot in a hazard street tree. The tree discs were sanded on their surface to ensure that resistograph readings could be compared to features in wood *i.e.*, rot, checks and other wood abnormalities. The resistograph readings recorded on graph paper were then placed on the top of the tree discs and photographed to compare resistograph readings with abnormalities in wood (Figure 21). Comparisons of resistograph readings were made between conifers and deciduous trees as well as between species and different types of wood abnormalities *i.e.,* differing levels of rot, checks and included bark *etc.*

Smaller discs had only two drillings rather than four as the drill bit could easily pass from one side of the disc to the other. A few discs had half of the disc missing, were too thin to drill on certain sides, or contained other deformities that limited the number of drillings on the disc. For discs where some deformity or other problems limited the number of drillings, the reason for fewer than four is recorded. The resistograph readings were then numbered on the reading and where it was drilled on the disc. Once all the discs were drilled and photographed, they were broken in half if rot was present, in order to collect a sample with the intention to culture out the species of wood decay fungus present in the disc. All samples of decayed wood were kept in separate labelled plastic bags, and stored in a freezer to keep the fungus alive and the sample fresh (See Chapter 4).

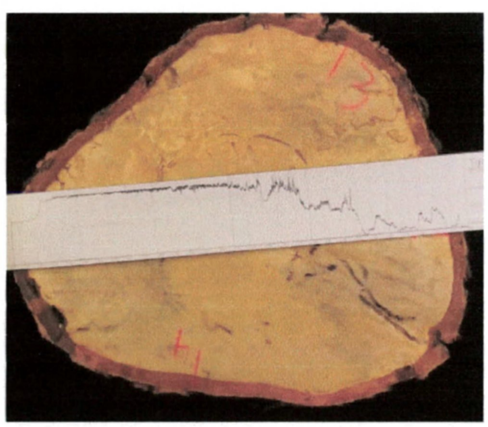


Figure 21: Example of a sanded disc with resistograph reading, comparing internal features to resistograph reading.

3.3 RESULTS AND DISCUSSION

The majority of tree discs were collected from areas similar to where felled street trees were located, (*i.e.*, mainly residential areas in former Port Arthur and Fort William) (Figure 22). Similarly, few tree discs were from the intercity region of Thunder Bay. One tree disc was collected from an exurban location (Figure 22).

In total, 177 street trees slated for removal by the City of Thunder Bay were examined and evaluated for external characteristics. Ideally, tree discs should have been removed from all 177 street trees. However, only 26 tree discs were ultimately collected by the Parks crews which came from this pool of street trees (Figure 23). An additional 44 tree discs were collected by the Parks crews that came from trees not on the original tree removal lists provided by the City. In total, 70 tree discs were collected by the parks crews. These are illustrated in Appendix III.

Figure 22: Locations of collected tree discs from felled hazard street trees. Google Earth

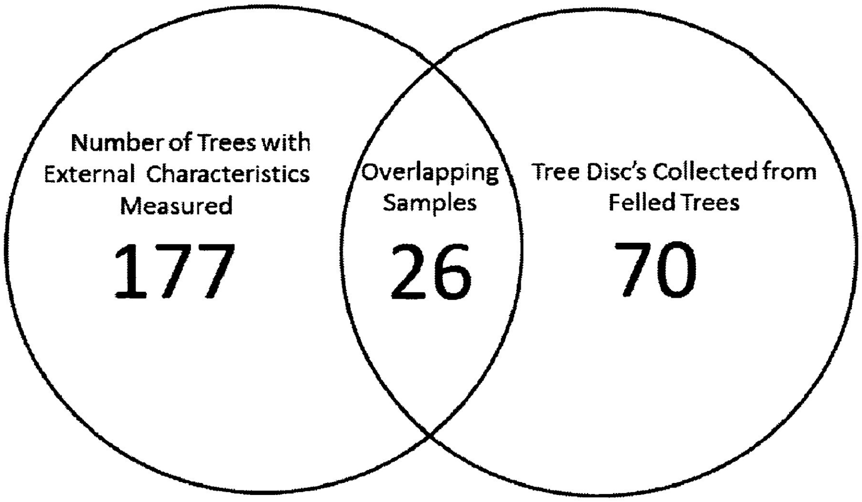


Figure 23: Number of trees with exterior characteristics sampled and overlapping tree discs collected.

In total, only 26 discs matched trees where exterior characteristics were measured (Table 8) representing 10 tree species. The most commonly occurring species was white birch with 7 discs followed by silver maple and chokecherry with four each. Balsam poplar, Lombardy poplar and green ash were the next highest occurring species with 3, 2 and 2 samples respectively. The remaining tree species only contained 1 sample each (Table 8). The lack of sufficient samples was a result of an unforeseen lack of co-operation from Parks crews who had originally agreed to the collection of discs from felled hazard street trees. While an ample number of trees were sampled for exterior characteristics, the small number of discs collected prevented any conclusions being made. Most of the tree discs were found to have been removed from trees not on the original removal lists and thus no exterior characteristics were measured. This was likely due to particular trees being removed before being entered in the system. High variability within tree species and their damages was also a major problem, a large sample size would be needed to properly analyze the variance in the data. To resolve this lack of discs in the future, a closer relationship between the researcher and the City may be needed. If the researcher was actually involved first hand in the tree removal process, trees could be externally measured directly before the tree is felled as well as ensuring the disc is properly collected and the location recorded. If this project had been carried out in the above mentioned way, it would have led to enough discs being collected to properly assess if a relationship between exterior tree characteristics and interior decay exists. The lack of co-operation from the Parks crews and specifically Parks North would need to be addressed to ensure that all discs from removed hazard trees would be collected and returned for examination.

The external health of the trees with matching discs ranged from as high as 81.25 (little leaf linden) to as low as 48.44 (chokecherry) with an overall average external health of trees being measured at 65.47 (Table 8). The overall health average of the external symptoms of this subset of 26 trees is relatively very high when compared to total health averages of all 177 trees presented in Chapter 2. Chokecherry was found to have the most exterior damages with a total of 7 damages occurring on the trees.

White birch had the second largest number of external damages occurring. Low health values for foliage and small branches as well as varying damages occurring on the tree are similar to what was found by Terho (2009). White birch commonly suffer from a range of problems which allows decay fungi to enter and lead to the eventual decline of the tree (Terho & Hallaksela 2005, Terho *et al.* 2007, Terho & Hallaksela 2008, Terho 2009). The extent of decay within the discs was found to be moderate with an average extent of decay having a value of 1.57 out of a potential 4. The extent of decay was found to run contrary to what was found by Terho & Hallaksela (2008) where a large number of the trees were reported to have hollow columns in the trunks of the trees. However the low number of discs collected makes comparison of results challenging.

Table 8: Tree disc decay extent with matching exterior characteristics by species and size

Species	Count of Species	Average of Root (Damage) /10	Average of Trunk (Damage) /10	Average of Scaffold (Damage)/ 10	Average of Small Branch (Damage)/5	Average of Foliage (Damage) /5	Total Average Health of Trees	Occurrence of Pruning Damage	Average of Pruning Damage	Occurrence of Codominant Stem	Average of Codominant Stem Damage	Occurence of Frost Crack Damage	Average of Frost Crack Damage	Occurrence of Physical Scrape Damage	Average of Physical Scrape	Extent of Decay (1=Minor to 4=Severe)
White Birch	7	5.43	4.00	4.00	2.29	2.29	56.25	2	3	1	1	2	2.5			1.57
0-25	1	2.00	2.00	2.00	1.00	1.00	25.00			1	1					1
26-50	1	6.00	5.00	6.00	2.00	2.00	65.63	1	4							1
51-75	4	6.00	4.50	4.25	2.50	2.50	61.72					1	3			2
No DBH Recorded	1	6.00	3.00	3.00	3.00	3.00	56.25	1	2			1	2			1
Silver Maple	4	7.25	4.50	4.00	3.00	3.25	68.75	1	2	1	2					3
51-75	3	7.67	5.33	4.33	3.00	3.33	73.96			1	2					3
76-100	1	6.00	2.00	3.00	3.00	3.00	53.13	1	2							3
Chokecherry	4	5.00	3.50	3.25	1.00	2.75	48.44	2	2.5	2	2	2	1.5	1	1	2.25
0-25	4	5.00	3.50	3.25	1.00	2.75	48.44	2	2.5	2	2	2	1.5	1	1	2.25
Balsam Poplar	3	6.33	5.67	3.67	2.33	2.00	62.50					2	1.5	1	2	3.33
26-50	3	6.33	5.67	3.67	2.33	2.00	62.50					2	1.5	1	2	3.33
Lombardy Poplar	2	6.00	4.00	3.50	2.50	2.00	65.63									2
26-50	2	6.00	4.00	3.50	2.50	2.00	65.63									2
Green Ash	2	8.00	5.00	3.50	1.00	2.00	65.63							1	4	1
0-25	1	6.00	6.00	3.00	1.00	2.00	56.25							1	4	1
26-50	1	10.00	4.00	4.00	1.00	2.00	40.63									0
Balsam Fir	1	5.00	5.00	6.00	3.00	3.00	68.75									4
26-50	1	5.00	5.00	6.00	3.00	3.00	68.75									4
Little Leaf Linden	1	8.00	4.00	7.00	3.00	4.00	81.25	1	2	1	1	1	1			1
0-25	1	8.00	4.00	7.00	3.00	4.00	81.25	1	2	1	1	1	1			1
American Elm	1	10.00	8.00	4.00	1.00	1.00	75.00									2
26-50	1	10.00	8.00	4.00	1.00	1.00	75.00									2
Jack Pine	1	10.00	6.00	2.00	1.00	1.00	62.50									0
0-25	1	10.00	6.00	2.00	1.00	1.00	62.50									0
Grand Total	26	7.10	4.97	4.09	2.01	2.33	65.47	4	2.375	4	1.5	4	1.63	3	2.33	2.02

Overall, seventeen species were represented among the total 70 tree discs, with the most commonly occurring species being silver maple, white birch and green ash with 16, 12 and 8 samples respectively. The remaining tree species and the number of samples for each species can be seen in Table 9. Silver maple, white birch and green ash had the highest representation due to being the three most common tree species in Thunder Bay. Silver maple and white birch had the highest representation as both species contain numerous trees either in decline or on the verge of declining. White birch comprises the highest population of declining trees in Thunder Bay while silver maple contains many trees on the verge of declining (Davey Resource Group 2011). The trees based on disc diameter from largest to smallest were silver maple, Manitoba maple (*Acer negundo* L.), white birch, green ash, trembling aspen (*Populus tremuloides* Michx.), jack pine (*Pinus banksiana* Lamb.), American elm (*Ulmus americana* L.) and Russian olive (*Elaeagnus angustifolia* L.). The oldest trees based on breast height age were Russian olive, jack pine, balsam poplar, and American elm (Table 9). Diameter of discs and tree age at disc level may not be representative of removed hazard trees as many of the species had low quantities of sampled discs such as American elm, Russian olive, *etc*. Even discs collected in higher quantities, such as silver maple, white birch and green ash, were not a large enough of a sample size to properly be representative of each species removed.

In total, 62 discs were deciduous while there were only 8 discs collected from conifers. Although there were significantly more discs from deciduous trees, a difference between resistograph readings of coniferous discs and hardwood discs was evident. This was an expected result as on average many conifers have lower specific densities than deciduous species as can be seen in Table 10. This results in higher values shown on the resistograph reading as the drill works harder to drill through the wood (Figure 25, Figure 26).

Table 9: Quantity of disc's, average DBH size and average disc age by tree species.

Species	Quantity	Average Diameter(cm)	Average Breast Height Age
Silver Maple	16	41.50	63.81
White Birch	12	48.58	50.66
Green Ash	9	40.78	43.52
Lombardy Poplar	4	29.75	27.80
Jack Pine	4	64.00	39.63
Schubert Choke Cherry	4	15.00	27.98
Little Leaf Linden	3	35.00	36.93
Trembling Aspen	3	43.33	44.30
Balsam Poplar	3	55.00	31.70
Balsam Fir	2	41.00	34.20
White Spruce	2	24.00	27.05
Manitoba Maple	2	36.50	51.00
American Elm	2	52.00	36.20
Hawthorn	1	11.00	19.50
Flowering Crab Apple	1	28.00	24.20
Russian Olive	1	78.00	40.00
Black Spruce	1	40.00	20.80
Total	70	41.61	44.89

A secondary significant difference between hardwoods and softwoods is the presence of growth rings appearing on the resistograph reading. On softwoods, growth rings are very distinct as late wood (*i.e.* wood produced late in growing season) is shown by a distinct peak and early wood (*i.e.* wood produced early in growing season) is shown as a gradually increasing line after the winter wood peak (Figure 25). A resistograph reading of a hardwood is distinctly different as there are no distinct differences between summer wood and winter wood within the growth rings (Figure 25).

Table 10: Average specific gravity at 12% by species. (Alden 1995, Alden 1997)

Species	Specific Gravity 12% MC
Silver Maple	0.47
White Birch	0.55
Green Ash	0.56
Balsam Poplar	0.34
Little Leaf Linden	0.37
American Elm	0.5
Black Cherry (Replacement for Schubert Choke cherry)	0.5
Trembling Aspen	0.38
Crab Apple (Malus sylvestris)	0.67
Lombardy Poplar	Missing
Russian Olive	Missing
Manitoba Maple	Missing
Hawthorn	Missing
Average (Hardwoods)	**0.48**
White Spruce	0.36
Black Spruce	0.42
Jack Pine	0.43
Balsam Fir	0.35
Average (Softwoods)	**0.39**

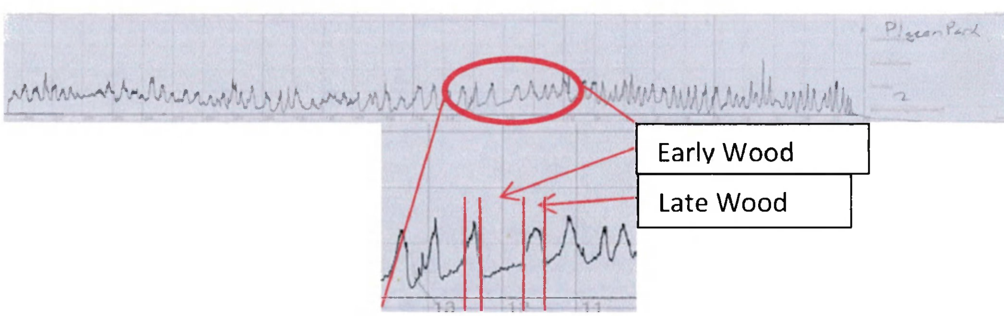


Figure 24: Resistograph reading of a Jack Pine from Pigeon Park. A close up of a small section of the resistograph is shown below the resistograph reading. Early wood and late wood is shown on the blown up section of the resistograph.

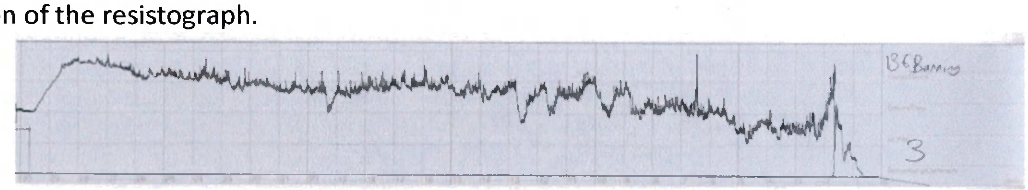


Figure 25: Resistograph reading of a Manitoba maple from 136 Banning St.

One feature that can show up on a resistograph reading are cracks. Cracks can be caused by rapid changes in temperature and a heavy load on the stem of a tree causing a break. Sometimes the break is associated with rot creating a weak point. Cracks most likely to be picked up by the resistograph are vertical cracks that run deep into the centre of the tree. When the resistograph drill bit passes through the void space created by the crack, a major drop in resistance is captured by the resistograph. The drop in resistance is virtually indistinguishable on the resistograph reading when compared to the drop in resistance associated with decay. Two examples of a crack and the associated resistograph reading can be seen in Figure 26. The best method to avoid confusing a crack with decay is by visually assessing the exterior of the tree for cracks before drilling. Cracks shown in Figure 26 were cracks present on trees during felling, however, the cracks expanded as a result of loss of moisture in the disc.

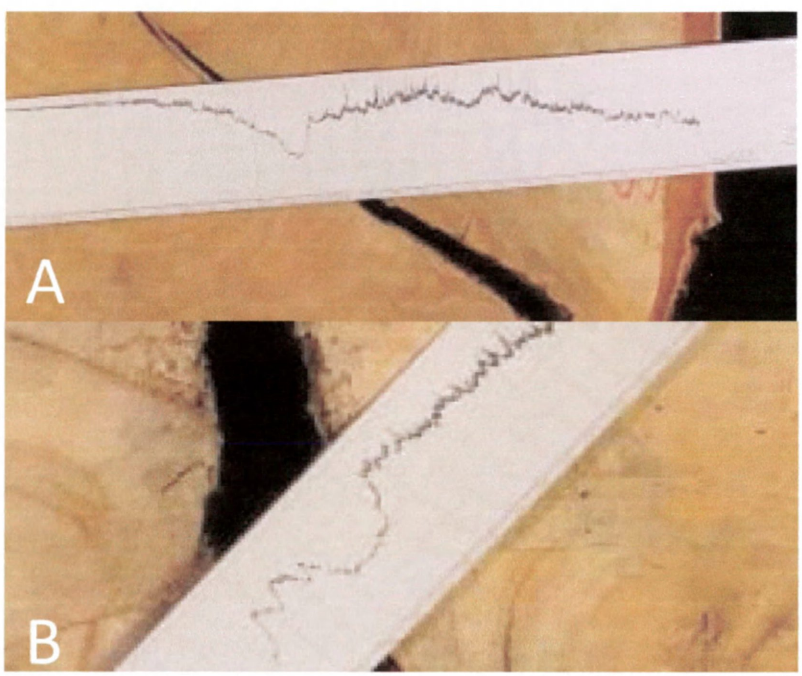


Figure 26: Resistograph reading showing a crack on a white birch from 1422 Ridgeway St E (A) and a crack on a tembling aspen disc from Harold St (B).

Decay in trees is a common problem in the urban forest. The resistograph is a very useful device for detecting decay, however there are a few common problems encountered. The first major problem is judging how advanced the decay is within the tree. Unfortunately the resistograph is unable to detect incipient decay within trees which can lead to a problem estimating the exact amount of decay within the tree. As shown in Figure 27, incipient decay is either not captured by the resistograph reading or indistinguishable from solid wood. This is a major problem as it is likely the incipient decay within the tree can turn to advanced decay very quickly if the tree experiences stress such as drought or physical damage. Due to the resistograph being unable to capture incipient decay it makes predicting future decay difficult.

Similar to being unable to show incipient decay in trees, the resistograph is unable to accurately show the transition between severely advanced decay and only minor advanced decay. An example is shown in Figure 28, where the resistograph captures the significantly advanced decay in the centre of the disc, but the differing levels of incipient decay around the outside of the disc are indistinguishable. This may not be a major problem in many cases, however it simply means the resistograph is a device not suitable for making accurate measurements of the advancement of decay or predicting the future decay of the tree.

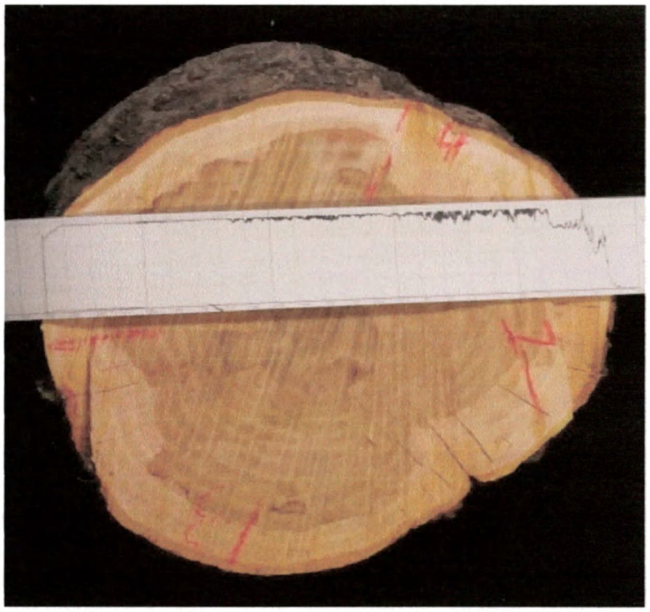


Figure 27: A resistograph reading of a flowering crab apple (*Malus* x 'Pink Spire') disc with significant incipient decay within the centre of the tree.

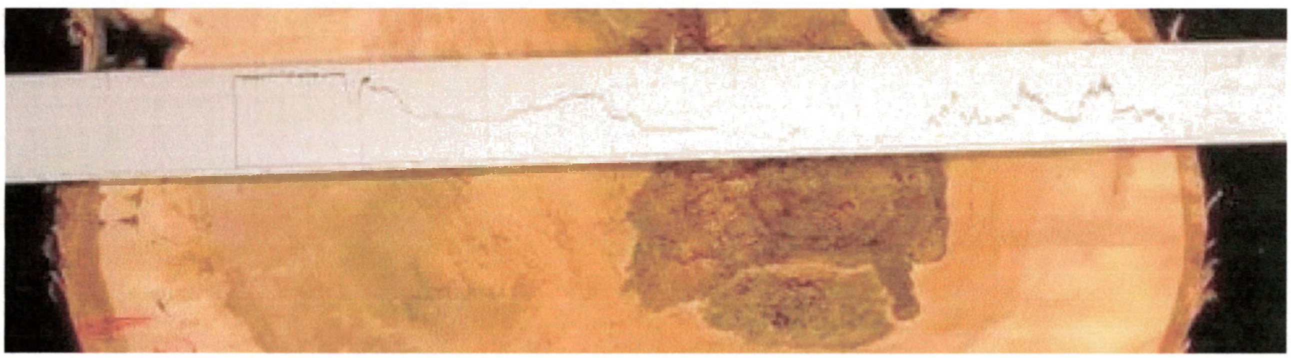


Figure 28: A resistograph reading showing differing levels of decay on a white birch disc.

Although the resistograph is very effective at detecting advanced decay, there are some significant problems that create errors in the resistograph readings. The first and foremost problem with the resistograph is the drill bit deflecting in the wood creating incorrect resistograph reading values. Certain characteristics in wood can cause the resistograph drill to change direction in the wood, such as knots, contours and meandering growth rings (Ukrainetz & O'Neil, 2010, Lin, *et al.* 2003, Chantre & Rozenberg 1997, Rinn *et. al.* 1996). Contours and meandering growth rings can be caused by reaction wood in trees. Drill bit deflection was a common problem in the discs sampled. Bit deflection is a problem that is amplified in street trees as many grow in conditions which encourage the growth of reaction wood. Below is an example of two resistograph readings from a silver maple disc. (Figure 29). When the resistograph drill bit passes through wood containing reaction wood, the density measurement greatly increases until the reading is simply a line at the top of the resistograph. As shown by the circles in the resistograph reading, the resistograph picks up abnormalities such as rot or cracks however the values are very high likely due to the added resistance of drilling through wood at an angle.

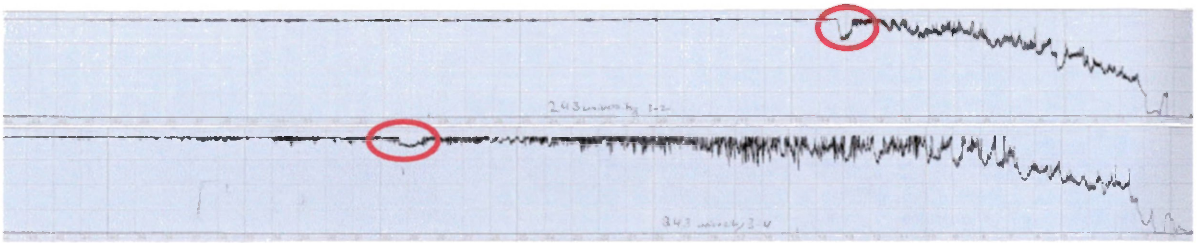


Figure 29: Resistograph reading from on a disc from a silver maple at 243 University Dr. The circles show a drop in resistance as a result of some abnormality such as rot or a crack.

Conclusions in this chapter were based on observations of the 70 tree discs drilled, however there were a few potential problems that could complicate the conclusions. The first potential problem is a flaw associated with the resistograph used for testing. The knob on the resistograph used to switch resistograph measurements between hardwoods and softwoods was found to be faulty. The knob was permanently fixed on one setting. To account for this, all resistograph measurements were made with the knob in the same position to ensure any potential errors would occur across the board on all resistograph measurements and all conclusions would factor in this potential issue.

As found by Ukrainetz & O'Neil (2010), temperature has the potential to affect the resistograph measurement. As all the tree discs in this study were frozen before being thawed, there is potential that discs may have been in differing stages of thawing when drilled with the resistograph, thus accounting for errors in the resistograph readings. To account for this potential problem, larger discs were allowed more time to thaw than smaller discs in order to equilibrate to room temperature. As best as possible, all discs were allowed to thaw and were drilled while fresh and not fully dried. Similarly, moisture which affects density can alter resistograph readings. Facilities were not available to store discs in a moisture chamber, so discs were kept as close as possible to their natural moisture content, still allowing for freezing and unfreezing of the discs to take place.

Discs from species with more dense wood (Oak) were found to produce less accurate results than discs with less dense wood (Balsam Fir). This is likely due to denser woods causing greater deflection of the drill bit within the disc resulting in increasing values for resistance as the drill moved farther into the wood. As a result of this problem, discs from conifers often more accurately showed the correct resistance across the entire width of the disc whereas readings of hardwood discs such as silver maple were much less accurate. A potential explanation for this problem is the setting on the resistograph which changes the device from a hardwood setting to a softwood setting is malfunctioning and is stuck on a single setting.

One potential way to account for many of the abnormalities recorded with the resistograph is through the use of a newer resistograph, which provides values for amplitude instead of a simple graph readout for the amplitude values. This would allow for a more accurate reflection of the actual resistance of the disc, making the readout more useful for determining abnormalities in the tree. By using a resistograph which only provides a graph readout it is impossible to adjust values to account for abnormalities. In the case of this project, a newer resistograph was unavailable for use.

3.4 CONCLUSION

There are many circumstances which can lead to errors in resistograph readings including temperature, moisture content, drill bit angle, drill bit deflection and operator error (Rinn *et al.* 1996, Chantre & Rozenberg 1997, Lin *et al.* 2003, Ukrainetz & O'Neil 2010). There is a difference between resistograph readings of conifers and deciduous trees. Significant drops in resistance also occur from cracks and advanced decay which occur on the graph as a smooth line where the abnormality occurred. Although the resistograph shows advanced decay it doesn't capture incipient decay or less advanced decay, so as a device to predict future decay the resistograph is not as useful as it is impossible to distinguish at what stage decay is at. The resistograph is however a very useful device for determining the current state of the tree.

Low numbers of discs collected and high variance of tree species and tree damages meant that the determination of a relationship between exterior tree characteristics and interior decay was impossible. As to addressing this problem in the future more involvement from the researcher in the actual removal process of the hazard trees may lead to more discs being collected. It would also be necessary for the Parks crews to be more involved and collect all the discs required in order for the project to be successful.

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CHAPTER 4:
Examination of species of wood decay and other fungi present on hazard street trees in Thunder Bay, Ontario.

4.1 INTRODUCTION

As one of the most influential factors affecting the stability of trees, wood decay fungi play a major role in creating hazard trees in the urban forest. To properly manage an urban forest, an understanding of the species and diversity of wood decay fungi affecting urban trees is required as certain species have the potential to cause more significant damage to trees than others (Sinclair & Lyon 2005). As there has been only a small amount of research looking at the species of wood decay fungi present in Thunder Bay, Ontario, an examination was undertaken to identify and enumerate the species occurring on hazard street trees as well as street trees not yet deemed hazardous.

4.2 MATERIALS AND METHODS

Three main methods were used to capture the occurrence of decay fungi in Thunder Bay. The first method was used in conjunction with Chapter two of this thesis. During the process of evaluating the exterior characteristics of a tree, if a fruiting body of a wood decay fungus was found, it was identified and recorded. If identification was not possible in the field, the fungus was collected and brought back to Dr. Hutchison's forest pathology lab at Lakehead University for further inspection and identification. The second method for recording the occurrence of decay fungi was also done in conjunction with Chapter two of this thesis. As wood discs from felled street trees were collected from the City of Thunder Bay, samples of decayed wood from each disc were removed while the disc remained moist. The decayed samples collected from the discs were then placed in sealed plastic bags and stored in a freezer at the forest pathology lab at Lakehead University to keep the wood decay fungi alive (Terho *et al.* 2007). To isolate the wood decay fungi, small sections of the samples were slivered off using a sterile razor blade until the uncontaminated centre of the sample was reached. A small piece of decayed wood was removed and placed aseptically (in triplicate) in a Petri dish with 2% malt extract agar (20g Malt extract, 1g Yeast extract, 15 g agar, 1L distilled water) to allow wood decay fungi to grow out in pure culture. The Petri dishes were then left in an incubator (at 20^0 C) to allow the wood decay fungi to grow out for identification. Wood decay fungi were then identified based on cultural morphology and microscopic features to the furthest extent possible depending on the species. The final method of recording the occurrence and species of decay fungi growing in Thunder Bay involves randomly sampling any trees observed to have a fruiting body of a wood decay fungus growing on them. The fruiting bodies from these randomly selected trees were then identified or brought to the forest pathology lab for identification. The randomly selected trees underwent the same examination as the selected hazard trees described in Chapter 2 of this thesis so comparisons can be made about tree size health and other conditions.

4.3 RESULTS AND DISCUSSION

In total, 101 trees were recorded as having a fruiting body of a decay fungus present. Twenty two of these trees were street trees selected for removal by the City of Thunder Bay. The remaining 79 trees were trees previously identified by Dr. Hutchison as trees with fruiting bodies or trees noticed to have a fruiting body. The location of the trees containing fruiting bodies can be seen in Figure 30 and Appendix I. As shown by Figure 30, the majority of the infected trees were located in residential areas found in the interior areas of Port Arthur and Fort William. Few infected trees were measured in the intercity area of the city, which is mainly commercial.

Figure 30: Location of 101 trees with fruiting bodies in Thunder Bay. Google Earth

A list of occurrence of decay fungi by tree species can be seen in Table 11 and Table 13. Silver maple (Table 11) was the most commonly infected tree. Forty nine of the total 101 trees were silver maple *(Acer saccharinum* L.). White birch (*Betula papyrifera* Marsh.) was found to be second in terms of occurrence of decay fungi with 23 trees infected. Manitoba maple (*Acer negundo* L.) had the third highest occurrence of decay fungi, with six trees being infected. The remaining ten tree species only had four or less trees having an occurrence of decay fungi (Table 11, Table 13).

The species of decay fungi found can be seen in Table 12 and Table 13. In some cases, more than one species of decay fungus was found on the same tree. The most commonly occurring decay fungus in the City of Thunder Bay was *Cerrena unicolor* (Bull.) Murrill. with 14 trees infected, followed by

Hypsizygus tessulatus (Bull.) Singer and *Pholiota aurivella* (Batsch) P. Kumm. with each infecting 13 trees. The next three most commonly occurring fungi include *Chondrostereum purpureum* (Pers.) Pouzar., *Pholiota squarrosa* (Vahl) P. Kumm. and *Ganoderma applanatum* (Pers.) Pat. with ten, nine and seven occurrences respectively. Of the remaining 20 fungi found, *Fomes fomentarius* (L.) Fr. occurred five times while the remaining species were found four times or less.

Table 11: Occurrence of decay fungi by tree species.

Species	Individual trees Infected
Silver Maple	49
White Birch	23
Manitoba Maple	6
American Elm	4
Chokecherry	4
Linden	3
White Spruce	2
Red Maple	2
Schubert Chokecherry	2
Balsam Fir	2
Green Ash	1
Balsam Poplar	1
Flowering Crab Apple	1
Lombardy Poplar	1
Total	101

Table 12: List of species of wood decay fungi and count of each species.

Disease	Count of Disease
Cerrena unicolor	14
Hypsizygus tessulatus	13
Pholiota aurivella	13
Chondrostereum purpureum	10
Pholiota squarrosa	9
Ganoderma applanatum	8
Daldinia concentrica	4
Fomes fomentarius	4
Panus serotinus	4
Piptoporus betulinus	4
Coprinus micaceus	3
Irpex lacteus	3
Pholiota spp	3
Inonotus tomentosus	2
Inonotus obliquus	2
Bjerkandera adusta	1
Climacodon septentrionalis	1
Crepidotus sp.	1
Lycoperdon pyriforme	1
Peniophora polygonia	1
Phaeolus schweinitzii	1
Pluteus cervinus	1
Schizophyllum commune	1
Volvariella bombycina	1
Phellinus pini	1
Stereum sp.	1
Unknown sp.	1
Total	108

Table 13: Occurrence of wood decay fungi by tree species and average tree health and DBH for infected trees.

Tree Species and Associated Fungi	Count of trees	Count of Disease	Average of Tree Health	Average of DBH (cm)
Silver Maple	49	55	41.29	77.98
Pholiota aurivella		12	46.88	76.96
Hypsizygus tessulatus		11	41.48	87.07
Ganoderma applanatum		7	38.84	80.40
Cerrena unicolor		4	32.81	85.10
Daldinia concentrica		4	29.69	66.93
Panus serotinus		4	38.28	80.78
Chondrostereum purpureum		4	33.33	108.30
Coprinus micaceus		3	54.17	68.37
Pholiota spp		2	62.50	55.25
Climacodon septentrionalis		1	31.25	63.30
Pholiota squarrosa		1	40.63	84.90
Pluteus cervinus		1	34.38	96.40
Volvariella bombycina		1	34.38	60.00
White Birch	23	26	33.88	52.91
Pholiota squarrosa		6	39.06	57.20
Cerrena unicolor		4	28.91	54.40
Fomes fomentarius		4	37.50	55.50
Piptoporus betulinus		4	33.59	51.93
Chondrostereum purpureum		2	18.75	52.90
Inonotus obliquus		2	50.00	58.35
Bjerkandera adusta		1	3.13	49.60
Irpex lacteus		1	31.25	
Pholiota aurivella		1	50.00	37.80
Schizophyllum commune		1	25.00	58.50
Manitoba Maple	6	8	27.08	68.95
Cerrena unicolor		3	17.19	68.15
Chondrostereum purpureum		2	23.44	90.85
Hypsizygus tessulatus		2	40.63	47.85
Stereum sp.		1	25.00	79.00
American Elm	4	3	36.72	44.60
Cerrena unicolor		2	35.94	41.10
Pholiota squarrosa		1	46.88	44.30

Table 13: Occurrence of wood decay fungi by tree species and average tree health and DBH for infected trees. (Continued)

Tree Species and Associated Fungi	**Count of trees**	**Count of Disease**	**Average of Tree Health**	**Average of DBH (cm)**
Linden	3	3	31.25	55.37
Irpex lacteus		1	56.25	21.10
Lycoperdon pyriforme		1	18.75	72.50
Pholiota sp		1	18.75	72.50
White Spruce	2	3	3.13	21.00
Inonotus tomentosus		2	3.13	21.00
Phaeolus schweinitzii		1	31.25	75.90
Schubert Chokecherry	2	1	32.81	19.55
Chondrostereum purpureum		1	31.25	15.60
Red Maple	2	2	60.94	33.80
Cerrena unicolor		1	87.50	19.60
Irpex lacteus		1	34.38	48.00
Balsam Fir	2	2	32.30	6.25
Chondrostereum purpureum		1	27.30	6.25
Phellinus pini		1	37.30	
Lombardy poplar		2	33.5	37.5
Crepidotus sp.		1	33.5	37.5
Unknown sp.		1		
Green Ash		1	43.75	42.13
Ganoderma applanatum		1	40.63	39.40
Balsam Poplar		1	0.00	17.80
Peniophora polygonia		1	0.00	17.80
Flowering Crabapple	-	1	50.00	27.00
Pholiota squarrosa		1	50.00	27.00
Total / Average	**101**	**108**	**34.31**	**41.11**

Different species of wood decay fungi are capable of causing differing types of decay and damages to trees. Many of the encountered fungi were heart rot fungi which decay the dead heart wood of the tree but don't affect the living sapwood. Examples of these types of fungi found include *Pholiota aurivella, Fomes fomentarius, Hypsizygus tessulatus, Piptoporus betulinus* and *Phellinus pini* (Boulet 2003, Luley 2005, Sinclair & Lyon 2005). Most of the heart rot fungi encountered are capable of infecting a wide range of host species (Farr *et al.* 1989). A few are considered to be more host specific including, *Inonotus obliquus* and *Piptoporus betulinus* on *Betula*, and *Climacodon septentrionalis* on *Acer*

(Sinclair & Lyon 2005). From the group of encountered fungi there are also species which are capable of infecting the living sap wood of the tree. Examples of these species include *Cerrena unicolor, Schizophyllum commune* and *Chondrostereum purpureum* (Sinclair & Lyon 2005). Usually these sapwood rotting fungi are opportunistic and are colonizing trees that are already in decline (Sinclair & Lyon 2005). Among some of the decay fungi encountered were those which rot the roots and butts of living trees. Examples of these species include *Ganoderma applanatum, Pholiota squarrosa* and *Inonotus tomentosus* (=*Onnia tomentosus*) (Sinclair & Lyon 2005). Species causing butt rots should be of special interest as they are capable of causing a tree to fail at the base and fall particularly during strong winds. A strong wind storm in Thunder Bay in September of 2010 resulted in considerable damage to trees in the Boulevard Lake area that either snapped in the stem due to heart rot fungi or snapped at the base due to root and butt rot fungi (Hutchison pers. comm.)

The most commonly occurring and problematic fungi for *Ace*r spp. in Thunder Bay included *Pholiota aurivella, Hypsizygus tessulatus, Ganoderma applanatum* and *Cerrena unicolor* (Table 13). Silver maple likely had the highest occurrence of fungi as many silver maples in Thunder Bay are reaching maturity but have not yet reached the point where they are in severe decline. Silver maples are not a target for City Parks crews and thus many infected trees still remain (Davey Resource Group 2011). Manitoba maple was third on the list for occurrence of decay fungi. Manitoba maple is considered a weak-wooded species and becomes a hazard when it reaches older age (Farrar 1995) so many of the Manitoba maples will have been removed before decay becomes a problem. In similar studies in Helsinki, many of the common species of decay fungi found on maples were the same as those that also occurred on street trees in Thunder Bay (Terho & Hallaksella 2008). These included *Ganoderma applanatum* (=*G. lipsiense*), *Pholiota aurivella, Chondrostereum purpureum* and *Climacodon septentrionalis* (Terho & Hallaksela 2008, Erkkilä & Niemelä 1986). *Ganoderma applanatum* and *Pholiota* spp. were major problems in both cities and occurred relatively often in both cases. Species commonly causing issues with maples in the Thunder Bay area but which were not recorded in the Helsinki study included *Cerrena unicolor* and *Hypsizygus tessulatus. Cerrena unicolor* did occur in the Helsinki study but on *Betula* spp (Terho & Hallaksela 2008). Problematic decay fungi which occurred commonly in the Helsinki study by Terho & Hallaksela (2008) but not in Thunder Bay included *Rigidoporus populinus*, and *Kretzschmaria deusta.* A large number of fungi were reported in Helsinki by Erkkilä and Niemelä (1986), however this study was conducted in the parks and forests of Helsinki, so it covered a large range of tree species which aren't planted as street trees, leading to a larger diversity of fungal species. Average health values for 49 silver maples in Thunder Bay with fruiting bodies, was 41.29, close to the 34.3, average health for all tree species (Table 13). Health ratings for Manitoba maple were very low with the average being 27.08, while the health average for 2 red maples was very high at 60.94 (Table 13).

It is important to take note of the high occurrence of decay fungi on silver maples. What this likely shows is a sign that in the upcoming future many of the silver maples in the city are likely to begin declining in health. As an urban forester, there is a responsibility to test for the soundness or presence/absence of decay and to plan for the eventual removal of these trees when they become hazards. Due to this responsibility, preparations should be made to ensure that when silver maples begin to dramatically decline, the number of silver maples needing removal will not overwhelm the current City Parks crews.

The most commonly occurring decay fungi on birch in Thunder Bay include *Pholiota aurivella*, *Fomes fomentarius, Cerrena unicolor* and *Piptoporus betulinus* (Bull.) P. Karst. (Table 13). White birch had the second highest occurrence of decay of any tree species in the city. However, it would have likely been higher on the list if white birch were not a target for removal by the City as many are in severe decline (Davey Resource Group 2011). Birch (*Betula pendula* Roth and *B. pubescens* Ehrh) in the city of Helsinki were infected with similar fungi to those which are problematic to birch in Thunder Bay. These included *Pholiota* spp., *Piptoporus betulinus, Inonotus obliquus, Cerrena unicolor, Chondrostereum* *purpureum* and *Fomes fomentarius* (Terho & Hallaksela 2008)(Table 13). *Kretzschmaria deusta* (Hoffm.) P.M.D. Martin., *Climacodon septentrionalis* Fries., *Armillaria* spp. were found in Helsinki on birch but not in Thunder Bay on birch and *Schizophyllum commune* Fr. and *Irpex lacteus* (Fr.) Fr. occurred in Thunder Bay but not in Helsinki (Terho & Hallaksela 2008)(Table 13). Once again in the Erkkilä and Niemelä (1986) study of Helsinki there was a large diversity of fungal species on *Betula*. However it is a result of a larger number of tree species and sampling being collected in forested and parkland areas. The tree health ratings for 23 white birch trees in Thunder Bay with an associated fruiting body was low with an average of 33.88 (Table 13).

Due to the high occurrence of decay fungi on white birch and the relatively low average health of the sampled trees, it is important to be aware that this is a tree species which is currently a high risk in the city. Special attention should be paid when assessing white birch as the high occurrence of decay shows how potentially dangerous many white birch could become in the near future, especially in storms and high wind events. White birch is no longer planted as a street or park tree in Thunder Bay.

Green ash was very low on the list of disease occurrence likely due to the younger ages of green ash trees in the city (Davey Resource Group 2011), many of which have not reached the ages necessary for decay fungi to successfully fruit on the trees. American elm had a low occurrence of individual trees with decay fungi. This is probably due to most trees already having been removed as a result of Dutch elm disease reducing the number of large trees susceptible to decay. The remaining tree species listed in Table 15 had lower incidences of decay due to the fact that the occurrence of decay was proportional to the total number of trees of that species.

All decay fungi found on street trees in Thunder Bay except *Hypsizygus tessulatus*, were previously recorded in similar studies of decay fungi on park and street trees (Seehann 1979, Erkkilä & Niemelä 1986, Gibbs & Greig 1990, Terho & Hallaksela 2008). These species of decay fungi have been reported in many manuals about wood decay fungi and field guides as being commonly occurring

(Barron 1999, Boulet 2003, Luley 2005, Sinclair & Lyon 2005, Schwarze 2008). *Hypsizygus tessulatus* is a widespread species, however, it is not a commonly occurring fungus (Barron 1999). Potential reasons why *Hypsizygus tessulatus* (=*Pleurotus ulmarius*) was reported so often could be due to the large size and appearance of the fruiting body making it very visible and showy, which could increase its occurrence in a study such as this where occurrence is based on visual recognition of the fruiting body (*i.e.,* noticing it).

A majority of the samples isolated from tree discs (53 out of 57 cultures) contained fast growing co-occurring contaminants which overgrew cultures of wood decay fungi (if present) within the discs. Often such contaminants such as *Trichoderma* commonly grow out from samples of wood faster than the species of wood decay fungi present in the samples. *Trichoderma* species are well known as mycoparasites and commonly occur in wood (Domsch *et al.* 1980). The most commonly occurring contaminants were *Trichoderma, Rhizopus, Penicillium, Alternaria* and *Fusarium* (Table 14). In total only 4 pure isolations of decay fungi were isolated from the 37 discs. The four species of wood decay fungi isolated from the discs were *Ganoderma applanatum, Pholiota aurivella, Crepidotus* sp. and an unidentifiable culture.

Table 14: Occurrence of fungal contaminants in wood decay isolations.

Species	Count of Species
Trichoderma sp	29
Rhizopus sp	12
Penicillium sp	5
Alternaria sp	4
Fusarium sp	3
Total	53

Although wood decay fungi are most directly responsible for loss of wood strength, other disease causing fungi can lead to a decrease in tree health and vigour and in some cases, depending on the species of fungus, death.

The fungus which occurred the most often on chokecherry, which is not considered a wood decay fungus was *Apiosporina morbosa* (Schwein.) Arx. which causes blacknot. *Apiosporina morbosa* occurred on four of the six chokecherry trees sampled (Table 15) and on two Schubert chokecherry trees. Because of the high susceptibility of chokecherry to infection by *Apiosporina morbosa* in Thunder Bay, chokecherry is no longer planted as a street tree (Shelley Vescio pers. comm.).

Other fungi which occur in the city of Thunder Bay were not recorded as occurring often but are still significant and include two foliar fungi *Gnomoniella fraxini* Redlin & Stack. and *Stegophora ulmea* (Fr.) Syd. & P. Syd. (Table 15). As previously mentioned in Chapter 2, *G. fraxini* causes ash anthracnose, resulting in misshapen foliage and in severe cases, twig and branch dieback (Sinclair & Lyon 2005). *Stegophora ulmea* usually causes a cosmetic disease in elm, as cases of low infection only causes small growths on leaves, but in cases of heavy infection can result in twig and branch dieback (Sinclair & Lyon 2005).

Table 15: Occurrence of other disease causing fungi by tree species, average of tree health and average DBH(cm) of tree.

Tree Species and Associated Fungi	Count of trees	Count of Disease	Average of Tree Health	Average of DBH (cm)
Chokecherry	4	4	25.00	15.65
Apiosporina morbosa		4	25.00	15.65
Green Ash	2	2	45.31	43.50
Gnomoniella fraxini		2	45.31	43.50
Schubert Chokecherry	2	2	34.38	23.50
Apiosporina morbosa		2	34.38	23.50
American Elm	1	1	28.13	51.90
Stegophora ulmea		1	28.13	51.90
Total / Average	**9**	**9**	**33.20**	**33.64**

Due to the occurrence of decay fungi being selected at random and based on visually occurring fruiting bodies, high traffic areas (*i.e.* commonly visited areas) will have been more heavily sampled than low traffic areas (*i.e.* less visited areas). This could lead to tree species more common in these areas having a larger sample size than tree species in different areas. Although the first and third method of recording species of decay fungi is done at random there is still potential for the second method of examining presence of decay fungi to skew the data to show certain tree species with a higher percentage of infection. No conclusions were made about the percentage of the population of street trees in Thunder Bay infected with decay fungi. In order to achieve this value a random sample would need to be made where entire streets are surveyed and trees without decay fungi are reported as well as trees with decay fungi to find an appropriate proportion of infected trees.

4.4 CONCLUSION

As shown by the occurrences of decay fungi, silver maple and white birch are two tree species where particular attention needs to be paid as they were the two tree species with the highest amount of decay fungi present. The wood decay fungi *Cerrena unicolor, Hypsizygus tessulatus, Pholiota aurivella, Pholiota squarrosa, Chondrostereum purpureum* and *Ganoderma applanatum* are species where a special interest should be paid as they were the most commonly occurring wood decay fungi occurring within the sample of trees measured. *Apiosporina morbosa* has been shown to be a commonly occurring fungus in the city of Thunder Bay, and when planting or managing trees which are potential hosts for this fungus, special care should be taken to insure it is dealt with properly. By knowing that silver maple and white birch seem to be high risk species, management practices can properly reflect this and ensure that a plan to deal with the occurrence of more hazard trees in the future and removal of the current hazard trees is more efficient. Similarly, by knowing the most commonly occurring species of decay fungi and the types of decay that they cause, the urban forester has the ability to more easily identify any potential problems they could cause in the future.

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CHAPTER 5:
Preliminary observations to determine the relationship between resistograph readings and wood strength values

5.1 INTRODUCTION

Resistographs are commonly used for detecting decay in wood of living trees. It is a portable drill with a graph attachment that records the relative resistance of wood on a chart. The purpose of this chart is to record the change in resistance when the drill bit passes from solid wood into decayed wood or vice versa, but the measurements recorded on the Y axis do not represent any quantitative values. When the drill bit enters decayed wood the resistance value will significantly drop. Based on the amount of decay present, an urban forester can determine if a tree has the potential to fail. In Urban forestry there are fixed standards for strength and stability used to determine if a tree is a hazard (Schwarze 2008). These fixed standards do not take factors such as tree species into account in the decision making process. Currently, if a tree has less than 1cm of sound wood for every 6cm of stem diameter, the tree is considered to be a hazard tree (Pokorny 2003). Although this rule covers a wide variety of situations, more accurate measurements based on tree strength values could be used to determine the minimum ratio of solid wood to decayed wood that would lead to a tree failing. By relating resistograph measurements to actual wood strength values, urban foresters could, with greater precision, predict if a tree has the wood strength to stay standing. The purpose of this chapter is to examine if a potential relationship exists between wood strength values and resistograph measurements, utilizing the stem of a felled silver maple (*Acer saccharinum* L.).

5.2 MATERIALS AND METHODS

The hazard tree selected for sampling was an average sized silver maple with a DBH of 44cm located at 243 University Drive, Thunder Bay, ON (Figure 31). The silver maple contained multiple exterior defects such as co-dominant forking and frost cracks, which led to decay entering the stem. One of the co-dominant stems was also dead leading to decay entering the stem of the tree. The tree was felled at the beginning of August 2012, and a 1.2m section directly above breast height was collected for wood testing.

Figure 31: Silver maple located at 243 University Dr. selected for sampling

Once the 1.2m section was collected, it was taken to the Lakehead University Wood Science and Testing Facility (LUWSTF) portable milling site for dissection. The log section was drilled with a resistograph (IML Resistograph F-Series) from bark to pith eight times at both ends, labeled A and B, resulting in 16 drillings from the resistograph. Each drill path was labeled one to eight on both sides, with a line marking the path the drill bit entered into the wood (Figure 32). The log section was demarked but not cut into two smaller sections labelled bolt A and bolt B. Although the two bolts, A and B, came from the same section of the trunk, they each contain differing characteristics, such as amount of decay and reaction wood. Bolt A, located in the centre of the tree starting at DBH, contained one frost crack running through the length of the section and much of the centre of the wood contained incipient decay. Bolt B differed, as the diameter of the bolt was larger, being located right below where the tree separates into two co-dominant forks. The fork above bolt B of the tree caused decay to enter in the tree, resulting in the decay in bolt B being more advanced than the decay in bolt A. Bolt B of the tree also had a lot of reaction wood to compensate for the strain of the two co-dominant stems on the main trunk of the tree. The differences between the two bolts can be seen in Figure 32.

Figure 32: Bottom of 1.2m section labeled bolt A (left), and the top of the 1.2m section labeled bolt B (right) showing the path of the eight resistograph drillings.

The log section of wood was then cut length wise into 2.5cm thick slabs on a Wood Mizer LT40 Hydraulic portable mill band saw. On both ends of the log section, a grid system was marked prior to cutting as a means of labelling and identifying where each sample of wood was located in the tree (Figure 33). The resistograph charts were then placed on their corresponding line and grid segments through which the resistograph drill bit passed and was photographed (Figure 34).This would later allow for the correlation of wood strength values with the resistograph measurements. The slabs were then piled with sticks between each slab, and left to dry until they reached a MC level of approximately 16%.

Figure 33: A 1.2m section cut into one-inch thick slabs and labeled using the grid system.

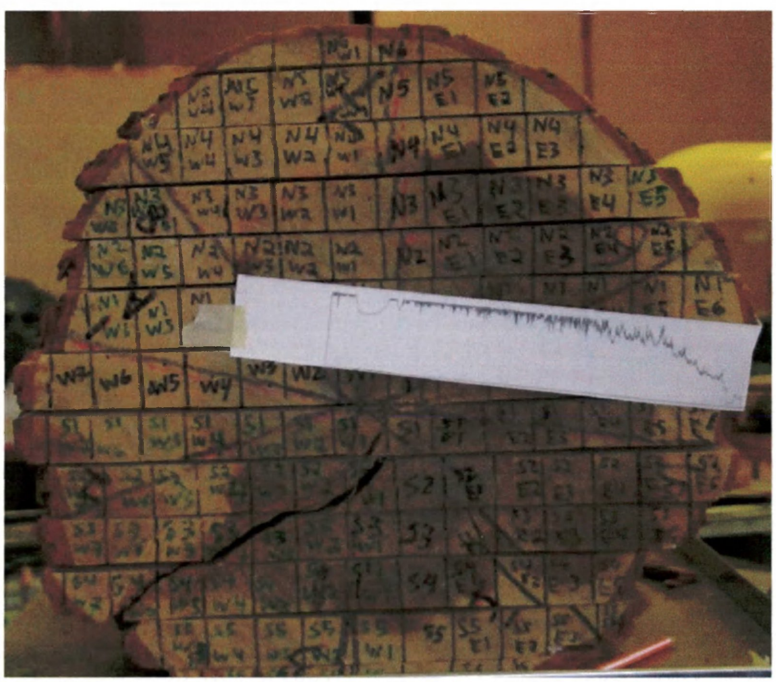

Figure 34: Slabs with resistograph chart placed above corresponding marked line on tree section

When the slabs reached a MC of 16%, they were cut in half into bolt A and bolt B measuring at least 60cm in length. Both bolts were then cut into 2.5cm x 2.5cm x 30cm sticks. The excess 30cm on each stick was removed. These sticks were left in a conditioning chamber set at 60% relative humidity and 20°C to ensure they were conditioned to the industry standard testing moisture content of 12% (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). The sticks were cut once more when they reached the 12% MC to a final dimension of 2cm by 2cm with a length of 30cm. At this point, all the test sticks from bolts A and B were removed from the conditioning chamber and wood testing was conducted on a Tinius Olsen H10kt Universal Wood Testing Machine using the MOE 3-ptn testing tool to determine their wood strength values (MOE) (Figure 35). All mechanical testing was conducted according to American Society for Testing materials (ASTM) standard D143-09 with the exceptions that defects such as rot were left in samples (ASTM 2009). Directly after each group of sticks was tested, one cube was cut from each stick and weighed. The cubes from each stick were placed in an oven to dry (21^{0}C for 5 Days) in order to determine moisture content of the sticks when MOE testing was done. Cubes were weighed and then volume was calculated by the water displacement method (according to ASTM standard D143-09) after which the density for the cubes was calculated (ASTM 2009). All sticks from each of the two boards where a resistograph line passed through, or within one cube distance, also had their densities calculated.

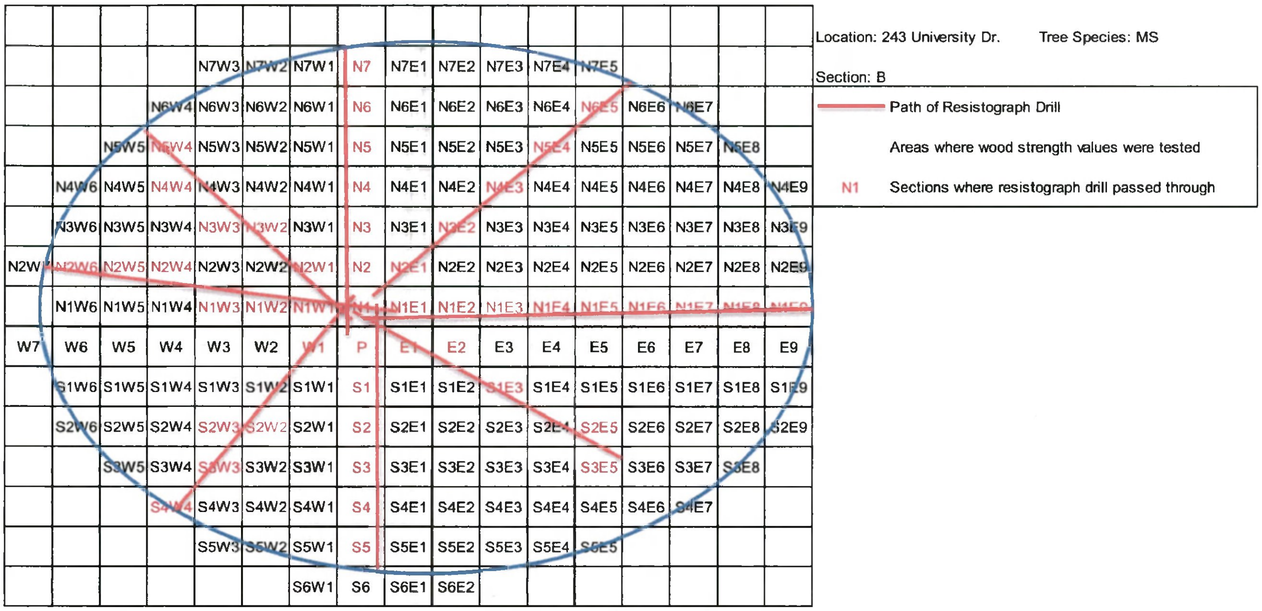

Figure 35: Representation of bolt B, showing location of wood testing and approximate location where resistograph drilling measurements were taken.

To determine densities, cubes were initially weighed at approximately 12% moisture content and these values were recorded. A beaker of distilled water was then placed on a balance and tared to zero. The density cubes were then fully submerged into the distilled water using a lab needle inserted into the cube. It is important during this step to watch the weight on the scale and record the value which stabilizes the scale. This value represents the volume of the cube in cubic centimeters at 12% MC before the cube volume begins to increase due to the cube absorbing water. The resulting weight displacement measured on the scale in grams represents the weight of the cubes at 12%. The weight of the cubes at 12% is then divided by the volume of the cubes at 12% to give the density of the wood at 12% (Density 12% =Mass 12%/ Volume 12%). This process is repeated when the cubes have been oven dried giving the density of the oven dried wood (Density Oven Dry(OD) =Mass OD/ Volume OD).

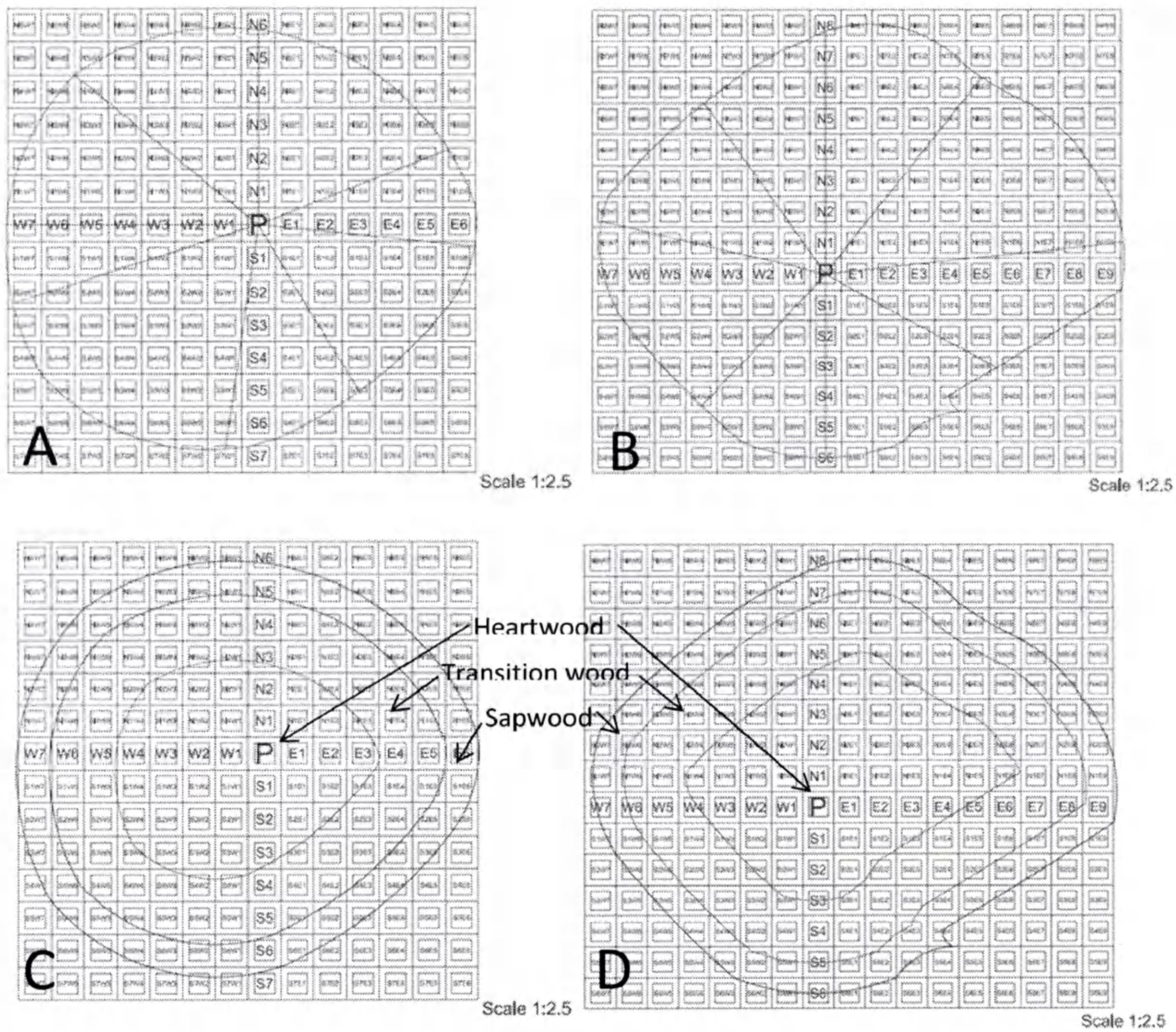

Figure 36: Four charts showing scale models of the ends of bolts. Chart A Shows Bolt A with the resistograph paths shown. Chart B shows Bolt B with paths of resistograph lines shown. Chart C shows the three radial positions of Bolt A. Chart D shows the three radial positions on Bolt B.

The first step in correlating resistograph measurements with wood strength values, is to ensure the location of the resistograph measurements match the locations in the disc so they can be directly compared. To do this, a scale model of the end of each bolt was made (Figure 36). The entry point of the resistograph drill bit is the most accurate measured location of the resistograph drill path, so a line is drawn from this point to the pith of the tree. The line is drawn on a scale model of the bolt, so the exact distance from the entry point of the drill bit to the bolt can be calculated (Figure 36 A, B). From the length of the line on the scale model, the location of the pith can be determined on the resistograph reading ensuring resistograph values are directly compared to wood strength values in the same location. Bolts were broken into radial positions (ie. sapwood, transition wood and heart wood) to account for natural strength changes in wood across the radius of the bolt (Figure 36 C, D). The bolts were further broken into eight sectors allowing for comparison of density values from the resistograph and wood by sector and radial position.

To provide MOE values for sticks not within the cross section in the centre of the bolts, the bolts were broken into eight sectors. For sticks not within the cross, average MOE values were given based on density and MOE measurements within the cross. These estimates of density and MOE can be given as long as the stick with the missing MOE value is located in the same radial position and has a density measurement within the same sector and radial position (Miller 2010).

As the resistograph chart has no known quantitative values for the Y axis, they were produced to properly compare resistograph densities to wood densities. This can only be done once the resistograph reading values are determined to be in the correct locations and compared to the correct wood strength values. To give a value to the Y axis, a simple scale was made based on the highest density measurements encountered. Once the Y axis values were determined, the line on the resistograph can be averaged in sections and given a value. This resistograph value can then be directly compared to densities and MOE values.

As the bolt was drilled when the wood was still green (*i.e.*, MC of 24%) and wood strength testing was done when the sticks were at 12% MC, shrinkage also needed to be accounted for in order to properly align the wood strength values and resistograph values. The cubes in which the resistograph drill bit passed through are measured with the orientation of the cubes in the same direction, giving a base length. This will provide a measurement for shrinkage as the total distance of the resistograph line is known. Once wood lost to the width of the cutting blades and extra wood around the cubes is removed, the remaining distance can be accounted for by shrinkage. This will further increase the accuracy of comparing the resistograph measurements with wood strength values.

As previously mentioned, the bolt was drilled with the resistograph while still green. To account for the change in density from 28% MC to 12% MC, an ANOVA ($Y_{(ijk)l}=\mu+ WD_i+RD_j +\sum_{(ij)k}$) was conducted comparing densities of wood with a MC of 28% and densities of wood with a MC of 12%. Results from this ANOVA were used to determine whether density values need to be averaged. Tests of homogeneity and normality were then conducted on the data to show that the data meets the assumptions of ANOVA. A regression model (Y=-0.083+1.28012x) was also used to further describe how density values of the two different MC's relate to each other.

$Y_{(ijk)l}=\mu+ WD_i+RD_j +\sum_{(ij)k}$
$Y_{(ijk)l}$ =Density.
μ= Grand Mean
WD_i = fixed effect of the $_i$ Green 28% Moisture content.
RD_j = fixed effect of the $_j$ relative density of oven dry.
$\sum_{(ij)k}$ =the random effect of the k rep in the treatment of $_{ij}$
$\sum_{(ij)k}$ = Assumed to be $N(0,\sigma^2)$

Locations of sticks with defects were compared to photographs of the end of bolts to ensure that defects recorded matched actual real defects in the bolts. To do this, two ANOVA's ($Y_{(ijkl)m}=\mu+A_i+S_j+AS_{ij}+R_k+AR_{ik}+SR_{jk}+ASR_{ijk}\sum_{(ijk)l}$) were conducted, one on sticks with defects and one on sticks without defects. A sorted count was then conducted showing occurrences of defect sticks by radial position, sector, and finally, bolt. This gave values which can be used to calculate a percentage of sticks by location with defects.

$Y_{(ijkl)m}=\mu+A_i+S_j+AS_{ij}+R_k+AR_{ik}+SR_{jk}+ASR_{ijk}\sum_{(ijk)l}$
$Y_{(ijkl)m}$ =Defects.
μ= Grand Mean
A_i = fixed effect of the $_i$ Axial position.
S_j = fixed effect of the $_j$ Sector position.
AS_{ij}= mixed interaction effect of the $_{ij}$ Axial and Sector position.
R_k= fixed effect of the $_k$ Radial position.
AR_{ik}= mixed interaction effect of the $_{ik}$ Axial and Radial position.
SR_{jk} = mixed interaction effect of the $_{jk}$ Sector and Radial position.
ASR_{ijk} = mixed interaction effect of the $_{ijk}$ Axial Sector and Radial position.
$\sum_{(ijk)l}$ =the random effect of the $_l$ Rep in the treatment of $_{ijk}$
$\sum_{(ijk)l}$ = Assumed to be $N(0,\sigma^2)$

Similarly, to show a difference between the mechanical strength of sticks with defects versus sticks without defects, an ANOVA ($Y_{(ijk)l}=\mu+D_i+R_j+DR_{ij}\sum_{(ij)k}$) was conducted.

$Y_{(ijk)l}=\mu+D_i+R_j+DR_{ij}\sum_{(ij)k}$
$Y_{(ijk)l}$ = Mechanical Strength.
μ= Grand Mean
D_i = fixed effect of the $_i$ Defect.
R_j = fixed effect of the $_j$ Radial position.
DR_{ij} = mixed interaction effect of the $_{ij}$ Defect and Radial position.
$\sum_{(ij)k}$ =the random effect of the $_k$ Rep in the treatment of $_{ij}$
$\sum_{(ij)k}$ = Assumed to be $N(0,\sigma^2)$

Average values for the Y axis were given to the resistograph line so they could be directly compared to wood strength values to determine if a relationship exists. Two ANOVA's ($Y_{(ijk)l}=\mu+S_i+R_j+SR_{ij}\sum_{(ij)k}$) were conducted to show whether resistograph densities contained significant differences or no significant differences across the same sectors and radial positions. To compare wood densities to resistograph densities, bar graphs as well as line graphs were created to visually compare the average values by sector, radial position and resistograph line. A regression model (Y=-15.602+1.01434x) was used to correlate statistically if resistograph densities related to the wood densities.

$Y_{(ijk)l}=\mu+ S_i+R_j +SR_{ij}\ \Sigma_{(ij)k}$
$Y_{(ijk)l}$ = Density.
μ= Grand Mean
S_i = fixed effect of the $_i$ Sector postion.
R_j = fixed effect of the $_j$ Radial position.
SR_{ij} = mixed interaction effect of the $_{ij}$ Sector and Radial position.
$\Sigma_{(ij)k}$ =the random effect of the $_k$ Rep in the treatment of $_{ij}$
$\Sigma_{(ij)k}$ = Assumed to be $N(0,\sigma^2)$

5.3 RESULTS AND DISCUSSION

To determine if a difference exists between densities in wood with a MC of 24% and wood with a MC of 12%, an ANOVA was conducted (Table 16). Results of the ANOVA show that no significant difference was found between the densities of wood with a MC of 24% and a MC of 12% (P value= 0.6395) (Table 16).

Table 16: Results from ANOVA examining difference between wood density at MC 24% and relative density (density at MC 12%).

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)
Axial	1	631	630.75	0.2223	0.6395
Residuals	46	130501	2836.98		

Wood density averages were plotted in a bar graph (Figure 37) and a line graph (Figure 38) to show the difference between wood densities with the two different MC. As shown by the two figures, in both cases, the density of wood was higher for wood at a MC of 12% than it was for wood with a MC of 24%. This pattern should be seen because as moisture content in wood increases, wood density decreases (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). This is because wood is stronger and more dense when dry, however, density changes at a constant rate allowing for densities at different MC's to be compared.

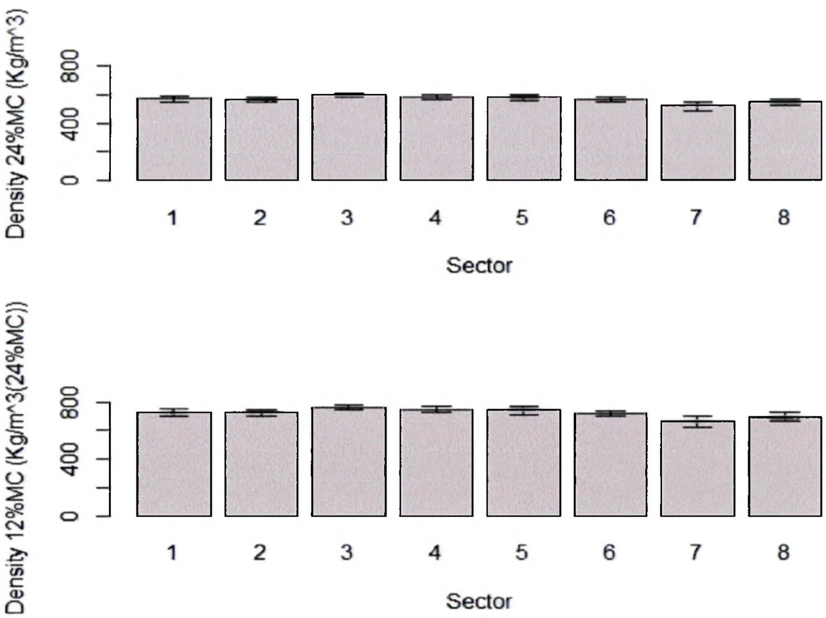

Figure 37: Bar graph showing density averages by section of wood with a MC of 24% on top and wood with a MC of 12% on the bottom with standard error bars shown.

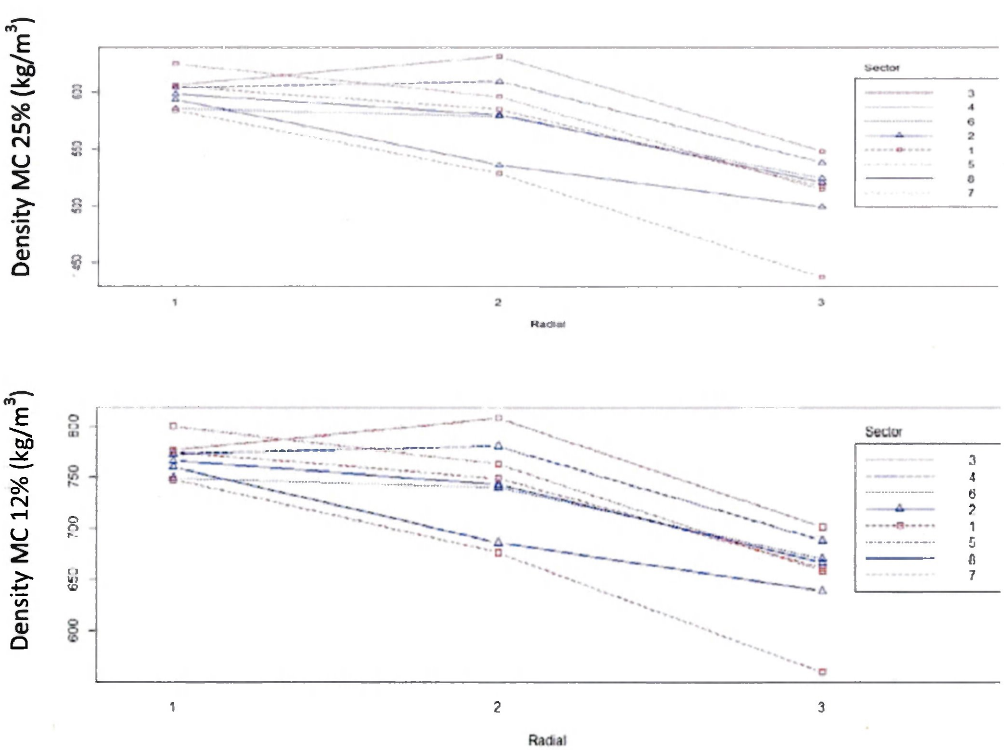

Figure 38: A line graph showing differences in wood density by radial position between (Top) wood with 12% MC and (Bottom) wood with 24% MC.

A regression model (Y=-0.083+1.28012x) was also conducted to show how densities of the two MC's relate. The two moisture contents were shown to very strongly relate with a correlation value of 0.999978. Similarly an adjusted R^2 for the relationship was found to be 1 or perfect. The relationship between densities of wood with differing MC's has been shown to be very strong, meaning the MC of the two wood densities do not need to be adjusted to determine if a relationship is present between resistograph and wood densities.

To determine if defects recorded in the sticks matched the actual locations of defects and decay in the bolts, an ANOVA was run which examined whether there was a significant difference in the number of defects between bolts, sectors or radial positions. The results of the ANOVA indicate there was no significant difference in the number of defects in any of the positions including bolt, sector or radial position. When the percentage of defects per bolt was visually compared to the actual defects visible in the photographs of the bolts, it was possible to see that the defects generally matched the location of decay and other defects visible in the photographs (Figure 39). This indicates that sticks tested for their strength properties match the discs as best as possible.

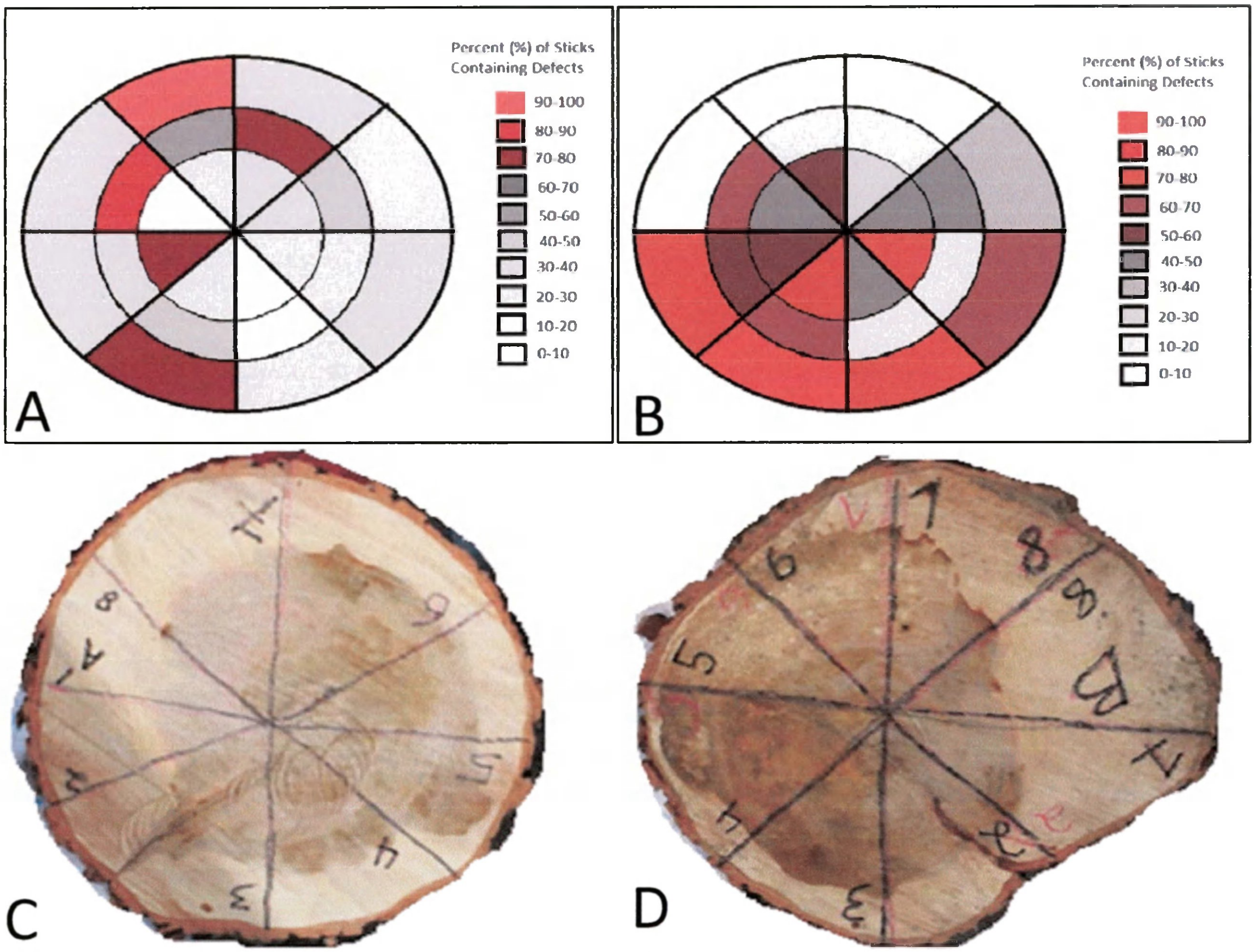

Figure 39: A comparison of the percent of sticks containing defects compared to a photograph of the bolt showing the location of decay and other defects. Diagram (A) represents Photo (C), and diagram (B) represents photo (D).

Potential sources of error which could occur include heavily damaged sticks being culled and not counted as defects. As severity of defect is not measured and only occurrence is recorded, heavily decayed areas may potentially only be represented by a small number of sticks. If only a small number of sticks within the section were testable, the percentage of heavily decayed sticks may be less due to loss to cull. Abnormalities which are not visible on the surface of the disc could also be potential sources of error.

To show there is a significant difference in wood strength between sticks with defects, MOE, Modulus of Rupture (MOR) and sticks without, MOE and MOR values were entered into an ANOVA. For both MOE and MOR it was found that there was a significant difference between clear sticks and sticks with defects (MOE P value=0.002462, MOR P Value= 0.00932). This indicates that the observed defects on sticks were significant, and did cause a drop in wood strength. The difference between sticks with defects and sticks without can be seen in Figure 40.

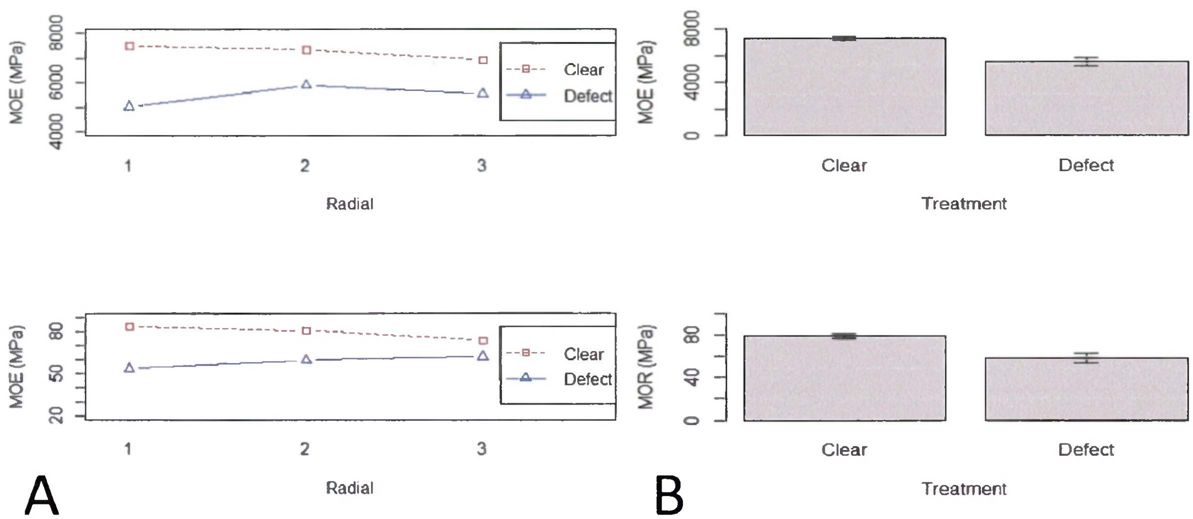

Figure 40: (A) Line graphs showing differences in strength between clear sticks and defect sticks. (B) Bar graphs showing difference in strength between clear sticks and defect sticks with standard error bars shown. In both cases Modulus of elasticity is the top graph and Modulus of rupture is represented below.

To determine if a relationship exists between resistograph densities and wood strength densities, two ANOVA's were conducted. Resistograph densities showed significant differences in the sector and radial positions (Sector P value=1.546e-07, Radial P value=<2.2e-16). Similarly, wood densities showed a significant difference in the sector and radial positions (Sector P value=1.223e-07, Radial P value=<2.2e-16). This difference is expected as it has been shown wood qualities differ by radial position and due to location of rot by sector (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). A significant difference in wood density was not found between the bolts, so bolt was used as a replicate to provide a degree of freedom and increase the accuracy of results. An example of averages of wood density compared to resistograph densities by sector can be seen in Figure 41. Each resistograph line was broken into nine radial positions with the first closest to the pith and the ninth closest to the bark. Averages of the nine radial positions for resistograph density and wood density by sector can be seen in Figure 42. A comparison of the average values for wood density and resistograph density by the nine radial positions and replication or bolt can be seen in Figure 43. The average densities for the resistograph reading in all cases closely match the density values by sector, showing that a close relationship exists between the wood values and resistograph values for density (Figure 41, Figure 42, Figure 43). In all three cases, densities are lower in the positions closest to the bark or edge of the bolt. From the positions closest to the bark to the centre of the bolt, density values increase. A difference between resistograph densities and wood strength value exists in the three radial positions closest to the pith, where there is a small drop in density in wood densities. This trend of lower densities near bark, to higher densities in the middle and slightly lower densities in pith best represents actual density trends in trees (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). As resistograph densities do not drop near radial positions closest to the pith, it suggests that density values are less accurate the further into the bolt the resistograph drill bit enters or, due to the nature of the resistograph reading, it reaches a ceiling but actual density values are above these recorded values.

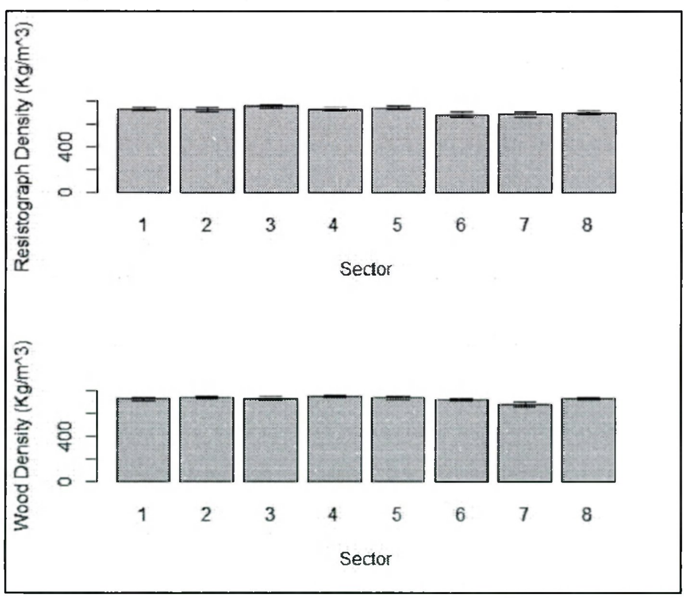

Figure 41: Average density of wood blocks compared to resistograph density by radial sector with standard error bars shown.

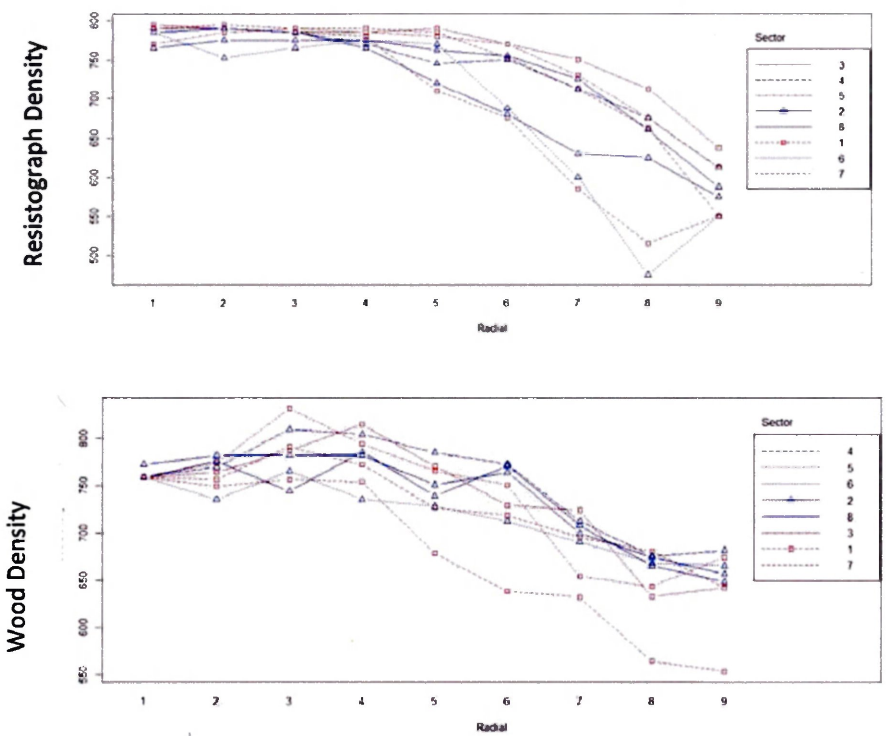

Figure 42: Mean of nine radial positions for resistograph density and wood density by sector.

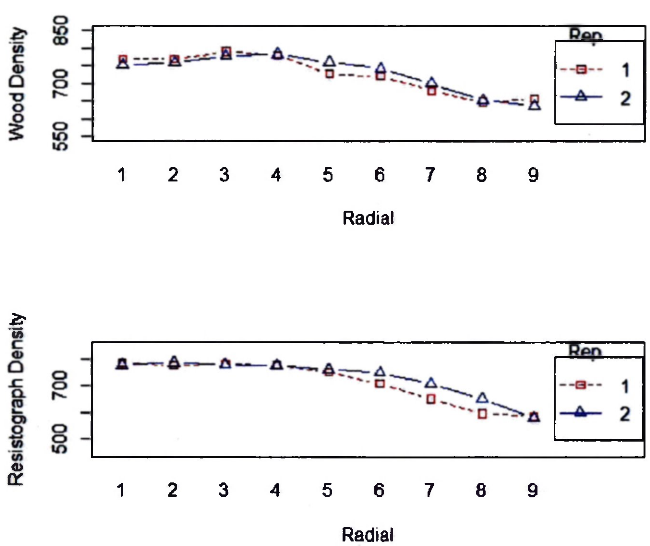

Figure 43: Average of wood density compared to average of resistograph density by the replication (bolt) and the nine radial positions.

A linear regression was conducted to determine the strength of the relationship between wood density values and resistograph values. The results of the linear regression model (Y=-15.602+1.01434x) show there is a relationship between the resistograph densities and wood densities. The adjusted R^2 value which represents the strength of the relationship reports a value of 0.5745 with a p-value of <2.2e-16 showing it is significant.

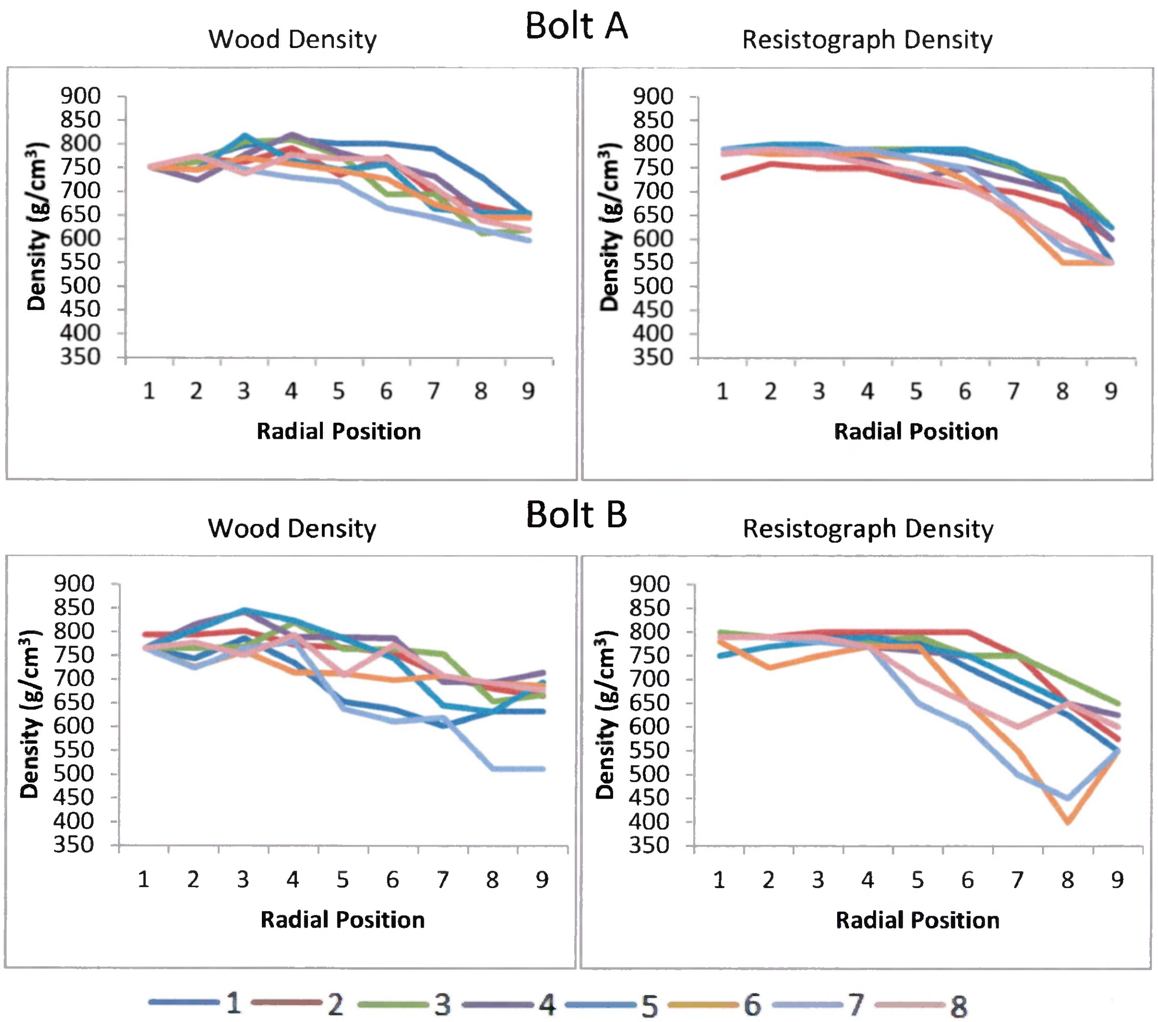

Figure 44: A comparison of average resistograph densities and wood densities by the nine radial a positions and the two bolts for each resistograph drill profile. The number of each drill profile is show in the label below the four graphs.

This value indicates a relationship exists, however it is likely that more samples would be needed to strengthen the interpretation of the relationship and more accurately describe the relationship. A Pearson's product-moment correlation value was also found and the reported value was 0.7599485. Pearson's product-moment would give a value of 1 for a perfect correlation so a value of 0.7599485 suggests a relationship does exist.

Finally all the resistograph lines were compared individually by bolt radial position and resistograph line. When the general trend for all the resistograph densities are compared for the nine radial positions, it shows there is a relationship between resistograph density values and wood density (Figure 44).

When all of the graphs (Figure 41, Figure 42, Figure 43 and Figure 44) presented are compared along with the results of the two ANOVA's and the linear regression, it is possible to conclude that a strong relationship does exist between resistograph density values and wood density values. As shown by the regression line and Pearson's product correlation, more samples would be needed to better describe the relationship. From this project, a usable equation or methodology to determine wood strength quickly based on a resistograph drill of a tree was not found. To accomplish this goal, many trees by species would have to be examined. Future studies would follow the same methodology presented in this chapter, but sample size would have to be increased to multiple trees for each tree species. This project should be continued as results could allow urban foresters to more precisely measure tree strength values and to accurately predict when a tree could fail.

Some of the potential errors which can affect a resistograph reading including temperature, moisture content, drill bit angle, drill bit deflection and operator error (Ukrainetz & O'Neil 2010, Lin *et al.* 2003, Chantre & Rozenberg 1997, Rinn 1996). These potential sources of error could lead to incorrect wood density measurements. To account for this problem, values for resistograph density are averages for nine radial positions across the length of the resistograph reading. By averaging values on the resistograph reading many of the spikes and errors in the resistograph reading can be averaged out giving a density value closer to the actual density value of the wood.

A secondary problem is sorting out what the resistograph can and cannot detect. Incipient decay is a major problem as the resistograph cannot detect this type of decay. As incipient decay can cause a loss of strength but is not detected, it can be a major potential issue. Incipient decay is not captured by the resistograph reading or the density reading as the weight of the mycelium in the wood compensates for the loss in fiber from decay. When a density measurement is done on a piece of wood in this condition, the extra weight of mycelium and fungal matter is enough to mask an expected decrease in density. However, if the block of wood were to be left for a period of time a significant drop in density would eventually be seen (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). The use of a shigometer may help to detect incipient decay and, if used in conjunction with a resistograph, accuracy could be greatly increased (Shigo & Shigo 1974, McGinnes & Shigo 1975).

One project by Tsai (2003) suggested that density could be related to resistograph readings, and presented three linear regression equations for estimating density based on three different fibre orientations (longitudinal, tangential and radial tangential). For the three different linear regression equations the R^2 values were 0.91, 0.37 and 0.43 for longitudinal, tangential and radial tangential, respectively. As the R^2 values were so low for both the tangential and radial tangential directions, only resistograph drillings from the longitudinal direction should be considered (Figure 45). Although the linear regression equation represents the relationship fairly well, drilling from only the longitudinal direction is impossible in the field as a typical drill is on the tangential plane and drilling in on a radial plane to the pith. To complicate drilling more, urban trees grow in open grown situations and develop reaction wood (compression in softwoods and tension in hardwoods) offsetting the pith from the centre of the tree making it difficult to hit the pith every time. Other naturally occurring properties in wood such as cracks, knots and swirling grain can also affect resistograph readings and deflect the resistograph drill bit changing the direction of the drill bit and lowering the accuracy of the equation. Tsai (2003) was able to achieve these precise results with clean, straight grain 4x4x8cm samples being used which contained few abnormalities unlike what would occur in an urban tree.

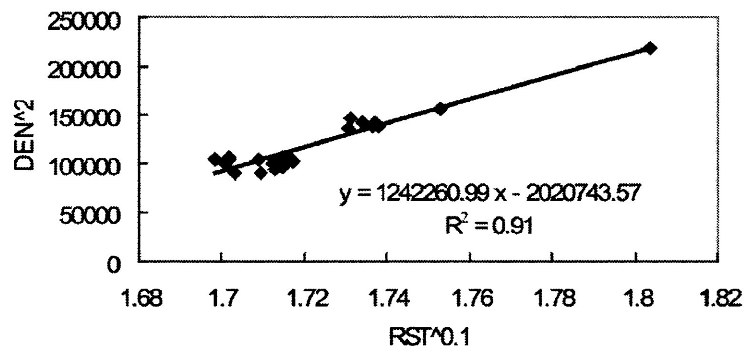

Figure 45: Density versus drilling resistance in the longitudinal direction. (Tsai 2003).

It is likely that there is a relationship between a resistograph reading and MOE as it has been shown there is a relationship between resistograph amplitude and density of wood (Ukrainetz & O'Neil 2010, Stambaugh *et al.* 2008). Density of wood can also be directly related to MOE, and through two degrees of separation resistograph amplitude can be related to MOE (Panshin & Zeeuw 1980, Mullins & McKnight 1981, Bowler *et al.* 2007). The problem with this relationship, however, is that through the degrees of separation small errors in the resistograph measurements, density measurements, or MOE measurements are amplified and become harder to deal with. By averaging resistograph values by nine radial positions this should allow for comparisons to be made and reduce error significantly.

Potential error could have also occurred in the modulus of elasticity measurements as sticks were not culled if they contained abnormalities such as rot. Standards for wood strength testing would normally have these sticks culled out; however, for the purposes of this chapter, strength measurements for areas of rot are needed to compare with resistograph measurements so potential error in modulus of elasticity measurements are acceptable. A secondary source of potential error in this chapter is the exact line the resistograph drill bit took within the wood, which may be slightly different than the anticipated line drawn on the surface of the wood. To help account for this problem, when drill holes from the resistograph were noticed on the sticks they were noted for reference to the anticipated lines on the surface of the bolts to check for accuracy. The scale model of the bolt used to measure the exact distance between edge of the bolt and the pith was crucial for reducing this potential source of error. The model could give an exact distance of where pith would occur on the resistograph line increasing the accuracy of the resistograph line.

5.4 CONCLUSION

As shown by the resistograph density measurements and the wood density graphs there is a strong relationship between density values and resistograph reading values. However, due to the single sample in this project, results have not been obtained that would allow an urban forester to apply this relationship in the field. If more sampling was done, it is likely that a methodology could be created which would give urban foresters measurements that could precisely predict when a tree will fail. By creating such rules it would eliminate the need for general rules such as the 1cm of sound wood for every 6cm of diameter, which is not species specific, currently leading to the removal of trees which are still strong or leaving trees which are hazards.

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APPENDICES

APPENDIX I: EXTERNAL CHARACTERISTICS OF HAZARD TREES

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location.

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Pruning Damage	Codominant Fork Damage	Frost Crack Damage	Physical Scrape Damage
Ag	149 Theresa	21.4	0-25	10	4	2	4	1	40.625				
Ag	81 Ray st	27.5	26-50	10	4	4	1	2	40.625				
Ag	401 Rainbow	33	26-50	8	9	1	1	1	37.5				
Ag	361 McKellar st n	25.2	0-25	8	6	2	2	2	37.5				
Ag	4305 Broad Oaks pl			4	2	2	1	1	6.25				
Ag	101 Spruce crt	46.1	26-50	4	6	8	4	4	56.25				
Ag	669 Mohawk cres	27.5	26-50	8	8	2	1	2	40.625				
Ag	669 Mohawk cres	24.6	0-25	8	8	2	1	2	40.625				
Ag	669 Mohawk cres	34.7	26-50	8	8	2	1	2	40.625				
Ag	135 Elmwood cres	29	26-50	8	2	2	1	1	18.75				2
Ag	471 Parkwood Ave	23	0-25	6	6	3	1	2	31.25				1
Ag	Heath st. Pool 4	60.7	51-75	6	2	4	3	3	31.25		4		
Ag	132 Francis st e	21	0-25	4	2	2	1	1	6.25		3		
Ag	Crossbow x Pioneer	12	0-25	2	2	2	1	1	0	3			3
Ag	1411 Murray Ave	11.8	0-25	10	6	4	3	1	50	1	3		
Ag	321 Phillips	29.4	26-50	6	3	4	2	2	28.125		2	1	
Ag	640 Minto PL	48	26-50	6	2	3	1	2	18.75			4	4
Ag	908 McIntosh	19.2	0-25	8	6	3	1	1	34.375				
Ag	183 Windemere Ave N	30.5	26-50	8	6	5	1	1	40.625				
Ag	2555 Caspian Pl	4.5	0-25	2	2	2	1	1	0				
Ag	2554 Caspian Pl	3.8	0-25	2	2	2	1	1	0				
Ag	426 Norah	56.5	51-75	8	7	5	2	2	50	1			1
Ag	420 Vickers s s	20.8	0-25	2	2	2	1	1	0	2			
Ag	550 Luci st	56.1	51-75	6	4	4	2	2	31.25	4			
Bf	2210 Rankin st	27.3	26-50	4	2	2	1	1	6.25				1
Bf	Bp 9-4	37.3	26-50	5	5	6	3	3	43.75				
Bp	514 Riverview across st	17.8	0-25	2	2	2	1	1	0				2
Bp	Bp 8-3	28.9	26-50	8	6	5	3	2	50				2
Bp	Bp10-5	35.1	26-50	6	6	3	2	2	34.375				
Bp	Bp 11-6	34.9	26-50	5	5	3	2	2	28.125				
Bp	Beaver crt 1	42	26-50	6	2	6	2	3	34.375				2
Bp	Beaver crt 2	44.1	26-50	6	4	6	3	3	43.75				2

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location (Continued).

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Prune Damage	Codominent Fork Damage	Frost Crack Damage	Phyisical Scrape Damage
Bw	2135 west riverdale rd	27.9	26-50	4	2	2	1	1	6.25				
Bw	1104 brown st	42	26-50	6	6	2	3	3	37.5		3		
Bw	220 fracis st w	63.1	51-75	4	6	2	1	1	18.75				
Bw	420 mckellar	42.5	26-50	7	4	4	3	3	40.625				
Bw	426 vickers st s	52.4	51-75	6	6	4	3	3	43.75			3	4
Bw	1422 ridgeway st e	54.7	51-75	6	4	4	3	3	37.5			2	
Bw	415 brodie st n	72.5	51-75	10	3	4	3	3	46.875				
Bw	314 brodie st n	5	0-25	10	2	2	1	1	25				2
Bw	323 archibald st n	64.1	51-75	10	6	4	4	4	62.5				
Bw	244 fracis st w	61	51-75	8	8	2	1	1	37.5		4		
Bw	1418 murray ave	64.7	51-75	10	8	4	2	3	59.375		4		
Bw	1417 Hamilton ave	61	51-75	5	6	4	3	3	40.625				
Bw	549 thorndale cres	29.4	26-50	5	2	2	1	1	9.375				
Bw	549 thorndale cres	34.6	26-50	5	2	2	1	1	9.375	2		4	
Bw	415 Norah st	59.6	51-75	6	3	2	2	2	21.875	1		2	
Bw	116 Huntington Ct			6	3	3	3	3	31.25	2		2	
Bw	1423 Hamilton Ave	58.7	51-75	6	5	5	3	3	43.75				
Bw	1429 Hamilton Ave	48.4	26-50	6	5	6	2	3	43.75	3	3		
Bw	1437 Hamilton Ave	58	51-75	6	4	3	2	3	31.25	2	4		
Bw	Heath st. Pool 1	54.7	51-75	8	5	3	3	3	43.75				
Bw	Hodge st	33.5	26-50	2	2	2	1	1	0				
Bw	1400 Ridgeway, Frankli	52.6	51-75	6	5	6	2	2	40.625				
Bw	404 Egan st	34.8	26-50	8	6	3	1	1	34.375				1
Bw	669 Strachan Cres or 6S	21	0-25	2	2	2	1	1	0				
Bw	713 Confederation dr.	56	51-75	4	5	4	3	2	31.25				
Bw	707 Confederation	36.3	26-50	6	5	6	2	2	40.625				
Bw	BP 6-1	62.3	51-75	5	4	3	4	4	37.5				
Bw	BP7-2	50.5	26-50	6	3	3	3	3	31.25				
Bw	Bp 12-7	43	26-50	6	5	3	2	2	31.25				
Bw	314 Archibald	41.2	26-50	6	3	3	2	2	25	3		2	
Bw	639 Catherine st	56.2	51-75	6	5	0	0	0	9.375	4		4	3
Bw	307 Dewe st	37	26-50	6	4	3	2	4	34.375		4		2

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location (Continued).

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Pruning Damage	Codominant Fork Damage	Frost Crack Damage	Physical Scrape Damage
Bw	299 Dewe st	43.8	26-50	6	4	3	2	2	28.125				2
Bw	1465 Moodie st	51.7	51-75	5	3	4	2	2	25				
Bw	438 Mark st s	40	26-50	6	5	3	2	2	31.25				
Bw	533 Catherine st	47.6	26-50	6	5	3	2	2	31.25		-		
Bw	327 Vickers st s	51	51-75	6	3	3	2	2	25				
Bw	512 Vickers st s	48.8	26-50	6	2	3	2	1	18.75		2	1	
Bw	251 Luci st Catherine si	47.2	26-50	4	2	2	1	1	6.25		3	2	
Bw	251 Luci ct	44	26-50	4	3	3	1	1	12.5			1	
Bw	532 Luci ct	41	26-50	6	5	3	2	2	31.25			2	
Bw	541 Norah st s	53.8	51-75	6	4	3	2	2	28.125				
Bw	637 Norah st s	50.2	26-50	6	5	3	2	2	31.25	1		2	
Bw	507 Marks across st	39	26-50	6	3	2	2	2	21.875	2	4	3	
Bw	718 Thorneloe Dr	32.4	26-50	8	5	4	3	3	46.875	3	4	1	
Bw	501 Mark st s	57	51-75	2	2	2	1	1	0	3			
Cm	77 College st	5.6	0-25	3	3	3	2	2	15.625				
Cm	347 Bay st	4.8	0-25	2	2	2	1	1	0				
Cm	141 Secord st	4.5	0-25	6	3	2	1	1	15.625				
Cm	65 College st	4.1	0-25	2	2	2	1	1	0				
Sch. Pr.	96 Secord st	23.5	0-25	6	3	6	1	3	34.375				
Sch. Pr.	443 Jameson st	15.6	0-25	4	6	3	2	3	31.25		2		
Lilac	67 Penfold st	9.3	0-25	4	4	6	3	3	37.5		4		
Linden	156 Newberry cres	40.9	26-50	4	4	4	5	5	43.75	3			
Linden	618 Atlantic	39.5	26-50	8	2	10	5	5	68.75				
Linden	405 Fairbrooke cres	2.6	0-25	6	4	6	3	2	40.625	4			
Linden	402 Simon Frasier Blvd	21.1	0-25	8	4	7	3	4	56.25	2	1		
Linden	523 Thornedale	59	51-75	6	2	6	3	3	37.5	3	2		
Linden	318 Cameron st	51.3	51-75	6	3	5	3	4	40.625	4	3		
Malus	211 Victoria st	19.8	0-25	8	8	8	4	4	75	3	3		
Malus	703 Grey Cres	24	0-25	7	3	4	2	3	34.375		4		
Malus	2601 Valour Pl	19.2	0-25	2	2	2	1	1	0	3			
Mn	43 Machar	10	0-25	2					-18.75	3			
Mn	2808 Isabella st	27.4	26-50	8	4	4	4	4	50				1

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location (Continued).

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Pruning Damage	Codominant Fork Damage	Frost Crack Damage	Physical Scrape Damage
Mn	1023 Victoria ave e	44.9	26-50	4	4	4	2	4	31.25			2	
Mn	Mckenzie st	46	26-50	6	4	4	2	2	31.25				
Mn	138 Finlayson st	57.2	51-75	6	4	4	2	3	34.375				
Mn	138 Finlayson st	5	0-25	8	9	10	5	5	90.625				
Mn	2612 Isabella st e	30.5	26-50	8	8	4	4	4	62.5				4
Mn	1303 Ridgeway	88.6	76-10(	4	2	2	1	1	6.25				
Mn	398 Dawson St	39.3	26-50	4	6	4	1	1	25				
Mn	210 Ross st-1	37.3	26-50	2	6	4	3	3	31.25				2
Mn	210 Ross st-2	32.7	26-50	4	4	5	3	3	34.375			4	3
Mn	210 Ross St -3	45	26-50	4	5	5	2	3	34.375		3	2	
Mn	64 Shuniah st-1 side st	31	26-50	4	3	4	2	2	21.875	1	1	4	
Mn	64 Shuniah st-2	79	76-10(	6	2	4	2	2	25	4	3		
Mn	259 Wellington st	103	101-1:	6	4	3	1	1	21.875				
Mn	184 Theresa st 2	12.6	0-25	2	8	6	1	1	31.25				2
Mnt Ash	413 Mckellar st	52.7	51-75	8	4	4	3	3	43.75				2
Ms	28 Jean st	61.8	51-75	10	4	2	4	4	50				
Ms	349 Van Norman	6.1	0-25	10	5	6	3	4	62.5				4
Ms	1831 Hamilton ave	63	51-75	6	4	10	5	5	68.75				4
Ms	2704 Willow pl	78	76-10(	6	3	6	4	4	46.875		1		
Ms	2624 Park row	64.1	51-75	8	4	4	2	3	40.625		1		
Ms	528 Riverview dr w	59.8	51-75	2	2	2	1	3	6.25		1		2
Ms	Mountain View								-25				
Ms	Mountain View	59.5	51-75	6	4	8	5	5	62.5				
Ms	Mountain View	92.3	76-10(	6	4	8	4	4	56.25				
Ms	Mountain View	79.6	76-10(	4	4	2	3	3	25				
Ms	Mountain View	78	76-10(	3	6	3	3	3	31.25				
Ms	424 Conmee st	29.8	26-50	8	8	6	3	3	62.5				
Ms	526 Wiltshire cres	93.8	76-10(	6	2	3	3	3	28.125				
Ms	104 Keyston ct	60.2	51-75	7	4	5	3	3	43.75				
Ms	629 Cherrydale Pl	86	76-10(	8	3	4	4	4	46.875	3			
Ms	1735 McGregor Ave			6	5				9.375	2			3
Ms	Heath st. Pool 3	33.1	26-50	6	3	6	3	3	40.625				1

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location (Continued).

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Pruning Damage	Codominant Fork Damage	Frost Crack Damage	Physical Scrape Damage
Ms	605 Avondale pl	96.6	76-10(	5	5	5	3	5	46.875	2			
Ms	588 Riverveiw Dr w	123	101-1:	6	4	5	4	4	46.875	2	3		
Ms	2604 Chestnut st	79.5	76-10(	6	4	6	3	3	43.75				
Ms	610 Winnipeg Ave	13.5	0-25	6	6	6	3	3	50				
Ms	607 Avondale Pl	62.9	51-75	8	8	4	4	4	62.5				
Ms	2015 Sills	84.5	76-10(	2	2	5	3	3	21.875				
Ms	243 University st	46	26-50	6	4	2	2	2	25				
Ms	137 Ibbetson st	31.9	26-50	6	4	3	2	2	28.125				
Ms	234 Phillips st	63.3	51-75	5	2	6	3	2	31.25				
Ms	416 Westveiw Pl	56.5	51-75	5	2	6	3	3	34.375	2			
Ms	236 Downing st	63.8	51-75	3	3	6	3	3	31.25	1			
Pi	420 Winnipeg ave -2	28.4	26-50	6	6	6	2	2	43.75				
Pi	420 Winnipeg ave-1	33.5	26-50	6	6	4	2	2	37.5				
Pj	1150 Onionlake rd	21	0-25	10	6	0	0	0	25				3
Pj	2010 Whitegates dr	40.2	26-50	2	2	2	1	1	0				
Pj	1615 Arthur st w	35	26-50	2	2	2	1	1	0				
Pj	1615 Arthur st w	37.8	26-50	2	2	2	1	1	0				
Pj	17 Hull st	26.5	26-50	3	3	4	2	2	18.75				
Pr	199 Academy dr	17.2	0-25	10	10	6	3	2	71.875				
Pr	199 Academy dr	21.4	0-25	10	10	8	2	1	71.875				
Pr	199 Academy dr	25.1	0-25	10	10	6	2	1	65.625				
Pr	199 Academy dr	22.8	0-25	10	10	5	2	1	62.5				
Pr	199 Academy dr	20.3	0-25	10	10	4	2	2	62.5				
Pr	199 Academy dr	21.5	0-25	10	10	2	1	1	50				
Pr	199 Academy dr	19.1	0-25	10	8	2	1	3	50				
Pr	199 Academy dr	26.5	26-50	10	10	9	2	2	78.125				
Prunus	419 Vickers st s	17.8	0-25	6	4	3	1	3	28.125		2		
Prunus	253 Mary st w	21.6	0-25	6	4	4	1	3	31.25		4		1
Prunus	261 Mary st w	18.5	0-25	6	4	4	1	4	34.375				
Prunus	706 Grey Cres	21.5	0-25	7	4	4	3	2	37.5				
Prunus	321 Phillips	20	0-25	4	2	6	3	3	31.25	3			
Prunus	Glengary/Wardrope	6.2	0-25	2	2	2	1	1	0	4	4		

Table 17: Removed hazard trees with external tree defects, DBH, species and tree location (Continued).

Species	Tree Location	DBH	Size class	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Pruning Damage	Codominant Fork Damage	Frost Crack Damage	Physical Scrape Damage
Pt	130 Castle Green dr	19.2	0-25	10	6	2	0	0	31.25				
Pt	3100 Lloyd st	31.8	26-50	6	6	3	2	3	37.5				
Pt	3100 Lloyd st	38.7	26-50	5	3	4	3	3	31.25				
Pt	3295 15th Side road	44.5	26-50	2	2	2	1	1	0				
Pt	4061 Vanguard ave	63.5	51-75	4	6	4	3	2	34.375				
Pt	4061 Vanguard ave	56.5	51-75	2	2	2	1	1	0				
Pt	2135 West Riverdale rd	21.8	0-25	4	2	2	1	1	6.25				
Pt	1110 Riverdale rd	47.9	26-50	8	3	8	5	5	65.625				1
Pt	4131 Vanguard ave	53.7	51-75	5	5	4	3	3	37.5				
Pt	184 Theresa st	16.5	0-25	4	2	2	1	1	6.25				
Sw	Heath st. Pool 2	38.8	26-50	6	4	4	3	3	37.5				1
Sw	505 Mary st side of hou	43.8	26-50	2	2	2	1	1	0				
Sw	587 Dewe st 1	29.5	26-50	2	3	3	1	1	6.25				2
Sw	587 Dewe st 2	12.5	0-25	2	2	2	1	1	0				
Ua	113 Elm st	28.2	26-50	10	8	2	2	2	50				
Ua	119 Elm st	43.5	26-50	10	8	4	1	1	50		3		
Ua	338 Egan st	51.9	51-75	6	6	2	1	2	28.125		2		

APPENDIX II: TREE DISC CHARACTERISTICS

Table 18: Tree disc measurements with species, DBH, extent of rot and location.

Species	Date of Resistograph Drilling	Location	DBH	Age	Measurement of Extent of Rot				Rot Present	Comments
					North	South	East	West		
Ag	June 29 2012	426 Vickers st	63.5	63					n	no rot
Ag	June 29 2012	92 Clarkson	48.5	47	4	25	22	16	y	small amount of rot
Ag	June 28 2012	134 Autumnw ood	47.6	37	4	4	3	2	y	
Ag	june 29 2012	166 Anten	46	39	7	15	15	13	y	Some very light rot
Ag	June 29 2012	Birch Point 4	44.2	34					n	no rot
Ag	Oct 18 2012	204 Kensington	40.1	35	14	10	11	8	y	
Ag	June 29 2012	50 Melon st	38.5	46	7	7	5	5	n	discolouration in centre might be heartw ood
Ag	Oct 29 2012	471 Parkw ood st	26.5	36	10	9	11	3	y	one drill very thin
Ag	March 3 2012	81 Ray	36.8	30					n	
Bf	Oct 29 2012	Bp 9	34.4	24	2	2	3	5	y	Phellinus pini
Bf	June 28 2012	Birch Point 2	34	58	1	1	1	1	y	Rot in rings White rot
Bw	Oct 6 2012	327 Vickers	66.5	64	19	13	20	11	y	
Bw	Oct 6 2011	508 Catherine st	65	60	10	14	16	13	y	major rot in centre
Bw	June 29 2012	52 Farrand	57.8	50	7	10	2	1	y	Major rot Ganoderma applanatum
Bw	June 29 2012	1422 Ridgew ay	54.4	55	7	5	6	9	y	Minor rot in frost crack did not pick up rpt
Bw	June 28 2012	496 Egan	53.8	49	17	24	22	16	y	Slight rot in interior
Bw	Oct 16 2012	Unkow n Bw 1	53.6	55	12	18	19	0	y	rot
Bw	June 29 2012	422 Vickres	53.5	69	20	22	10	8	y	some rot near centre In rings
Bw	Oct 6 2012	1400 Ridgew ay	52	55	1	7	5	15	y	
Bw	Oct 28 2012	707 Confederation	45.5	38	16	18	15	12	y	
Bw	Oct 16 2012	Unkow n 2 Bw	42.4	36					n	no rot
Bw	June 28 2012	116 Huntington ct	36.7	32	11	10	11	10	y	
Bw	Oct 6 2012	599 Strachan st	26.7	20	1	1	4	1	y	
Cg	Oct 7 2011	2821 Southcliff	19.5	11	3	5	5	4	y	
Linden	June 29 2012	408 Westbury	44.3	53	4	10	7	6	y	significant rot throughout
Linden	Oct 18 2012	279 Ironw ood Ave	43	37	10	11	10	10	y	
Linden	June 29 2012	402 Simon Fraser	23.5	15	1	1	1	1	y	Rot in rings White rot
Pi	Oct 19 2012	S Neeb Comm 3	28.4	46	10	11	13	2	y	
Pi	Oct 6 2013	420 Winnipeg Ave-1	34.5	25	1	1	1	1	y	
Pi	Oct 7 2013	420 Winnipeg Ave-2	27.2	22	1	1	1	9	y	
Pi	Oct 7 2012	420 Winnipeg Ave-3	21.1	26	1	9	11	11	y	
Malus	Oct 16 2012	2601 Valour	24.2	28	2	3	3	2	y	

Table 18: Tree disc measurements with species, DBH, extent of rot and location (Continued).

Species	Date of Resistograph Drilling	Location	DBH	Age	Measurement of Extent of Rot				Rot Present	Comments
					North	South	East	West		
Mn	June 28 2012	136 Banning	57	33	22	18	15	30	y	Need to determine photo numbers
Mn	Oct 28 2012	14 Wishart ct	45	40	9	7	12	0	y	
Ms	June 29 2012	Riverview 2	86.2	40	1	1	1	1	y	Rot through out
Ms	June 29 2012	Cemetary cut	84	65	15	13	13	15	y	Only half of cookie to big for w hole cookie
Ms	June 29 2012	611 Cherrydale	81.6	37					n	no rot, cut at butt fare
Ms	June 28 2012	526 Wiltshire	74.2	54	22	10	15	12	y	
Ms	June 28 2012	Cementary 1	68.5	38	10	6	4	7	y	Did not detect any rot but soace
Ms	June 29 2012	514 Thordale	66	35	14	16	16	26	y	major rot
Ms	June 29 2012	407 Dublin Ave	65.3	30	8	8	17	9	y	Lots of rot in centre
Ms	June 29 2012	104 Keystone	62	40	8	13	10	14	y	major rot
Ms	Oct 6 2012	349 University	61.5	49	20	13	16	20	y	
Ms	June 29 2012	2624 Parkrow	60	35	10	9	15	15	y	Discolouration+small rot
Ms	Oct 18 2012	607 Avondale	58.6	41	16	15	7	6	y	
Ms	June 29 2012	371 Daw n	58	43	8	23	21	23	y	Slight rot in interior
Ms	June 29 2012	153 Harrison st	55	48	18	13	11	10	y	Did not capture rot
Ms	June 29 2012	Riverveiw	48.3	32	9	12	11	10	y	Very slight
Ms	June 28 2012	166 Peter st	47.8	42	14	20	13	11	y	Didn't capture rot
Ms	Nov 5 2012	243 University dr	44	35					n	
Pb	Oct 28 2012	BP10	33.8	70	3	3	4	2	y	
Pb	Oct 28 2012	Bp11	33.5	70	4	3	1	3	y	
Pb	Oct 29 2012	Bp 8	27.8	25	3	3	3	2	y	Can see drill reflection in hollow centre
Pj	June 29 2012	Birch Point 1	55.8	108	1	1	1	1	y	ring rot
Pj	Oct 19 2012	S Neeb Comm 1	39	57	1	1			y	Blue stain insect
Pj	June 29 2012	Pigeon Park	35.6	56	1	1			y	Blue stain +w hite rot in betw een rings
Pj	March 3 2013	1150 Onionlake Rd	28.1	35					n	
Prunus	June 29 2012	419 Vickers st	41.4	21	5	4	4	2	y	Discolouration defintitely rot
Prunus	June 29 2012	253 May st	29	15	6	5	8	4		Dscolouration in centre, no rot captured
Prunus	June 29 2012	261 Mary st w	24.5	13	4	6	5	5	y	Potential rot in centre
Prunus	March 3 2012	112 Lombard Ct	17	11	5	5	5	2	y	
Pt	June 29 2012	Harold St	47	20	1	1	1	1	y	Small fruiting bodies like pluerotus
Pt	June 29 2012	Birch Point 3	44.7	80	5	4	7	4	y	major rot spikes from cookie moving
Pt	June 29 2012	Birch Point 5	41.2	30	1	1	1	1	y	Major all rot

Table 18: Tree disc measurements with species, DBH, extent of rot and location (Continued).

Species	Date of Resistograph Drilling	Location	DBH	Age	Measurement of Extent of Rot				Rot Present	Comments
					North	South	East	West		
Russ Ol.	Oct 19 2012	S Neeb Comm 2	40	78				1	y	
Sb	Oct 19 2012	S Need Comm 4	20.8	40					n	
Sw	June 28 2012	512 Egan st	37.9	27					y	
Sw	Oct 7 2012	MacNaughton st	16.2	21					n	no rot
Ua	June 28 2012	119 Elm	41	68	5	2	4	3		
Ua	March 3 2012	588 Leslie	31.4	36	5	6	7	5	y	

Acronym	Species Name	Acronym	Species Name
Ag	Green Ash	Ms	Silver Maple
Bf	Balsam Fir	Pi	Lombardy Poplar
Bp	Balsam Poplar	Pj/Pb	Jack Pine
Bw	White Birch	Pr	Red Pine
Cm/Cg	Crataegus x mordenensis	Prunus	Chokecherry
Sch. Pr	Schubert Chokecherry	Pt	Trembing Aspen
Lilac	Lilac	Red maple	Red Maple
Linden	Little Leaf Linden Basswood	Russ Ol.	Russian Olive
Malus	Flowering Crabapple	Sb	Black Spruce
Mn	Manitoba Maple	Sw	White Spruce
Mnt. Ash	Mountain Ash	Ua	American Elm

APPENDIX III: EXTERNAL CHARACTERISTICS OF PATHOLOGY TREES

Table 19: Hazard street trees infected with wood decay fungi by tree location, species, DBH, external condition and species of wood decay fungi.

Path Tree Species	Path Tree Location	DBH	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Disease	2nd Disease	3rd Disease
Ag	506 Lucci crt	39.4	6	3	6	3	3	40.625	Ganoderma applanatum		
Ag	183 Windemere	30.5	8	6	5	1	1	40.625	Gnomoniella fraxini*		
Ag	426 Norah	56.5	8	7	5	2	2	50	Gnomoniella fraxini*		
Bp	514 Riverveiw	17.8	2	2	2	1	1	0	Condrostereum purpureum		
Bw	123 Blanchard st		4	4	4	3	3	31.25	Irpex lacteus	Piptoporus betulinus	
Bw	1405 Moodie st	51.5	6	4	6	3	3	43.75	Pholiota squarrosa		
Bw	29 Emmerson	49.6	2	2	2	1	2	3.125	Bjerkandera adusta	Cerrena unicolor	Piptoporus betulinus, Pholiota aurivella
Bw	336 Archibald st	47.5	6	6	4	2	2	37.5	Cerrena unicolor		
Bw	338 Archibald st N	56.5	6	4	4	2	2	31.25	Pholiota squarrosa		
Bw	40 Peter st	59	10	8	10	5	5	93.75	Piptoporus betulinus		
Bw	428 Norah st	37.8	8	6	4	3	3	50	Pholiota aurivella		
Bw	508 Catherine st	58.5	4	4	4	2	2	25	Schizophyllum commune		
Bw	52 Ontario st	50.5	6	4	4	2	2	31.25	Cerrena unicolor		
Bw	530 Lucci crt	70	6	4	6	3	3	43.75	Cerrena unicolor		
Bw	531 Catherine st	58.2	6	6	3	1	2	31.25	Pholiota squarrosa		
Bw	535 Norah st	43	8	5	6	3	3	53.125	Inonotus obliquus		
Bw	535 Norah st	57.8	6	4	4	2	2	31.25	Pholiota squarrosa		
Bw	538 Norah st	49.8	8	5	6	3	3	53.125	Fomes fomentarius		
Bw	542 Lucci crt	75.9	2	4	6	3	3	31.25	Phaeolus schweinitzii		
Bw	609 Norah st	62.7	8	6	5	3	3	53.125	Fomes fomentarius		
Bw	633 Catherine st	51.8	6	3	6	3	3	40.625	Pholiota squarrosa		
Bw	634 Norah st	67.4	8	6	6	3	3	56.25	Pholiota squarrosa		
Bw	251 Luci st	47.2	4	2	2	1	1	6.25	Fomes fomentarius	Piptoporus betulinus	
Bw	512 Vickers st s	48.8	6	2	3	2	1	18.75	Chondrostereum purpreum		
Bw	BP 6-1	62.3	5	4	3	4	4	37.5	Fomes fomentarius		
Bw	501 Mark st s	57	2	2	2	1	1	0	Chondrostereum purpreum		
Hackber	443 Jameson st	15.6	4	6	3	2	3	31.25	Chondrostereum purpreum		
Hackber	96 Secord st	23.5	6	3	6	1	3	34.375	Apiosporina morbosa		
Linden	226 Leader ave	72.5	4	2	4	2	2	18.75	Pholiota aurivella	Lycoperdon pyriforme	
Linden	402 Simon Fraser	21.1	8	4	7	3	4	56.25	Irpex lacteus		
Malus	218 Rockwood ave	27	8	4	6	3	3	50	Pholiota squarrosa		
Mn	28 Hills st s	47.7	4	6	3	2	2	28.125	Cerrena unicolor		

Table 19: Hazard street trees infected with wood decay fungi by location, species, DBH, condition and species of wood decay fungi (Continued).

Path Tree Species	Path Tree Location	DBH	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Disease	2nd Disease	3rd Disease
Mn	844 Brodie st	47.6	5	6	3	3	3	37.5	Hypsizygus tessulatus		
Mn	91 Alogonquin st	48.1	6	6	6	2	2	43.75	Hypsizygus tessulatus		
Mn	1303 Ridgeway	88.6	4	2	2	1	1	6.25	Cerrena unicolor		
Mn	259 Wellington st	102.7	6	4	3	1	1	21.875	Chondrostereum purpureum		
Mn	64 Shuniah st-2	79	6	2	4	2	2	25	Chondrostereum purpureum		
Mn	1303 Ridgeway	88.6	4	2	2	1	1	6.25	Cerrena unicolor		
Mn	64 Shuniah st-2	79	6	2	4	2	2	25	Stereum		
Ms	101 Keystone cr	80	10	3	3	3	3	43.75	Cerrena unicolor		
Ms	102 Pinedale	102.5	8	3	3	2	2	31.25	Daldinia concentrica		
Ms	107 Algonquin	116.5	5	4	5	3	3	37.5	Chondrostereum purpur	Hypsizygus tessulatus	Ganoderma applanatum
Ms	131 Marlbourough :	79.5	4	6	6	3	3	43.75	Ganoderma applanatum		
Ms	125 Algonquin	86.7	6	2	6	3	3	37.5	Hypsizygus tessulatus	Ganoderma applanatum	
Ms	133 Algonquin st s	73.7	6	5	6	3	3	46.875	Inonotus obliquus		
Ms	160 kenogami ave	100.3	6	5	4	3	3	40.625	Pholiota aurivella		
Ms	18 Hodge st	60	4	6	3	3	3	34.375	Volvariella bombycina	Ganoderma applanatum	
Ms	188 Madeline st	58.5	6	3	4	2	3	31.25	Pholiota aurivella		
Ms	188 Madeline st	43.8	6	2	3	2	3	25	Pholiota aurivella		
Ms	19 Hodge st	65.7	6	6	4	3	4	46.875	Pholiota aurivella		
Ms	199 Clarkson st	68.5	8	8	4	2	3	53.125	Pholiota spp		
Ms	200 Hodge st	96.4	6	3	4	3	3	34.375	Pluteus cervinus		
Ms	2011 Moodie st	64.1	10	8	8	4	4	81.25	Coprinus micaceus		
Ms	2020 Hamilton St	101.6	5	3	3	2	2	21.875	Chondrostereum purpureum		
Ms	2021 Hamilton st	48.7	6	3	3	2	2	25	Hypsizygus tessulatus		
Ms	2021 Sills st	113.6	6	3	2	3	3	28.125	Hypsizygus tessulatus	Panus serotinus	
Ms	2033 Sills st	85.8	6	4	6	3	3	43.75	Hypsizygus tessulatus	Panus serotinus	
Ms	209 Hodge	112.8	6	4	6	4	2	43.75	Hypsizygus tessulatus		
Ms	212 Walsh	88	4	6	5	3	3	40.625	Pholiota aurivella		
Ms	213 Powley st	68.5	6	4	4	2	3	34.375	Pholiota aurivella		
Ms	217 Powely st	69.2	4	4	4	3	3	31.25	Hypsizygus tessulatus		
Ms	2222 Rankin st	80	2	2	3	2	2	9.375	Ganoderma applanatum		
Ms	2246 Sills st	94.3	6	5	4	5	5	53.125	Pholiota aurivella	Hypsizygus tessulatus	
Ms	225 Clavet	45	6	3	6	3	3	40.625	Panus serotinus		

Table 19: Hazard street trees infected with wood decay fungi by location, species, DBH, condition and species of wood decay fungi (Continued).

Path Tree Species	Path Tree Location	DBH	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Disease	2nd Disease	3rd Disease
Ms	227 Clavet	94.5	10	4	6	3	3	56.25	Hypsizygus tessulatus		
Ms	227 Kenogami ave	70.5	6	6	6	3	3	50	Hypsizygus tessulatus		
Ms	238 Prospect	94.6	6	2	2	2	3	21.875	Cerrena unicolor		
Ms	244 Rockwood st	86.5	8	8	8	4	4	75	Pholiota aurivella		
Ms	249 Kenogami	71.8	8	8	8	4	4	75	Pholiota aurivella		
Ms	2613 Walnut	78.7	8	4	3	3	3	40.625	Panus serotinus		
Ms	2629 Parkrow ave	65.2	8	4	6	3	3	50	Hypsizygus tessulatus		
Ms	329 Clavet st	79.5	6	4	3	3	3	34.375	Pholiota aurivella		
Ms	347 Queen	89.7	5	3	8	4	4	50	Pholiota aurivella		
Ms	364 Second ave	76.9	8	4	8	4	2	56.25	Pholiota aurivella		
Ms	388 Queen	77.7	5	3	8	4	4	50	Coprinus micaceus		
Ms	425 Walsh st	69.3	6	2	4	2	2	25	Daldinia concentrica		
Ms	448 Brown	38.4	4	6	4	2	2	31.25	Daldinia concentrica		
Ms	503 Wiltshire	84.9	6	5	4	3	3	40.625	Pholiota squarrosa		
Ms	503 Wiltshire	81.3	6	6	4	3	3	43.75	Cerrena unicolor		
Ms	509 Wiltshire crs	89.6	8	6	6	4	4	62.5	Ganoderma applanatum		
Ms	509 Wiltshire crs	50.5	8	5	4	3	3	46.875	Ganoderma applanatum		
Ms	516 Riverveiw dr	106.8	8	6	3	2	2	40.625	Chondrostereum purpureum		
Ms	605 Riverveiw	42	10	5	8	4	4	71.875	Pholiota spp		
Ms	637 Brown st	55.5	4	6	6	3	3	43.75	Fomes fomentarius		
Ms	507 Wiltshire cres	57.5	6	2	4	3	3	31.25	Daldinia concentrica		
Ms	2015 Sills	84.5	2	2	5	3	3	21.875	Cerrena unicolor		
Ms	234 Phillips st	63.3	5	2	6	3	2	31.25	Coprinus micaceus	Climacodon septentrionalis	
Pg	587 Dewe st 1	29.5	2	3	3	1	1	6.25	Innotus tomentosus		
Pg	587 Dewe st 2	12.5	2	2	2	1	1	0	Innotus tomentosus		
Prunus	603 Cherrydale Pl	16.3	6	4	4	1	4	34.375	Apiosporina morbosa		
Prunus	253 Mary st w	21.6	6	4	4	1	3	31.25	Apiosporina morbosa		
Prunus	261 Mary st w	18.5	6	4	4	1	4	34.375	Apiosporina morbosa		
Prunus	Glengary/Wardrop€	6.2	2	2	2	1	1	0	Apiosporina morbosa		
Prunus	419 Vickers st s	17.8	6	4	3	1	3	28.125	Ganoderma applanatum	Cerrena unicolor	
Red Maţ	178 Prospect	48	6	4	3	3	3	34.375	Irpex lacteus		
Red Maţ	372 Second ave	19.6	10	6	10	5	5	87.5	Cerrena unicolor		

Table 19: Hazard street trees infected with wood decay fungi by location, species, DBH, condition and species of wood decay fungi (Continued).

Path Tree Species	Path Tree Location	DBH	Root Condition	Trunk Condition	Scaffold Branch Condition	Small Branch Condition	Foliage Condition	Total Health Condtion	Disease	2nd Disease	3rd Disease
Ua	218 Rockwood ave	44.3	6	6	6	3	2	46.875	Pholiota squarrosa		
Ua	273 Toledo	44.2	6	4	4	2	2	31.25	Cerrena unicolor		
Ua	338 Egan st	51.9	6	6	2	1	2	28.125	Stegophora ulmea*		

Acronym	Species Name	Acronym	Species Name
Ag	Green Ash	Ms	Silver Maple
Bf	Balsam Fir	Pi	Lombardy Poplar
Bp	Balsam Poplar	Pj/Pb	Jack Pine
Bw	White Birch	Pr	Red Pine
Cm/Cg	Crataegus x mordenensis	Prunus	Chokecherry
Sch. Pr	Schubert Chokecherry	Pt	Trembing Aspen
Lilac	Lilac	Red maple	Red Maple
Linden	Little Leaf Linden Basswood	Russ Ol.	Russian Olive
Malus	Flowering Crabapple	Sb	Black Spruce
Mn	Manitoba Maple	Sw	White Spruce
Mnt. Ash	Mountain Ash	Ua	American Elm

APPENDIX IV: SPECIES OF ISOLATES CONTAMINATION.

Table 20: Species of contaminants in wood discs.

Disk location	First Species	Second Species
Harold St	*Rhizopus* sp	*Trichoderma* sp
River Veiw 2	*Rhizopus* sp	*Trichoderma* sp
512 Egan St	*Rhizopus* sp	*Rhizopus* sp
407 Dublin	*Rhizopus* sp	*Trichoderma* sp
1422 Ridgeway	*Rhizopus* sp	*Trichoderma* sp
253 W Mary St	*Rhizopus* sp	*Penicillium* sp
422 Vickers St	*Trichoderma* sp	
Cemetry Tree 1.1	*Trichoderma* sp	
508 Catherine St	*Trichoderma* sp	*Penicillium* sp
Birch Point 1	*Trichoderma* sp	
402 Simon Frasier	*Alternaria* sp	
496 Egan st	*Trichoderma* sp	
153 Harrison St	*Trichoderma* sp	
166 Anten	*Rhizopus* sp	*Trichoderma* sp
3 Elm	*Rhizopus* sp	
Birch Point 3	*Trichoderma* sp	
Riverveiw	*Trichoderma* sp	
Cemetry Tree 1	*Trichoderma* sp	*Rhizopus* sp
Complex 2	*Penicilium* sp	
261 Mary St W	*Trichoderma* sp	*Penicillium* sp
514 Thornloe	*Rhizopus* sp	*Trichoderma* sp
2624 Parkrow	*Trichoderma* sp	
136 Banning	*Trichoderma* sp	*Rhizopus* sp
526 Wiltshire Cres	*Trichoderma* sp	
Unkonwn Bw2	*Trichoderma* sp	
1400 Ridgeway	*Trichoderma* sp	*Alternaria* sp
116 Huntington	*Fusarium* sp	*Trichoderma* sp
Autumnwood	*Fusarium* sp	*Penicillium* sp
408 Westbury Ave	*Fusarium* sp	*Trichoderma* sp
2821 Southcliff	*Trichoderma* sp	
complex 3	*Trichoderma* sp	
371 Dawn	*Trichoderma* sp	
2603 Valour	*Alternaria* sp	
Unkonwn Bw2	*Trichoderma* sp	
Birch Point 2	*Alternaria* sp	
419 Vickers	*Trichoderma* sp	
599 Strachan	*Trichoderma* sp	

APPENDIX V: PHOTOGRAPHS OF SAMPLED TREE'S

TREE DISCS WITH MATCHING PHOTOGRAPHED STREET TREES

Green Ash (*Fraxinus pennsylvanica*)

471 Parkwood Ave

81 Ray St

Balsam Fir (*Abies balsamea*)

Birch Point Tree- 9

Jack Pine (*Pinus banksiana*)

1150 Onionlake Rd

Balsam Poplar (*Populus balsamifera*)

Birch Point Tree-8

Birch Point Tree-10

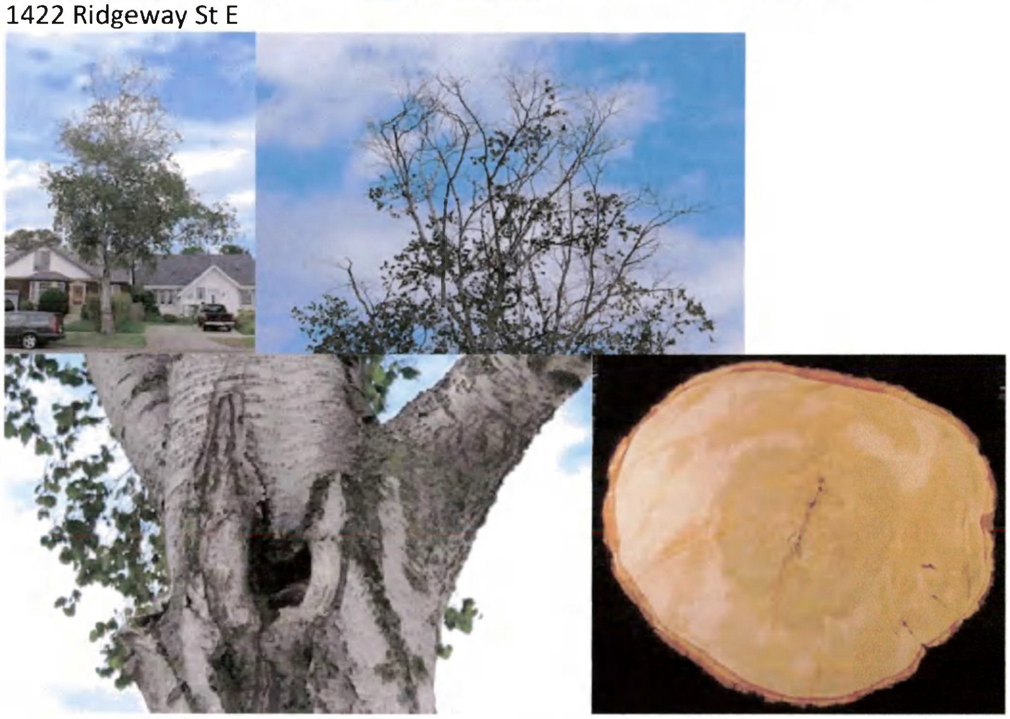
Birch Point Tree-11

White Birch (*Betula papyrifera*)

116 Huntington Ct

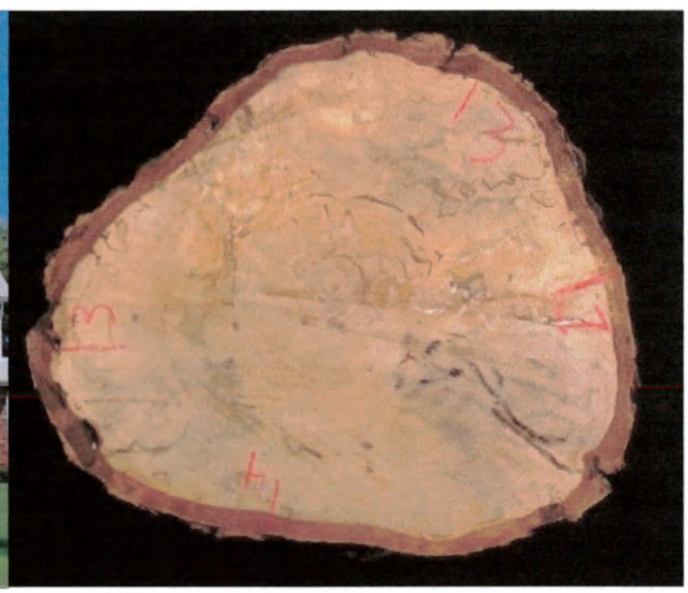
1400 Ridgeway St, Franklin side

1422 Ridgeway St E



327 Vickers St S

707 Confederation Dr



669 Strachan Cres

Little Leaf Linden (*Tilia cordata)*

402 Simon Frasier Dr

Silver Maple (*Acer saccharinum*)

104 Keystone ct

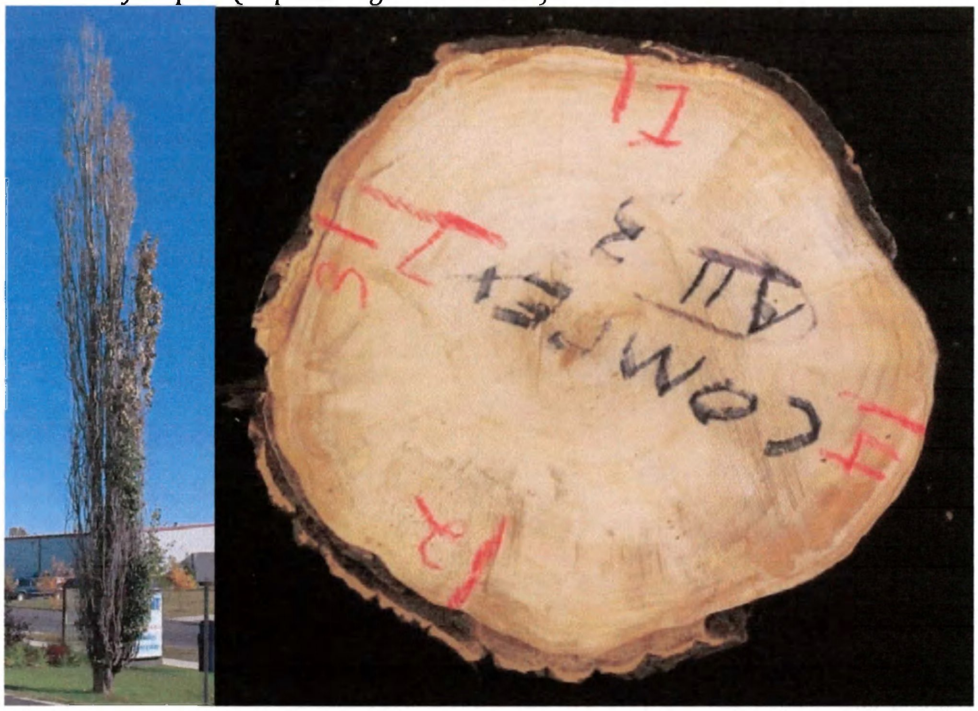
2624 Park Row

526 Wiltshire Cres

607 Avondale Pl

243 University St

Lombardy Poplar (*Populus nigra* cv. Italica)



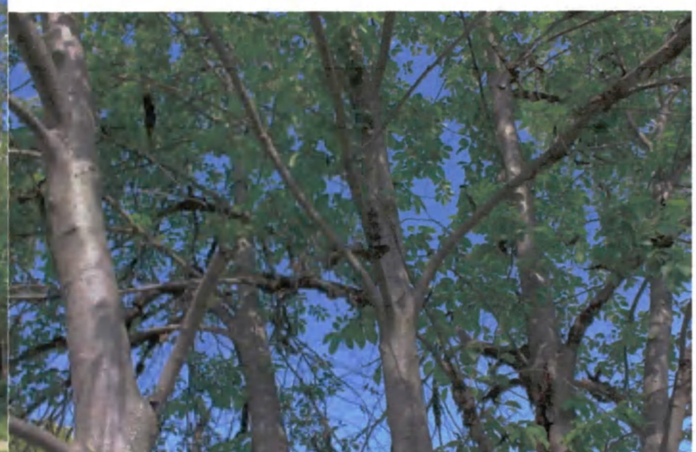
420 Winnipeg Ave -1

420 Winnipeg Ave-2

Schubert Chokecherry (*Prunus virginiana*)

253 Mary St W


261 Mary St W

419 Vickers St S

Flowering Crab Apple (*Malus* x 'Spring Snow)

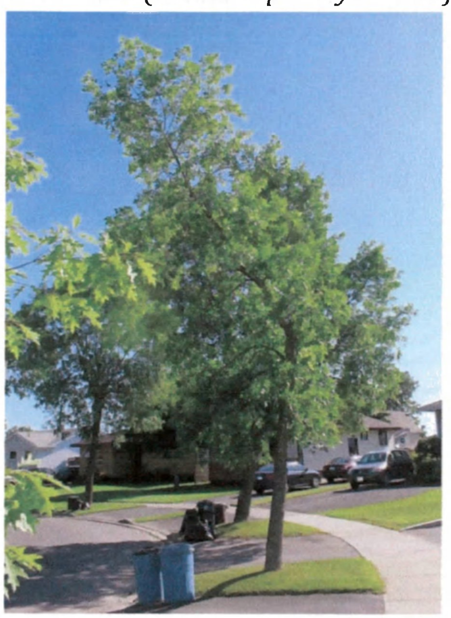
2601 Valour Pl

American Elm (*Ulmus americana*)


119 Elm St

TREES WITHOUT DISC'S

Green Ash (*Fraxinus pennsylvanica*)



149 Theresa St

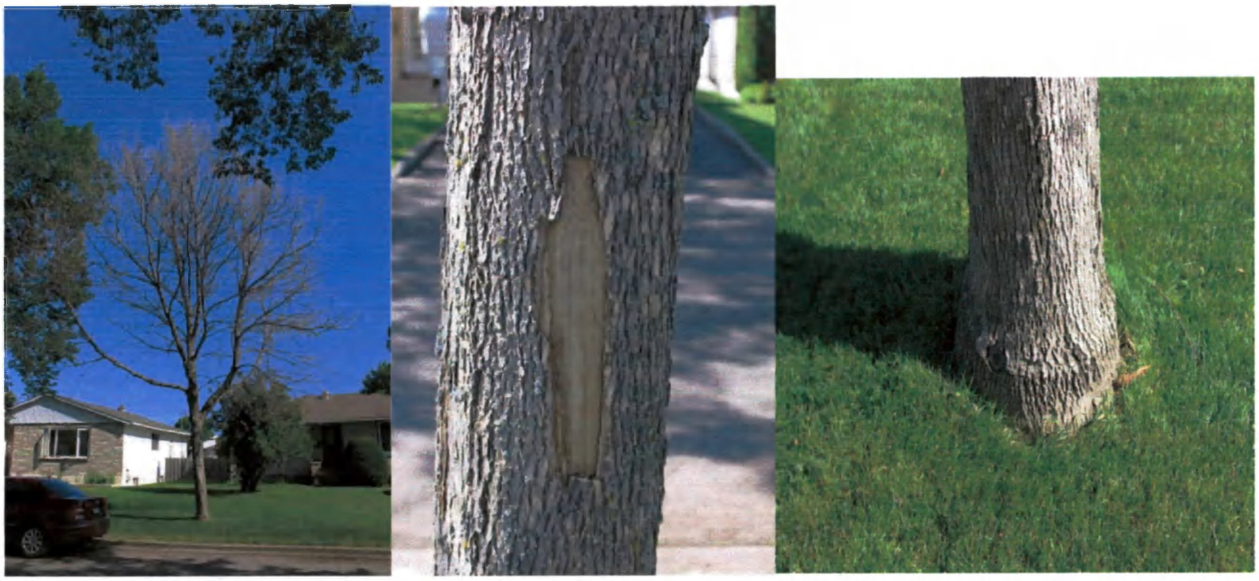
401 Rainbow St

361 McKellar St N

4305 Broad Oaks Pl

101 Spruce Crt

669 Mohawk Cres-1
669 Mohawk Cres-2(No Pictures)
669 Mohawk Cres-3(No Pictures)



135 Elmwood Cres

Heath St. Pool 4

132 Francis St E

Corner of Crossbow St and Pioneer Dr.

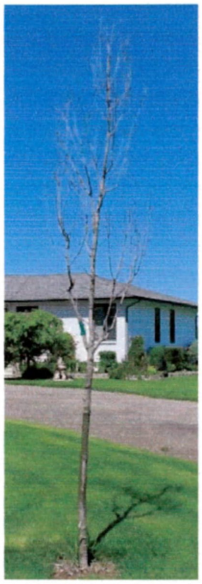
1411 Murray Ave

321 Phillips St

640 Minto Pl

908 McIntosh St

183 Windemere Ave N



2555 Caspian Pl-1

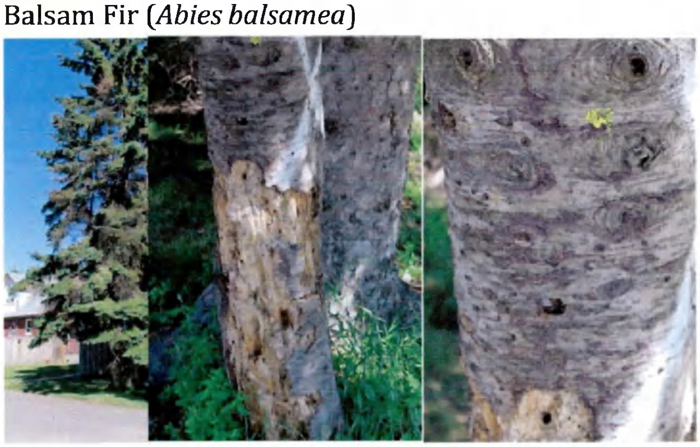
2554 Caspian Pl-2

426 Norah St

420 Vickers St S

550 Luci St

Balsam Fir (*Abies balsamea*)

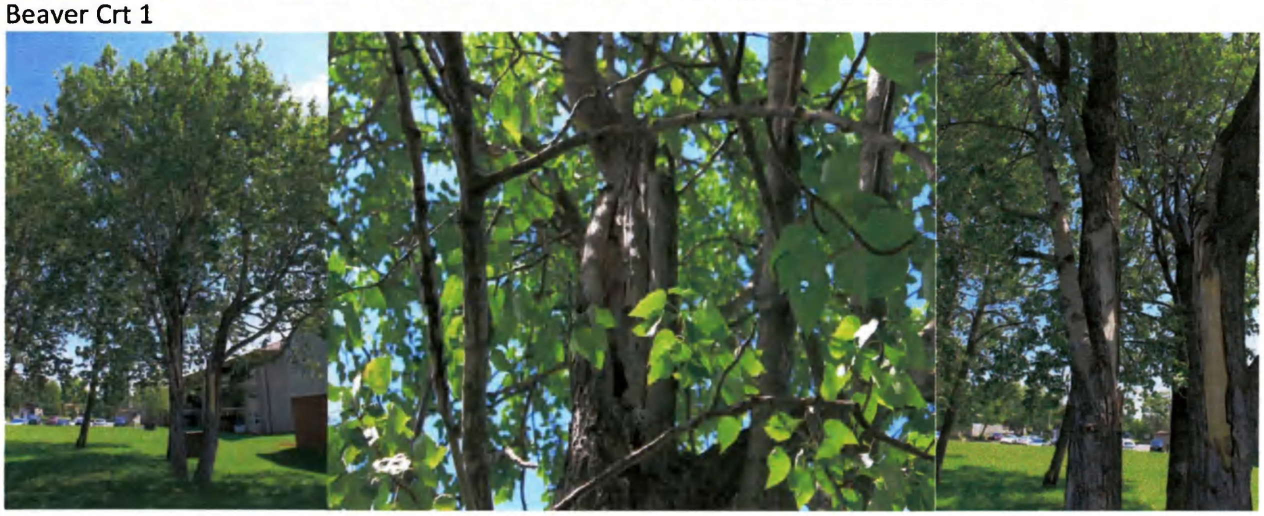


2210 Rankin St

Balsam Poplar (*Populus balsamifera*)

514 Riverveiw across St

Beaver Crt 1



Beaver Crt 2

White Birch (*Betula papyrifera*)

426 Vickers St S

2135 Riverdale Rd W

1104 Brown St

220 Francis St W

420 Mckellar St

415 Brodie St N

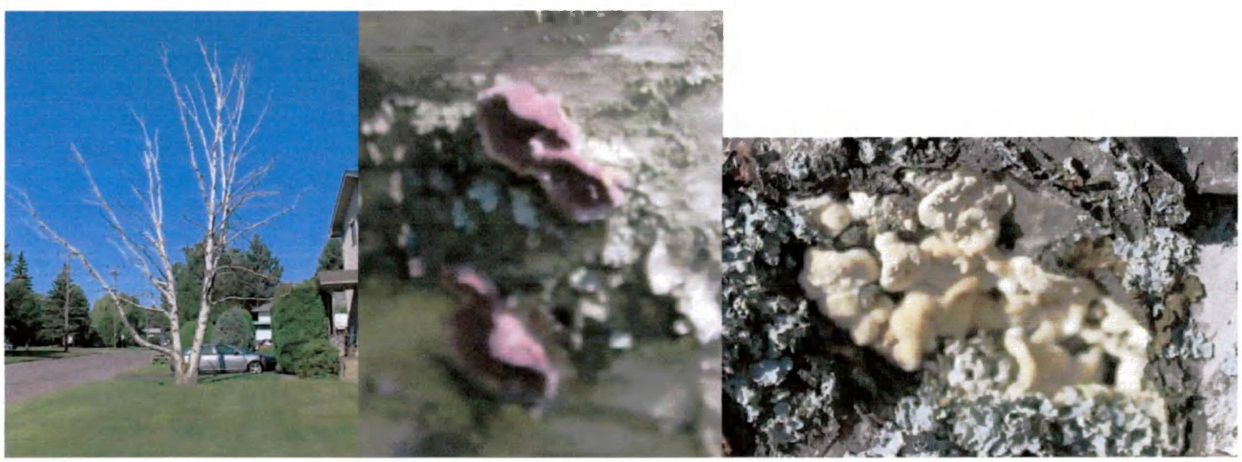
314 Brodie St N

323 Archibald St N

244 Francis St W

1418 Murray Ave

1417 Hamilton Ave



549 Thorndale Cres-1
549 Thorndale Cres-2 (Same tree two stems)

415 Norah St

1423 Hamilton Ave

1429 Hamilton Ave

1437 Hamilton Ave

Heath St. Pool-1

Hodge St

404 Egan St

713 Confederation Dr.

Birch Point Tree-6

Birch Point Tree-7

Birch Point Tree-12

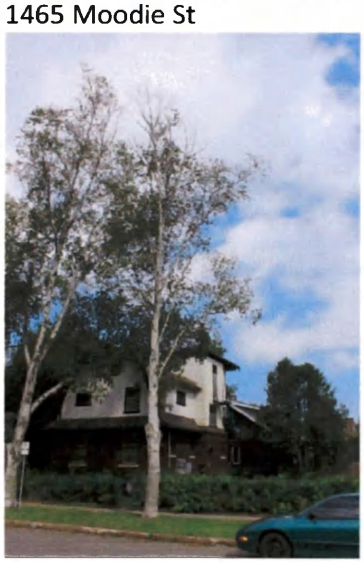
314 Archibald St

639 Catherine St

307 Dewe St

299 Dewe St

1465 Moodie St



438 Mark St S

533 Catherine St

512 Vickers St S

251 Luci St Catherine side

251 Luci Ct

532 Luci Ct

541 Norah St S

637 Norah St S

507 Marks across St

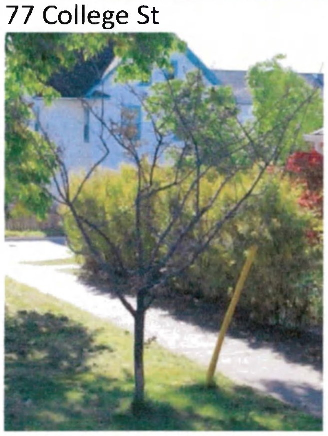
718 Thornloe Dr



501 Mark St S

Snow Bird Hawthorn (*Crataegus* x *mordenesis*)

77 College St



347 Bay St

141 Secord St

65 College St

Schubert chokecherry (*Prunus virginiana* cv Schubert)

96 Secord St

443 Jameson St

Lilac (*Syringa reticulata*)

67 Penfold St

Little Leaf Linden (*Tilia cordata)*

156 Newberry Cres

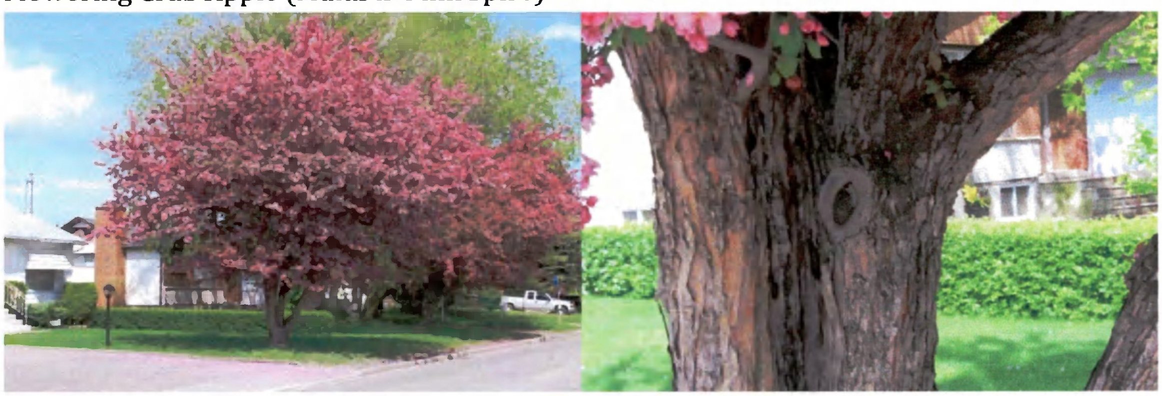
618 Atlantic Ave

405 Fairbrooke Cres

523 Thorndale Cr.

318 Cameron St

Flowering Crab Apple (*Malus* x 'Pink Spire)



211 Victoria St

703 Grey Cres

Manitoba Maple (*Acer negundo*)

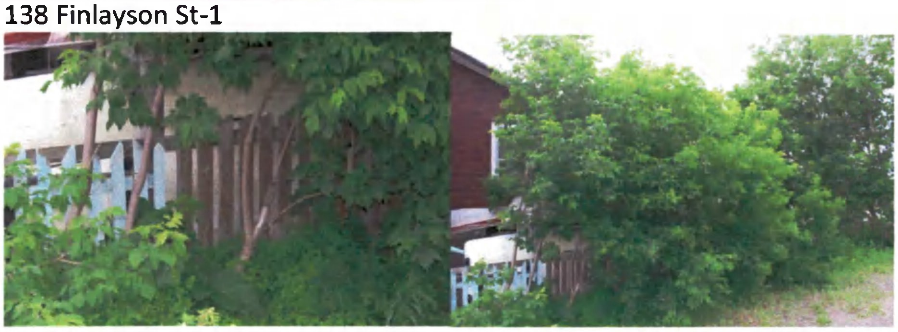
43 Machar Ave

2808 Isabella St

1023 Victoria Ave E

McKenzie St

138 Finlayson St-1



138 Finlayson St-2

2612 Isabella St E

1303 Ridgeway St

398 Dawson St


210 Ross st-1


210 Ross st-2


210 Ross St -3

64 Shuniah St-1 side st

64 Shuniah st-2

259 Wellington St

184 Theresa St 2

Mountain Ash (*Sorbus decora*)

413 Mckellar St

Silver Maple (*Acer saccharinum*)

28 Jean St

349 Van Norman St

1831 Hamilton Ave

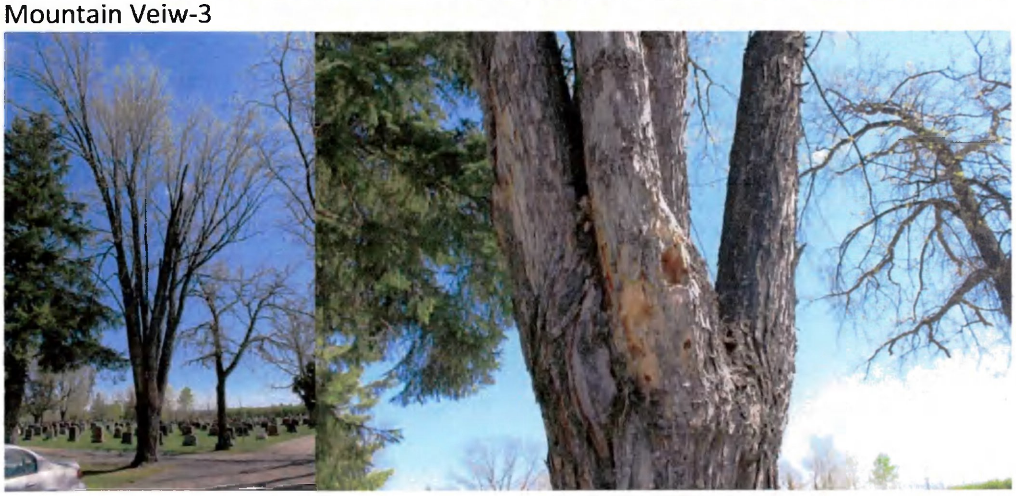
2704 Willow Pl

528 Riverveiw Dr W

Mountain Veiw-1

Mountain Veiw-2

Mountain Veiw-3



Mountain Veiw-4

Mountain Veiw-5

424 Conmee St

629 Cherrydale Pl

1735 McGregor Ave

Heath St. Pool-3

605 Avondale Pl

588 Riverveiw Dr W

2604 Chestnut St

610 Winnipeg Ave

2015 Sills

137 Ibbetson St

234 Phillips St

416 Westveiw Pl

236 Downing St

Jack Pine (*Pinus banksiana*)

2010 Whitegates Dr

1615 Arthur St W-1

1615 Arthur St W-2


17 Hull St

Red Pine (*Pinus resinosa*)

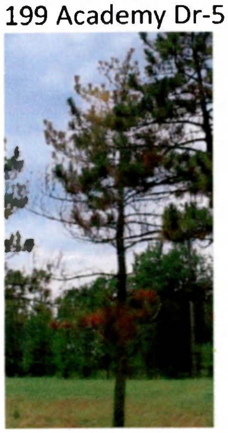

199 Academy Dr-1


199 Academy Dr-2


199 Academy Dr-3


199 Academy Dr-4


199 Academy Dr-5


199 Academy Dr-6

199 Academy Dr-7

199 Academy Dr

Chokecherry (*Prunus virginiana*)



706 Grey Cres



321 Phillips

Glengary/Wardrope

Trembling Aspen (*Populus tremuloides*)

130 Castle Green Dr

3100 Lloyd St-1

3100 Lloyd St-2

3295 15th Side Road

4061 Vanguard Ave-1

4061 Vanguard Ave-2

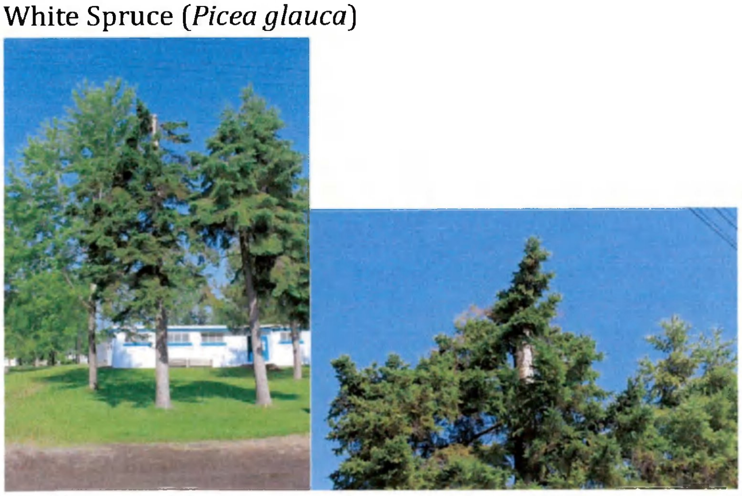
2135 Riverdale Rd W(356-359)

1110 Riverdale Rd W

4131 Vanguard Ave

184 Theresa St

White Spruce (*Picea glauca*)



Heath St. Pool-2

505 Mary St side of house

587 Dewe St- 1

587 Dewe St -2

American Elm (*Ulmus americana*)

113 Elm St

Siberian Elm (*Ulmus pumila*)

338 Egan St

PATHOLOGY TREES

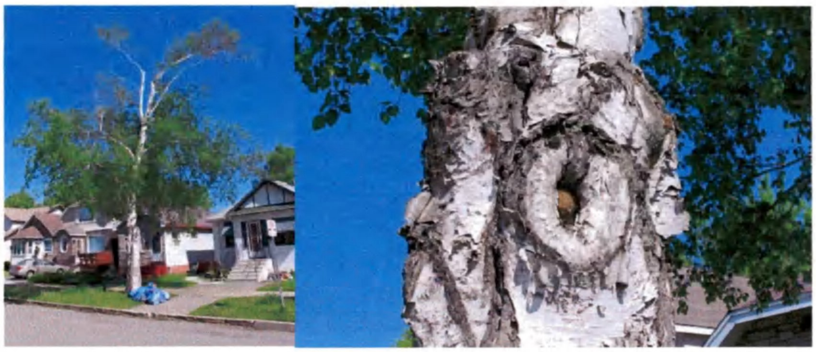
Green Ash (*Fraxinus pennsylvanica*)

506 Luci Crt

Missing 1

White Birch (*Betula papyrifera*)

123 Blanchard St



1405 Moodie St

29 Emmerson Ave

336 Archibald St N

338 Archibald St N

40 Peter St

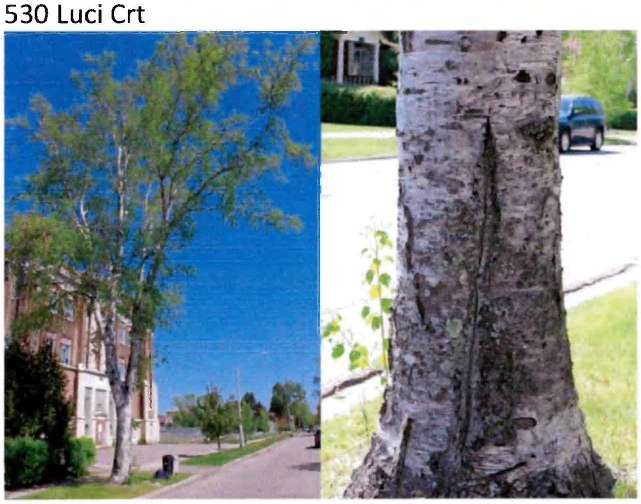
415 Norah St

428 Norah St

508 Catherine St

52 Ontario St

530 Luci Crt



531 Catherine St

535 Norah St-1

535 Norah St-2

538 Norah St

542 Luci Crt

609 Norah St

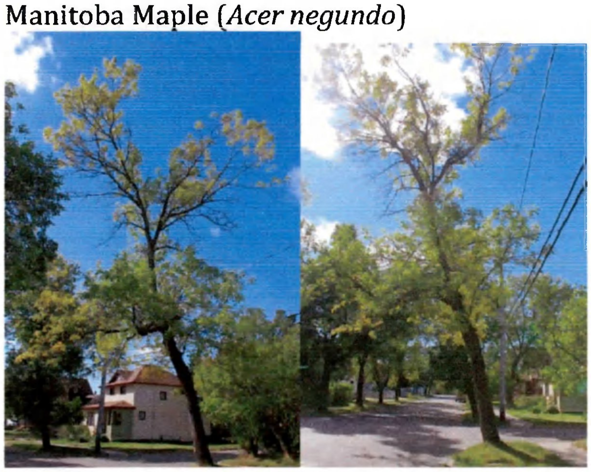
633 Catherine St

634 Norah St

Flowering Crab Apple (*Malus* x 'Spring Snow, *Malus* x 'Pink Spire)

218 Rockwood Ave N

Manitoba Maple (*Acer negundo*)



28 Hills St S

844 Brodie St

91 Alogonquin St

Silver Maple (*Acer saccharinum*)

507 Wiltshire Cres


101 Keystone Crt


102 Pinedale Pl


107 Algonquin Ave

125 Algonquin Ave

131 Marlbourough St

133 Algonquin St S

160 Kenogami Ave

18 Hodge St

188 Madeline St-1

188 Madeline St-2

19 Hodge St

199 Clarkson St

200 Hodge St

2011 Moodie St

2020 Hamilton St

2021 Hamilton St

2021 Sills St

2033 Sills St

209 Hodge St

212 Walsh St

213 Powley St

217 Powely St

2222 Rankin St

2246 Sills St

225 Clavet St

227 Clavet St

227 Kenogami Ave

238 Prospect Ave

244 Rockwood St

249 Kenogami Ave
2613 Walnut St (No Picture)


2629 Parkrow Ave


329 Clavet St


347 Queen St

364 Second Ave

388 Queen St

425 Walsh St

448 Brown St

503 Wiltshire Cres

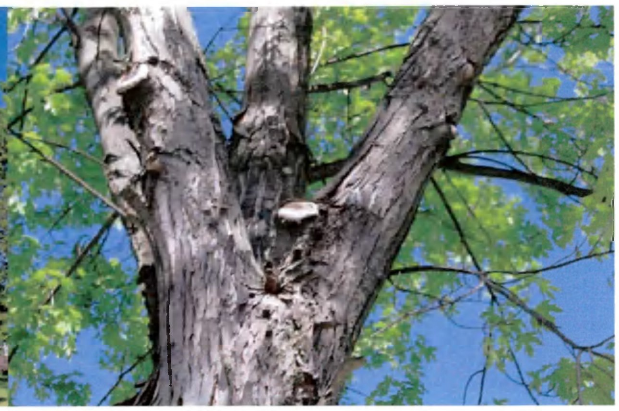
503 Wiltshire across St

509 Wiltshire Cres

509 Wiltshire Cres across

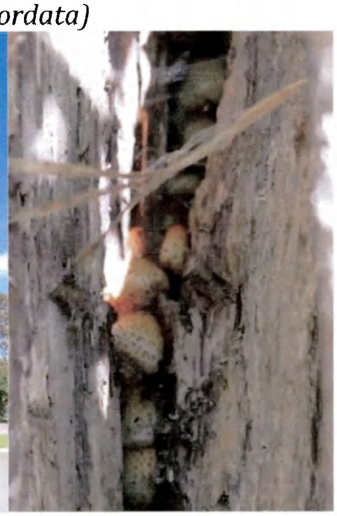
516 Riverveiw Dr


605 Riverveiw Dr

637 Brown St

Chokecherry (*Prunus virginiana)*
603 Cherrydale Pl (Pictures missing 1119-1125)
Little Leaf Linden (*Tilia cordata)*

226 Leader Ave

Red Maple (Acer rubrum)

178 Prospect Ave

372 Second Ave

American Elm (*Ulmus americana*)

218 Rockwood Ave

273 Toledo St

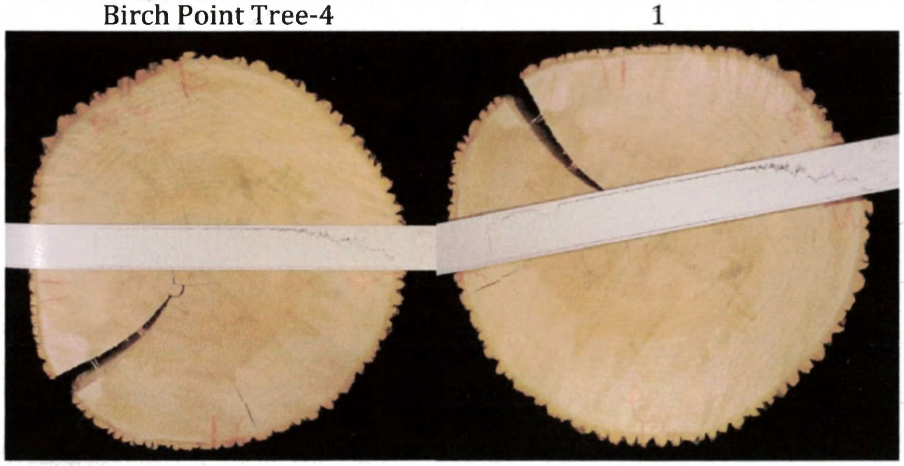
273 Toledo St-2

APPENDIX VI: RESISTOGRAPH ATLAS

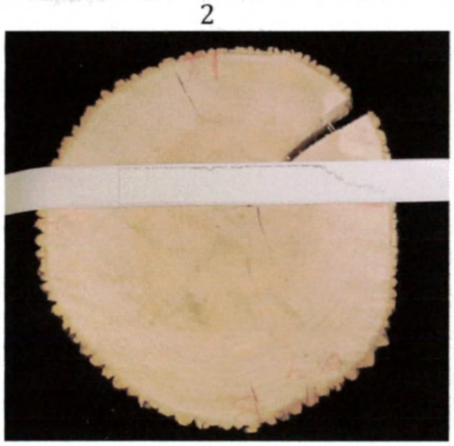
RESISTOGRAPH ATLAS TABLE OF CONTENTS

Green Ash (*Fraxinus pennsylvanica*)

Birch Point Tree-4 1



2 3



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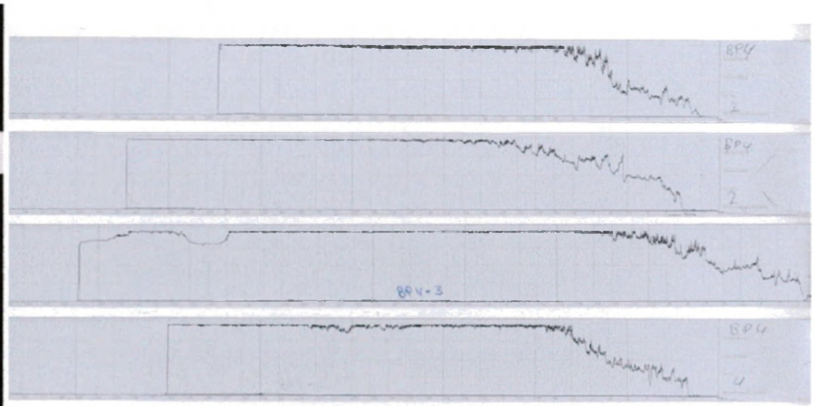
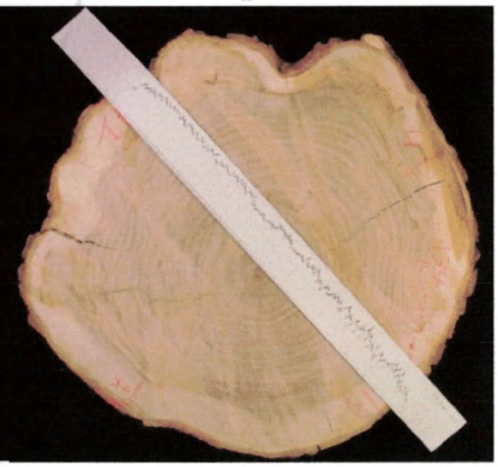


Resistograph Scans 1-4

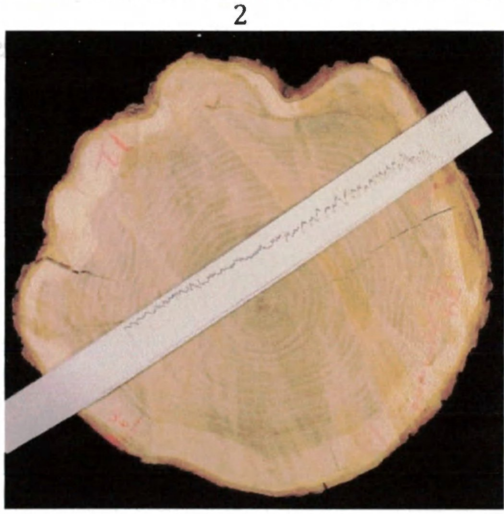
134 Autumnwood Dr.

1

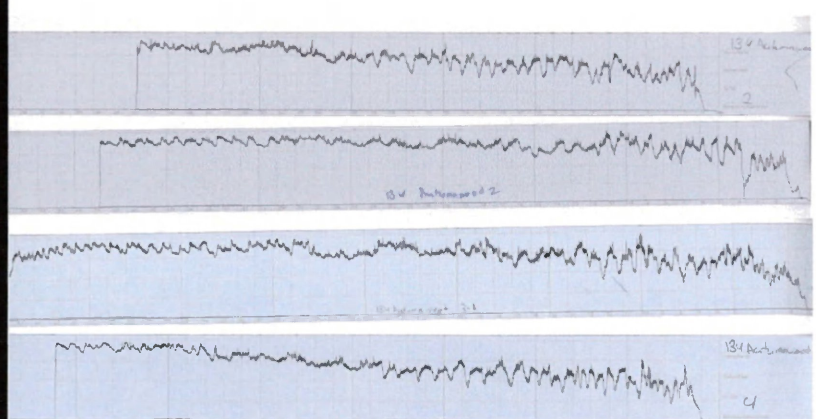
2



3

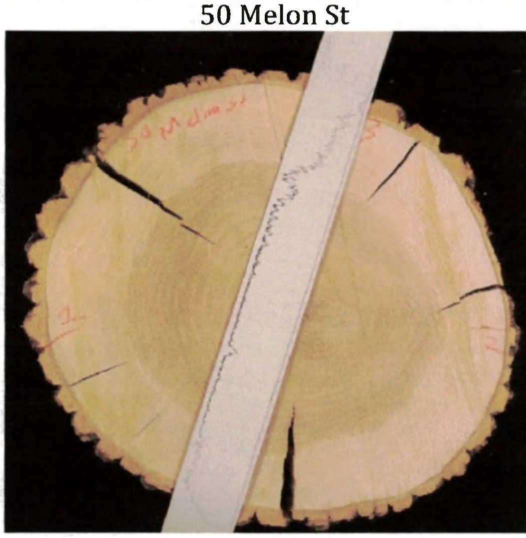


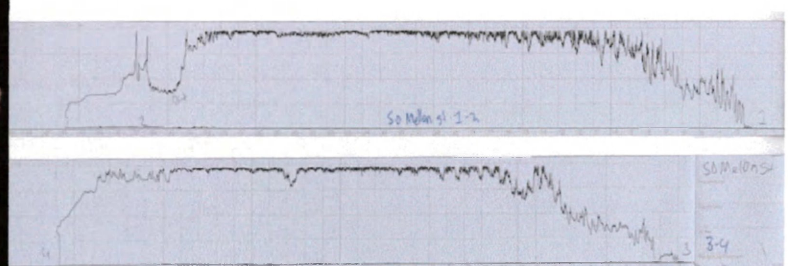
4



Resistograph Scans 1-4

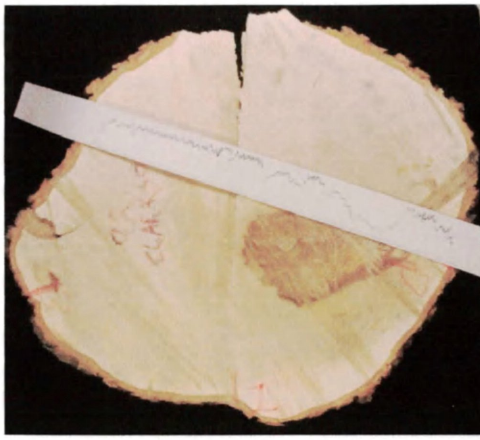
50 Melon St 1-2





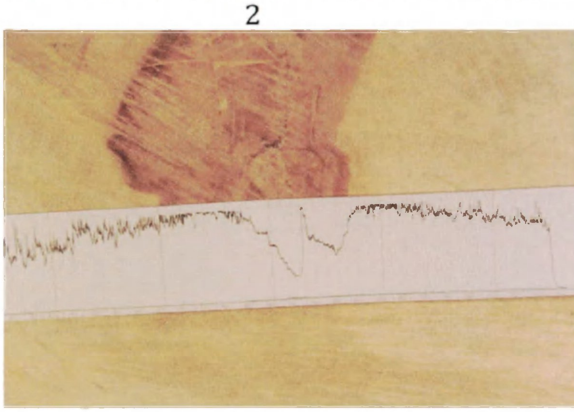
3-4 Resistograph Scan1-4

92 Clarkson St 1

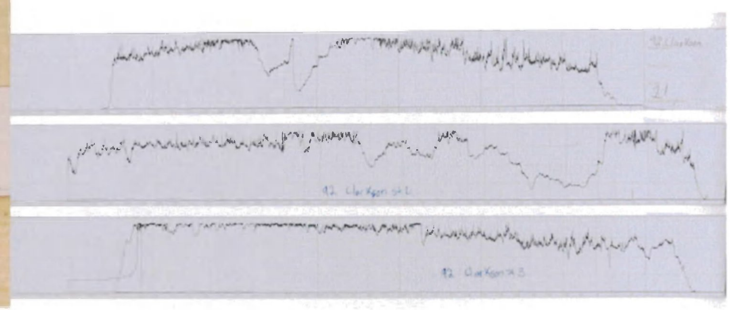


2

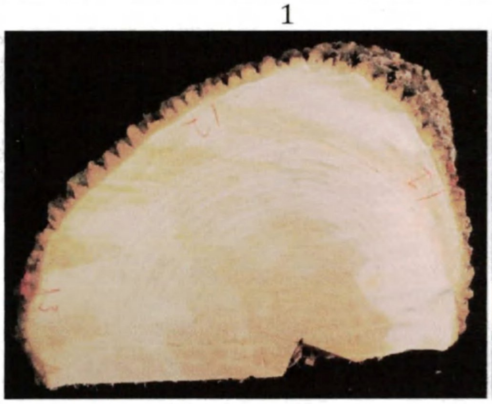
3



1

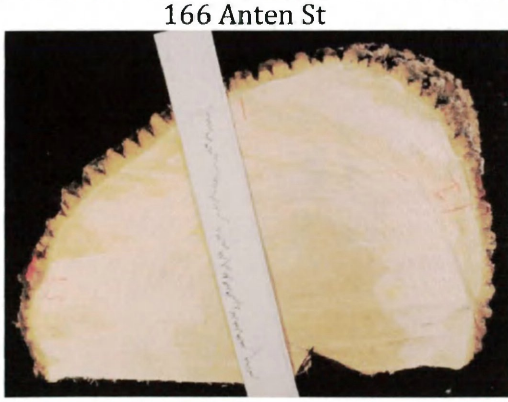


Resistograph Scans 1-3



166 Anten St

1-3



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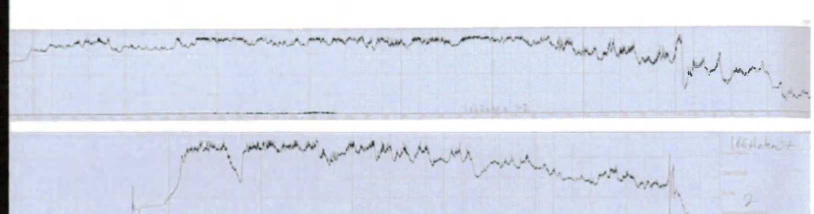


Resistograph Scans 1-3

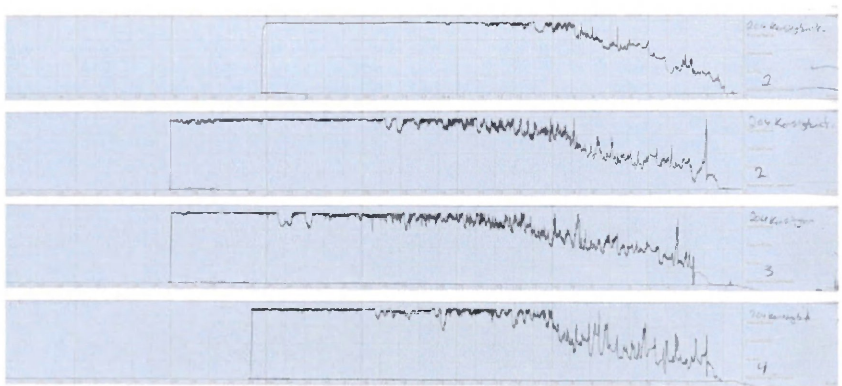
204 Kensington Dr.

1

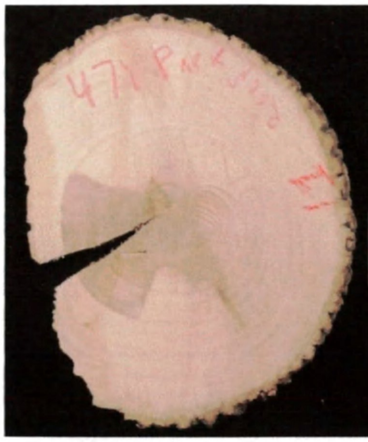
2

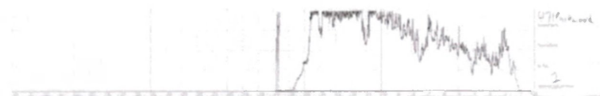
3

4

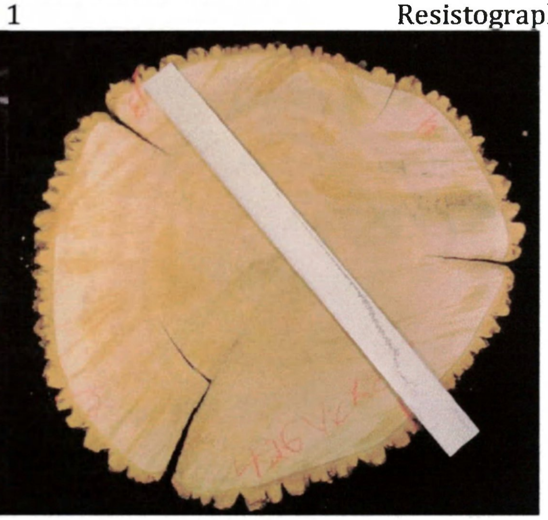


Resistograph Scans 1-4

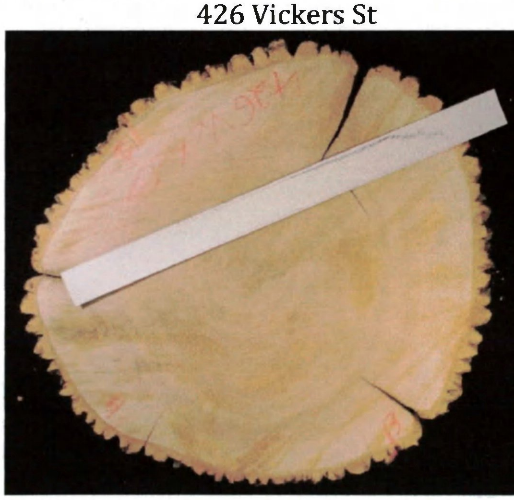
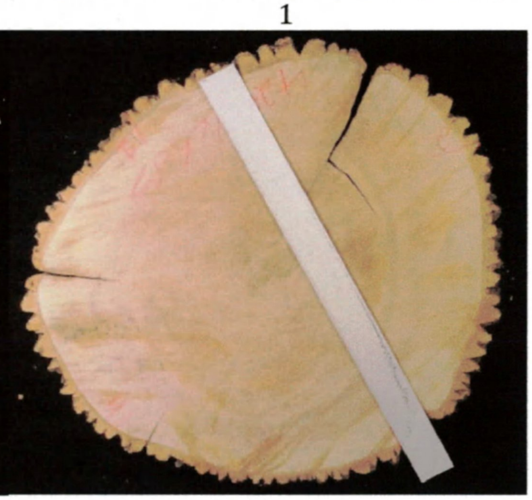




471 Parkwood St 1 Resistograph Scan 1

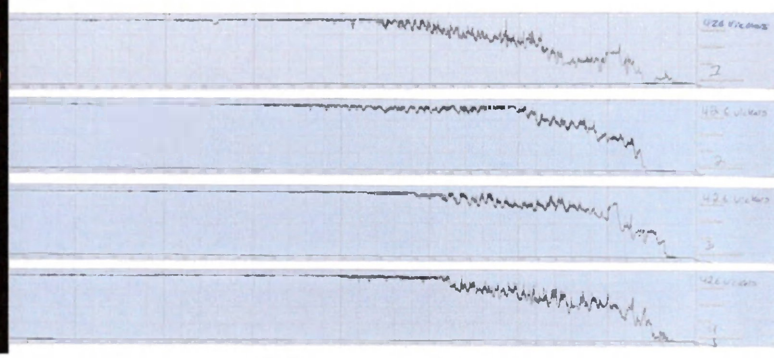



426 Vickers St 1

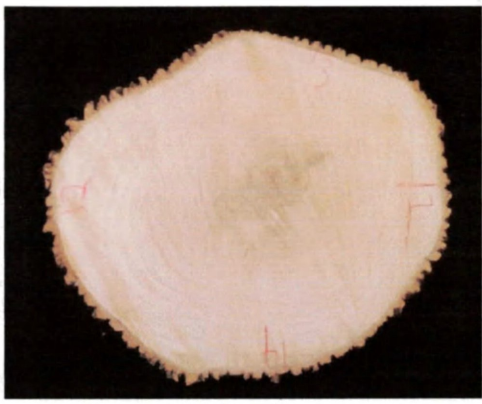



2 3

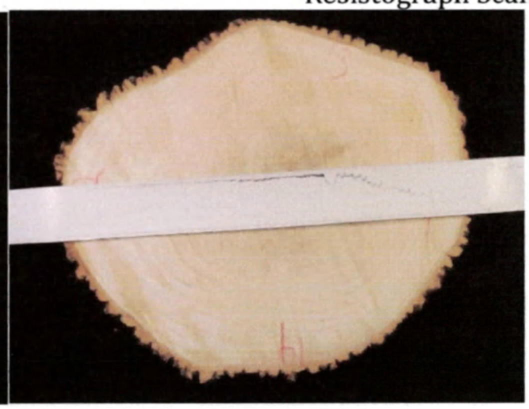
4



Resistograph Scans 1-4



81 Ray St



1-2

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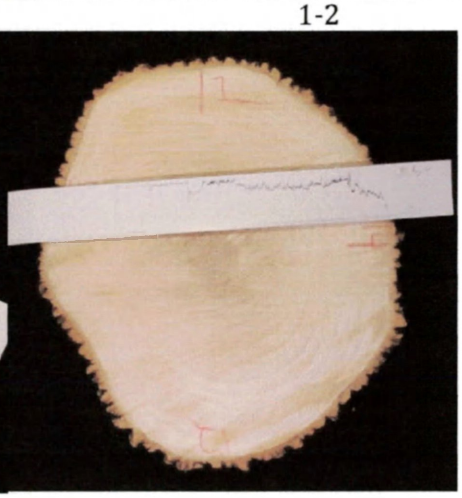

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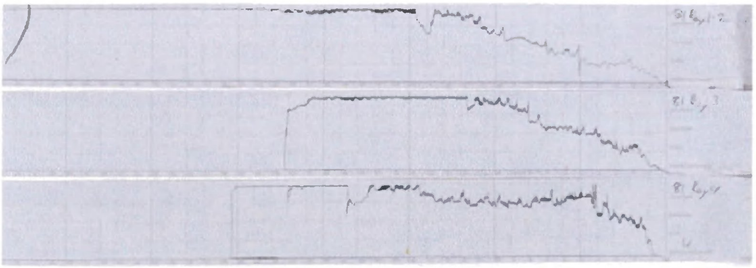
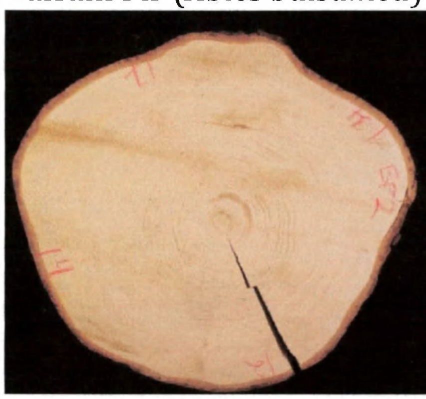
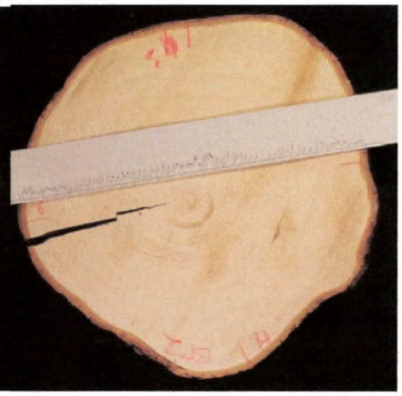


Resistograph Scans1-4

Balsam Fir (*Abies balsamea*)



Birch Point Tree-2



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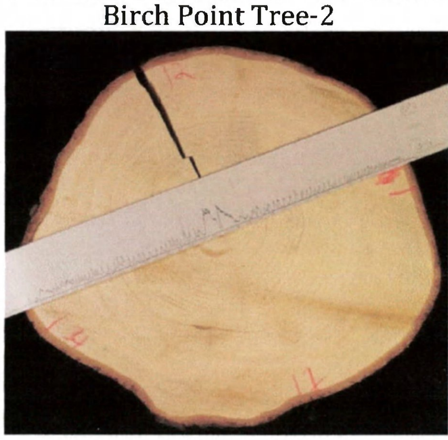

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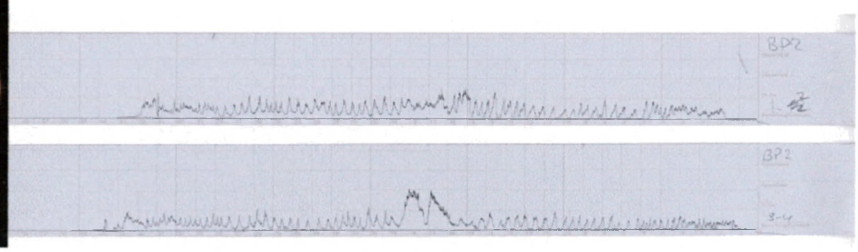
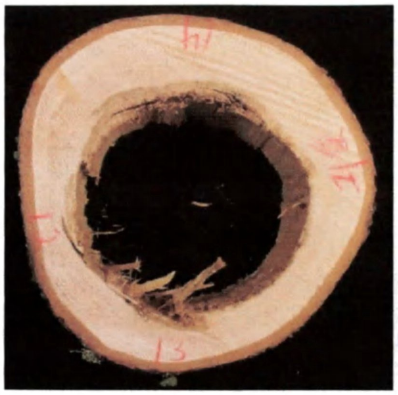
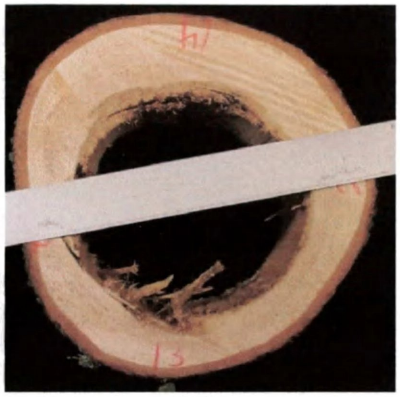
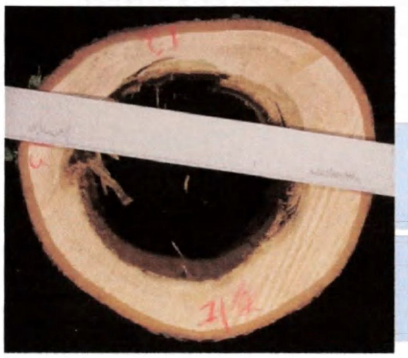
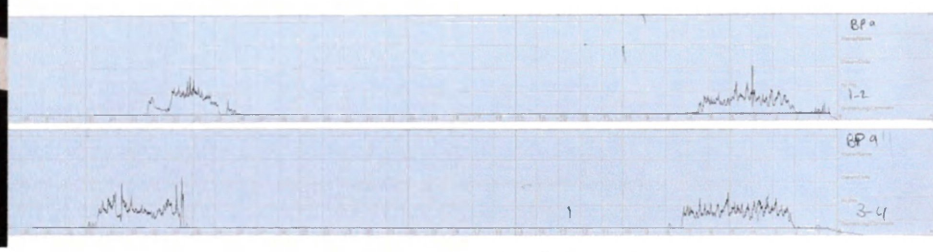


Resistograph Scans 1-4

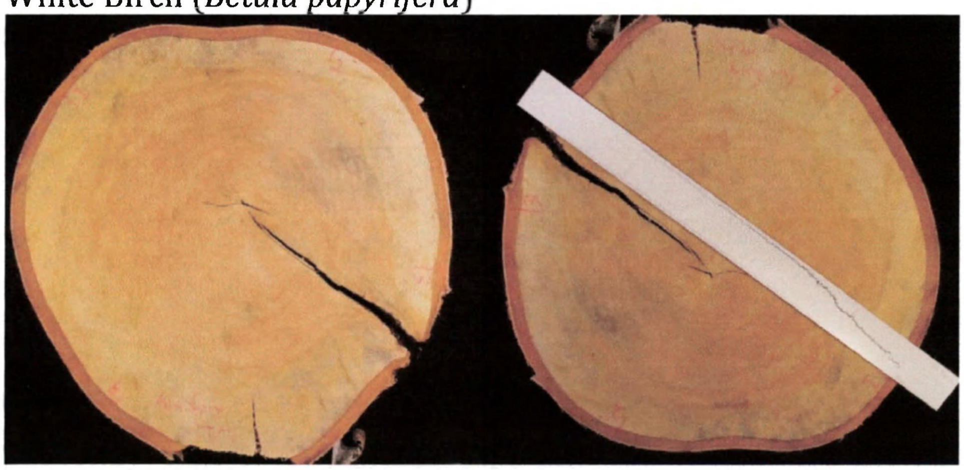
Birch Point Tree-9 1-2





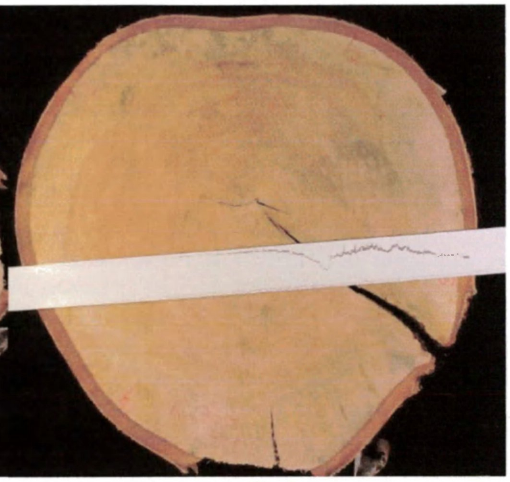
3-4 Resistograph Scan 1-4

White Birch (*Betula papyrifera*)



1422 Ridgeway St 1

2



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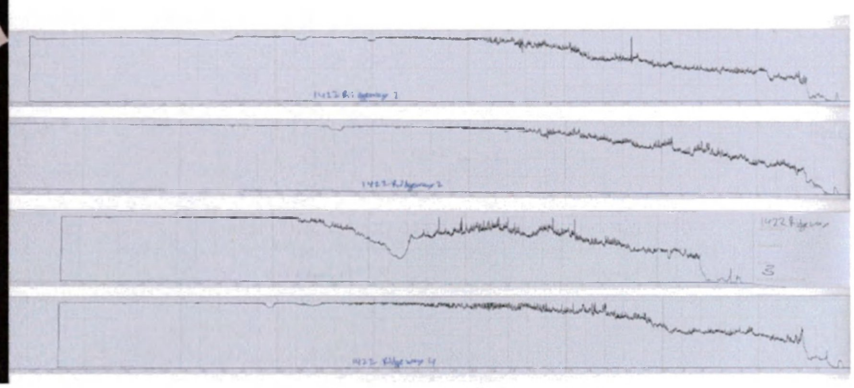
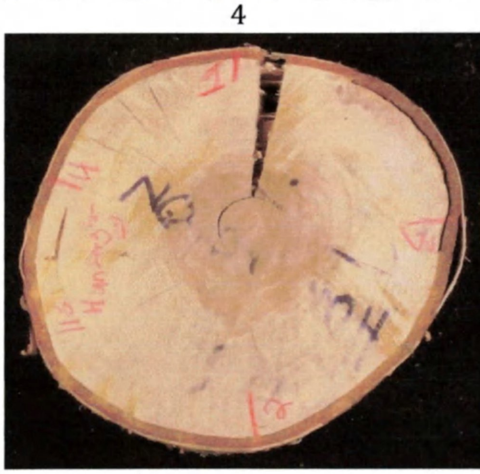
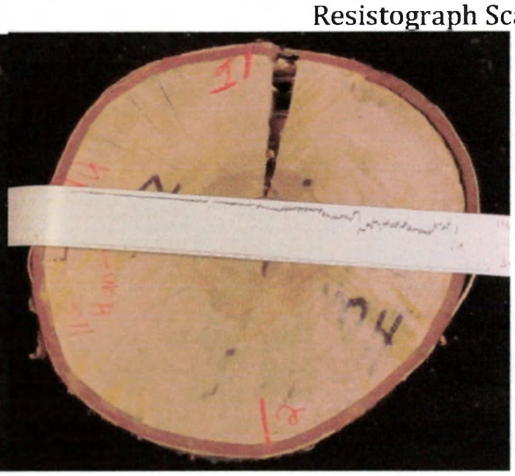


Resistograph Scan 1-4



116 Huntington Ct



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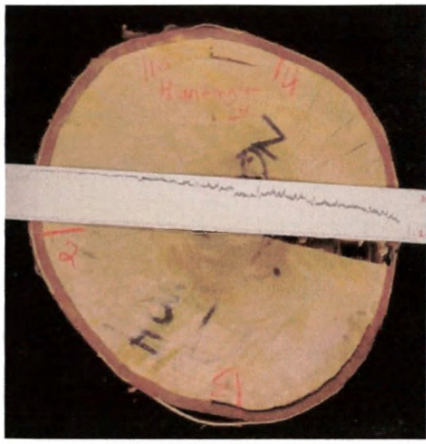

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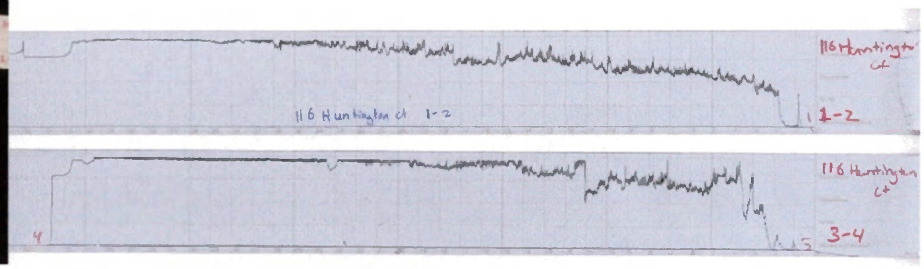
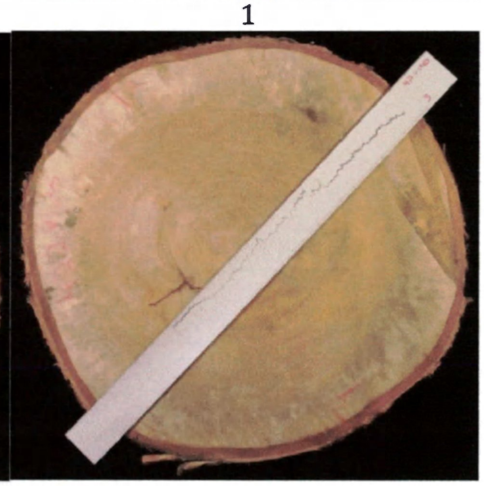


Resistograph Scans 1-4

422 Vickers St

1

2



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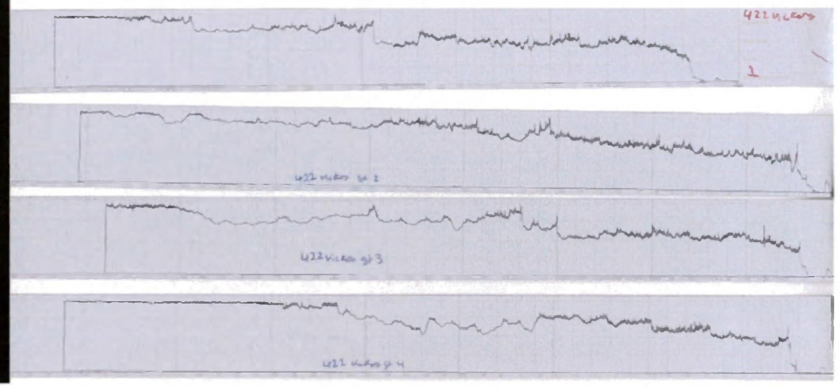
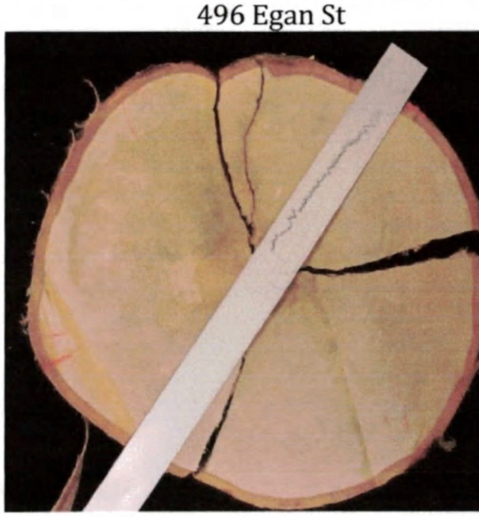


Resistograph Scans 1-4

496 Egan St

1



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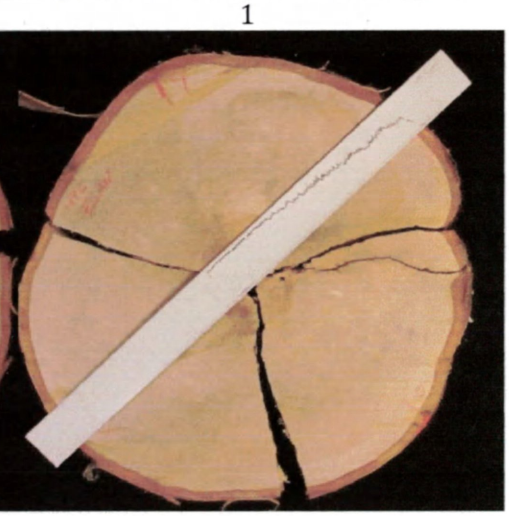

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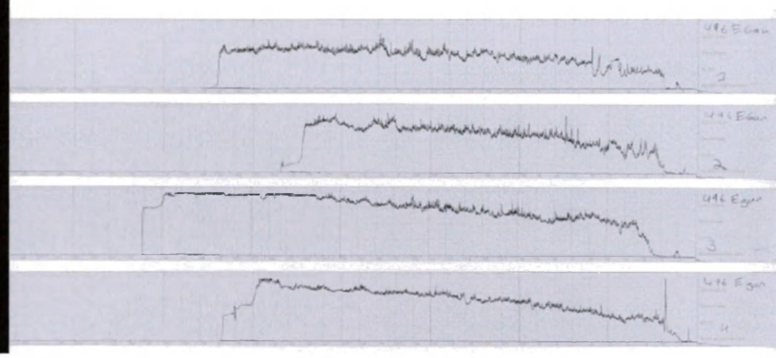
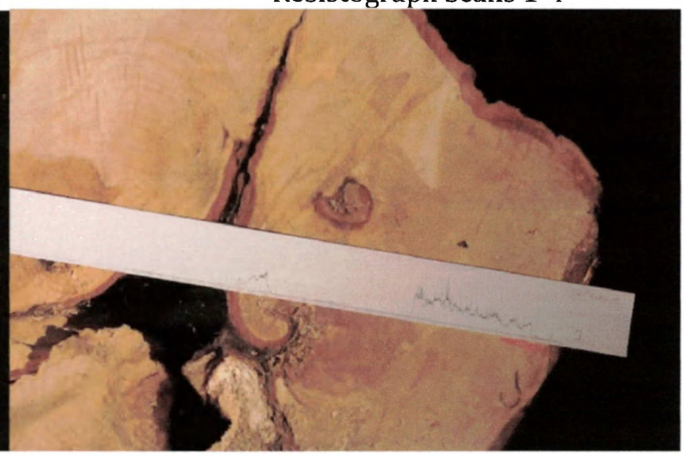


Resistograph Scans 1-4

52 Farrand St



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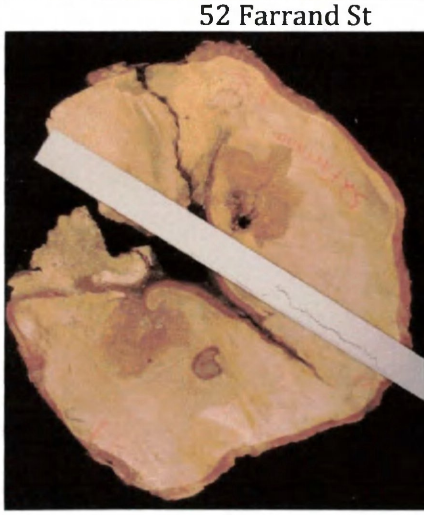

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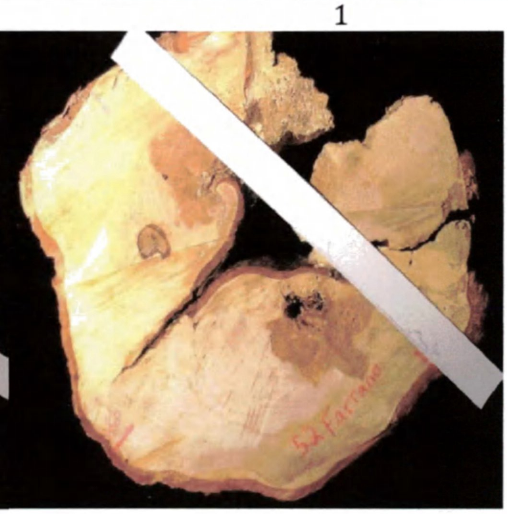

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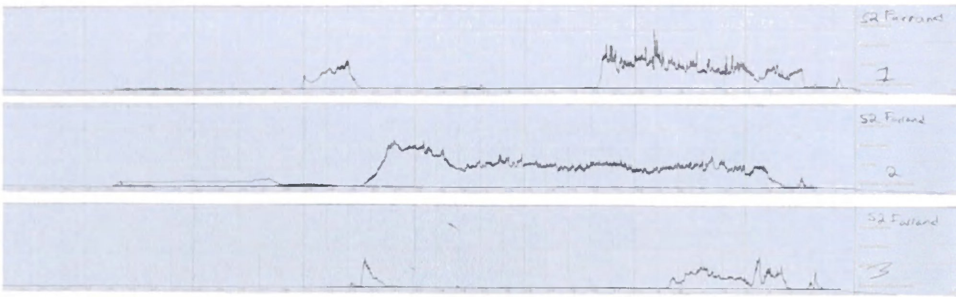
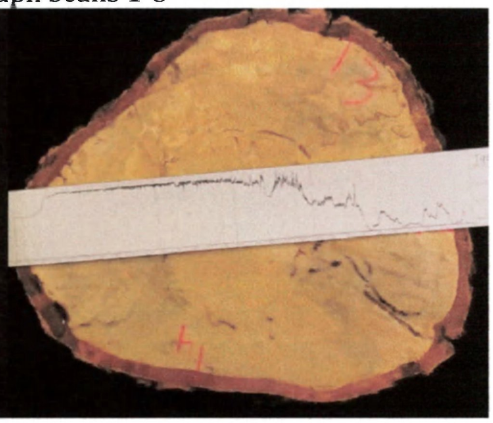


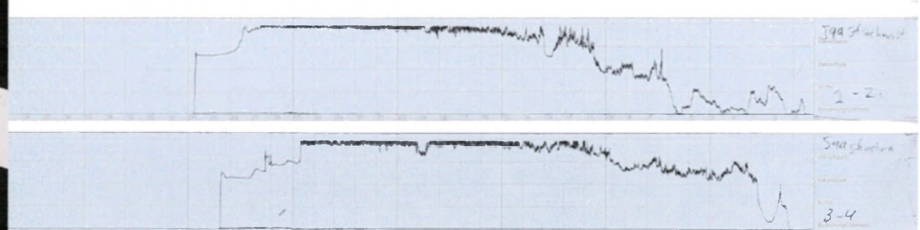
Resistograph Scans 1-3

599 Strachan St



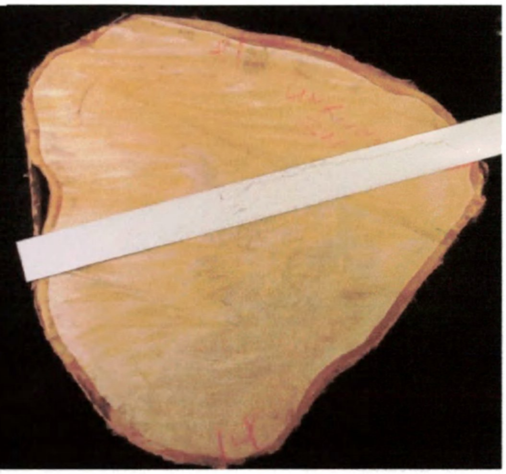
1-2

3-4



Resistograph Scans 1-4


Unknown Address 1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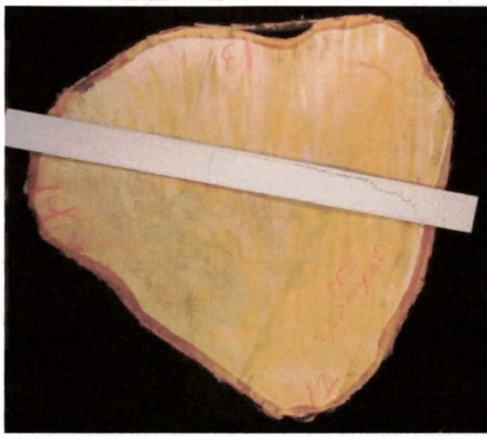
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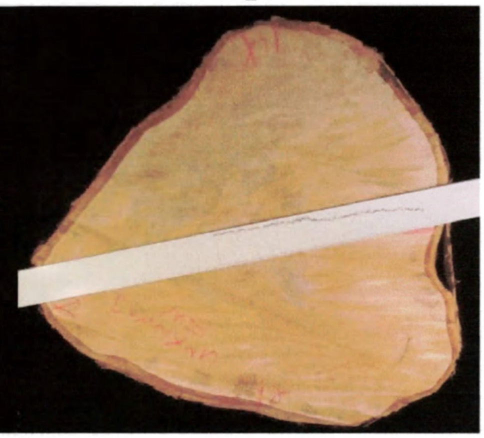
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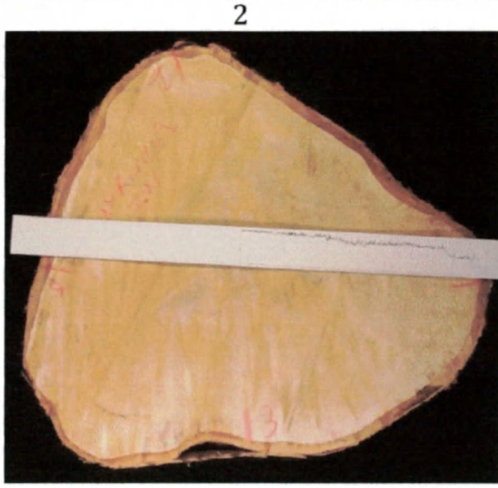
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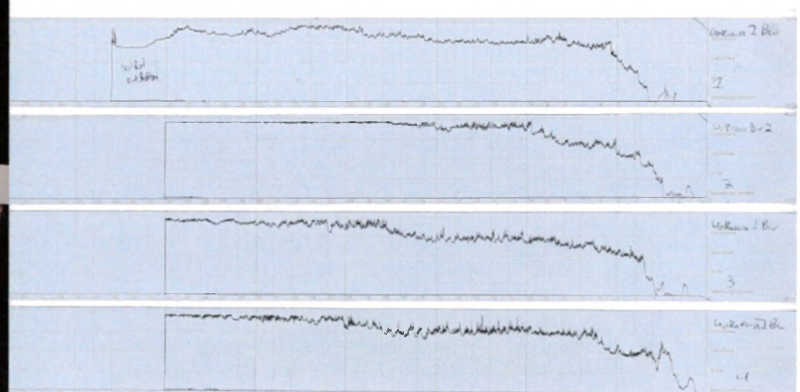
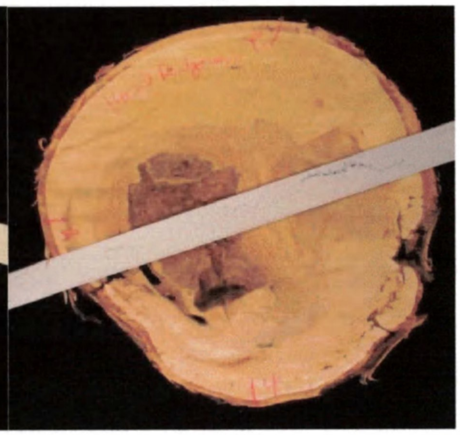

Resistograph Scan 1-4

1400 Ridgeway St

1

2



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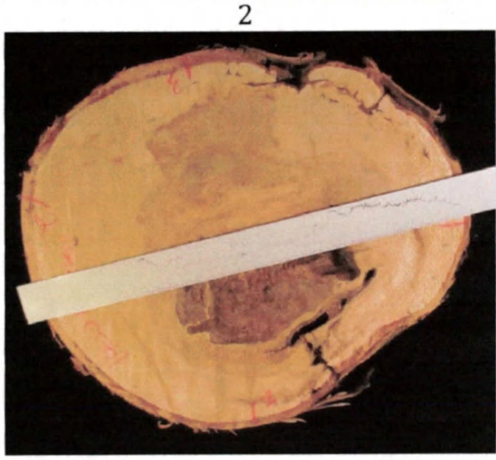

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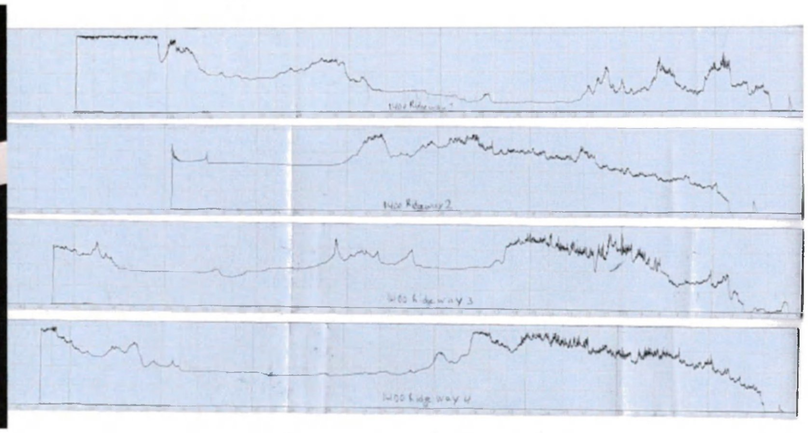
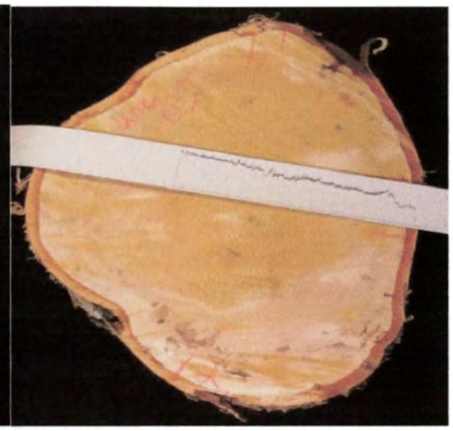


Resistograph Scans 1-4

Unknown Address 2



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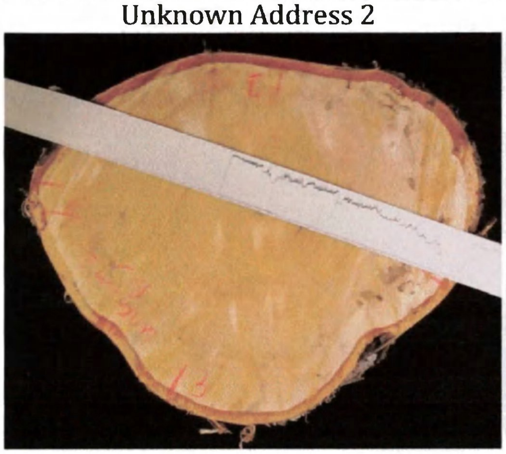

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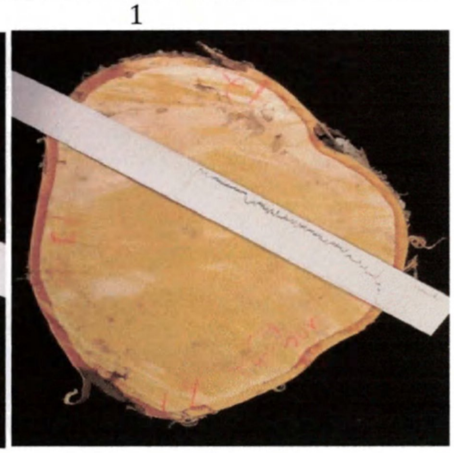

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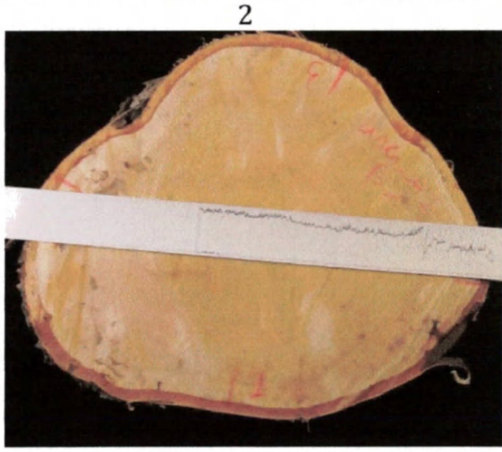

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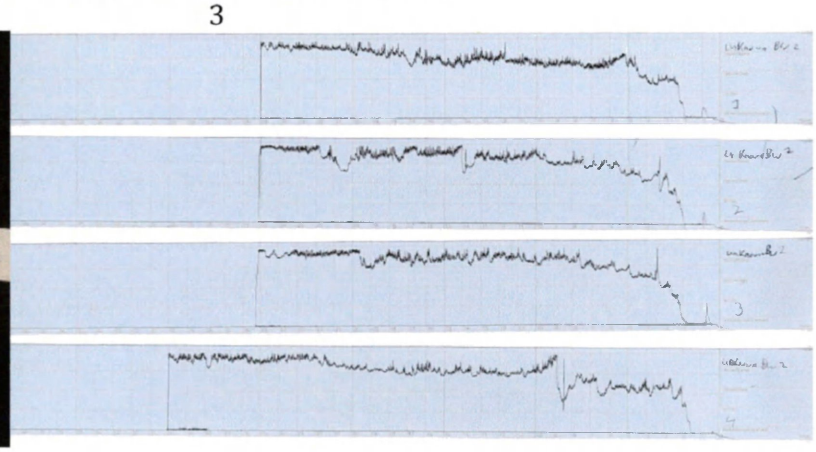
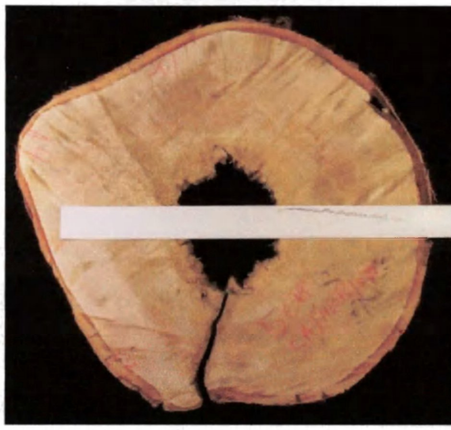


Resistograph Scans 1-4

508 Catherine St

1



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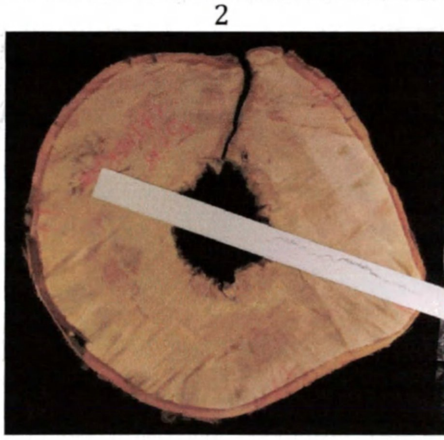
3



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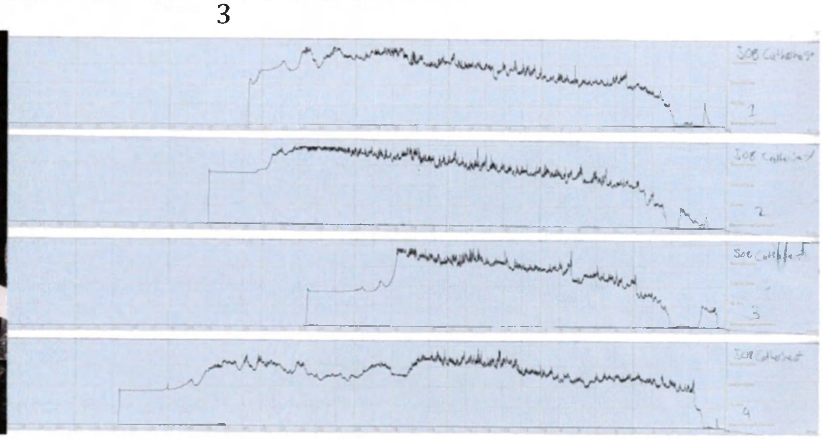
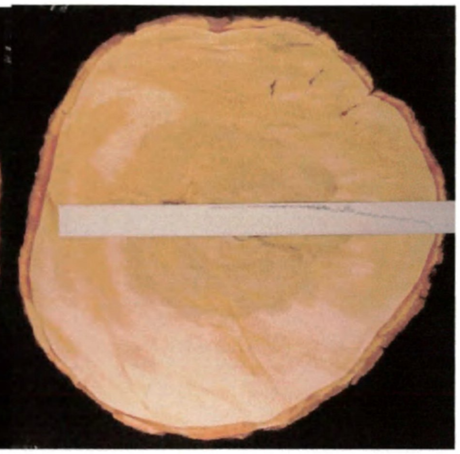


Resistograph Scans 1-4

327 Vickers St



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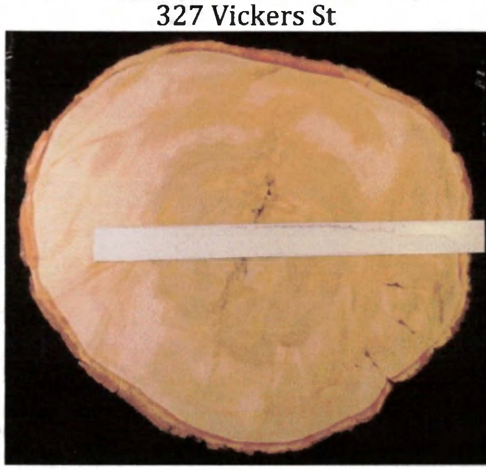

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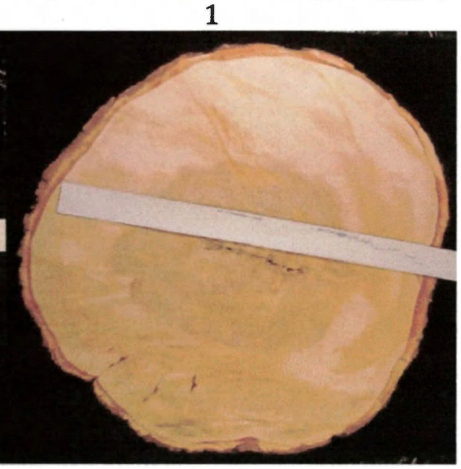

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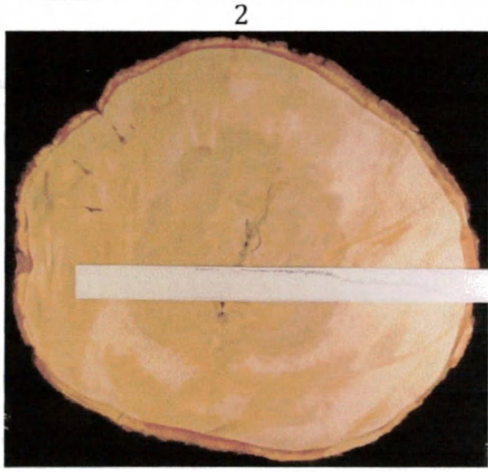

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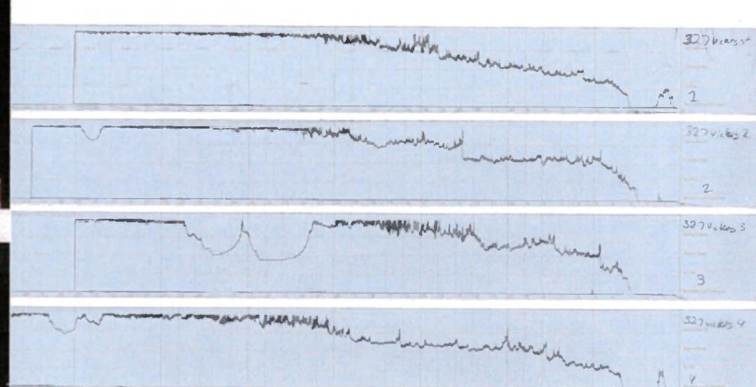
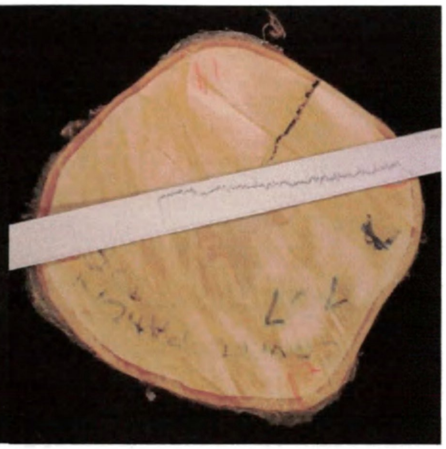


Resistograph Scans 1-4

707 Confederation Dr.



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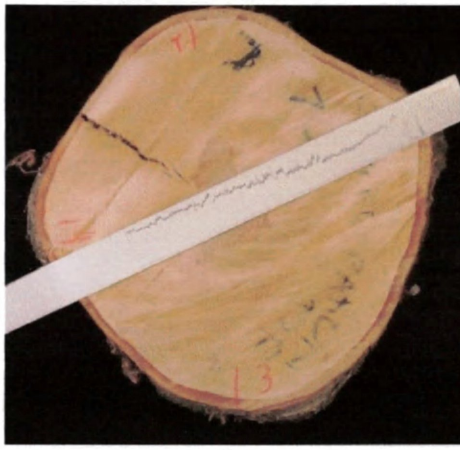

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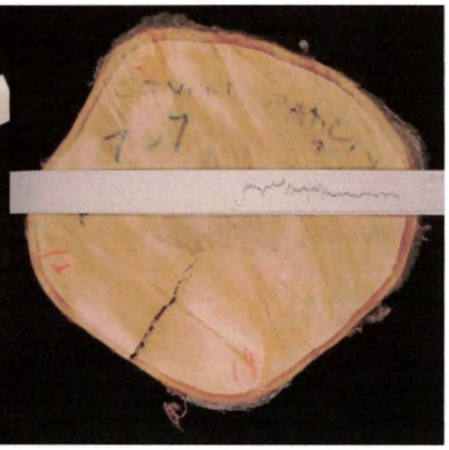

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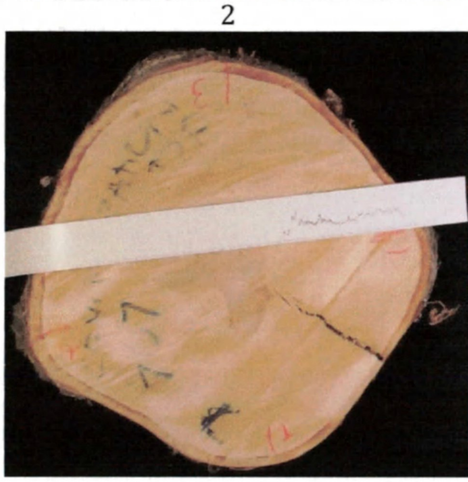

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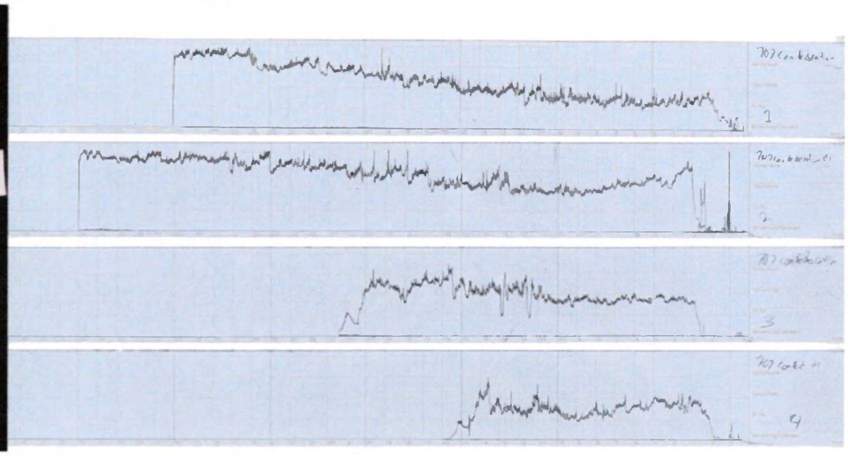
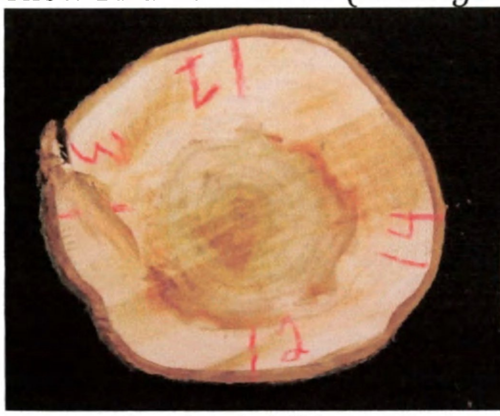
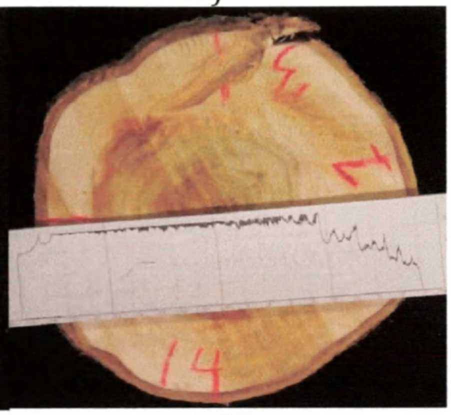


Resistograph Scans 1-4

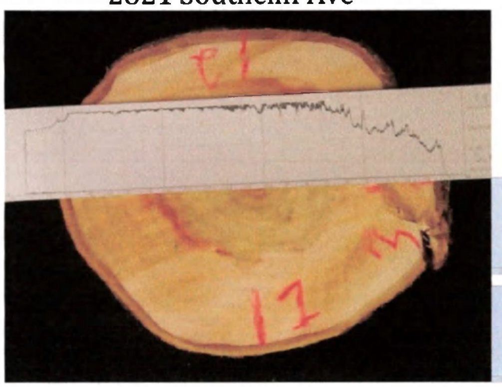
Snow Bird Hawthorne (*Crataegus* x *mordenesis*)



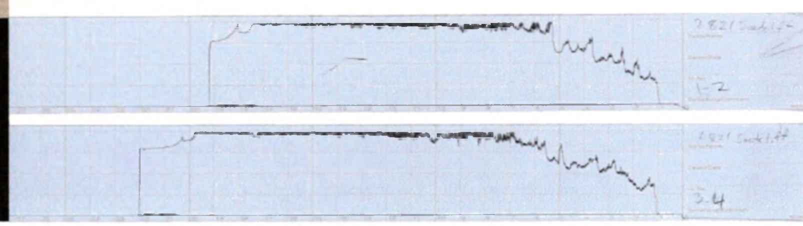
2821 Southcliff Ave



1-2



3-4

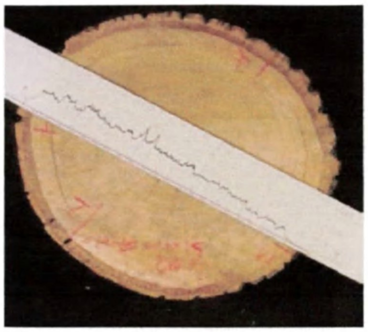


Resistograph Scans 1-4

Little Leaf Linden (*Tilia cordata)*

402 Simon Frasier Dr.

1-2



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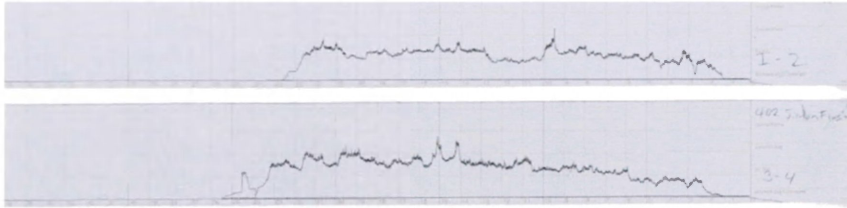


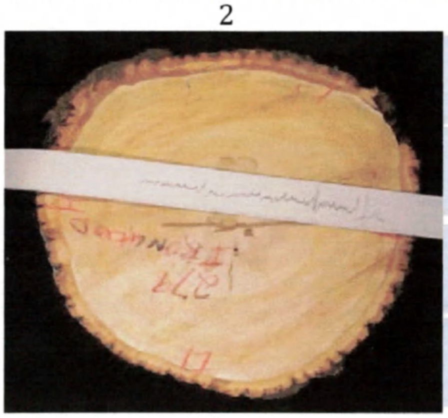
Resistograph Scans 1-4

279 Ironwood Ave

1

2

3



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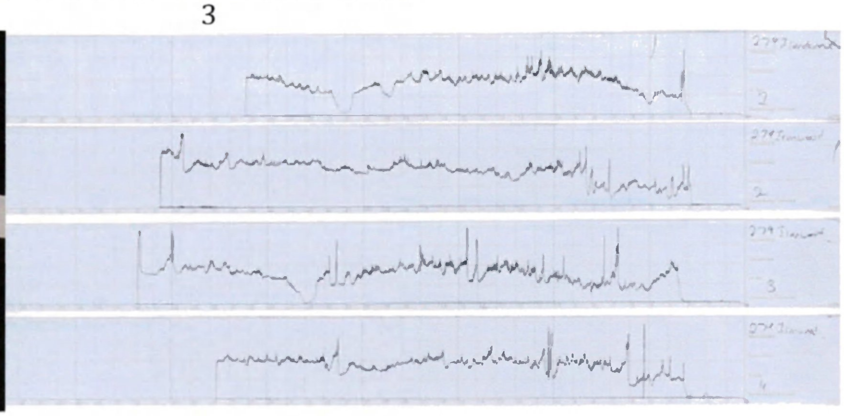
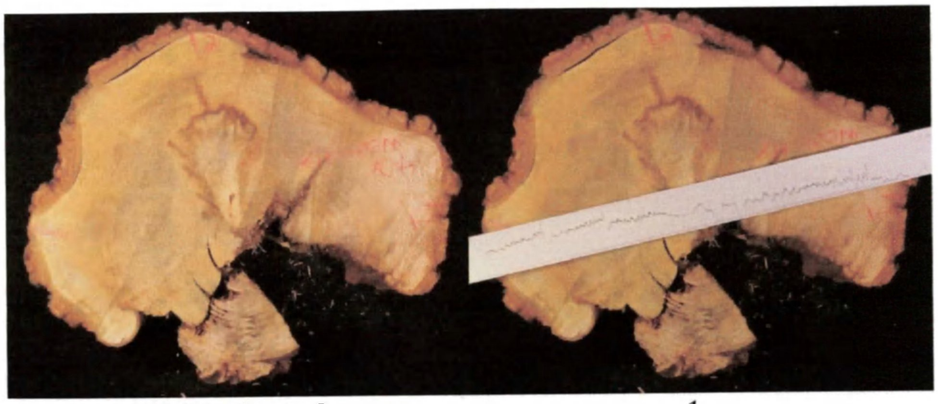
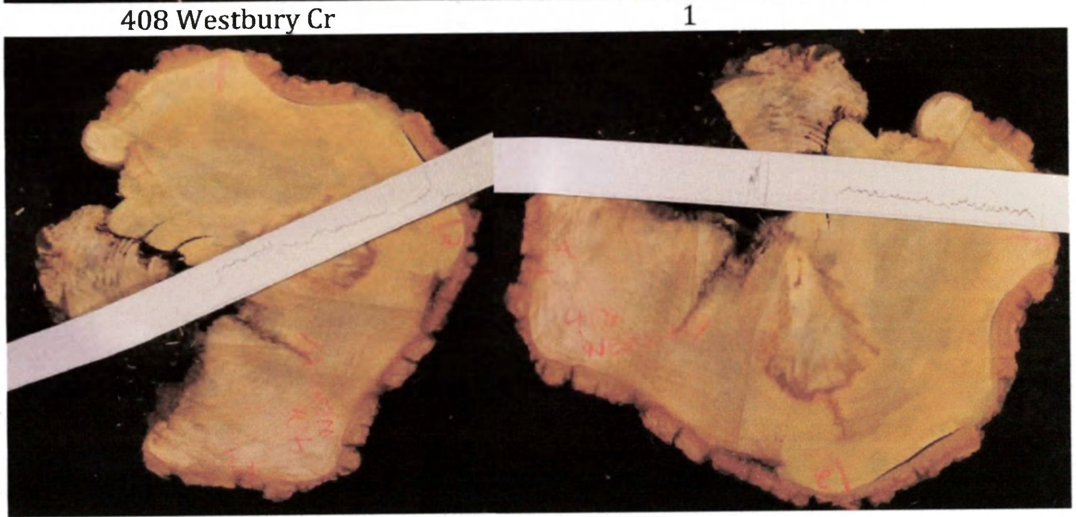


Resistograph Scans 1-4



408 Westbury Cr 1



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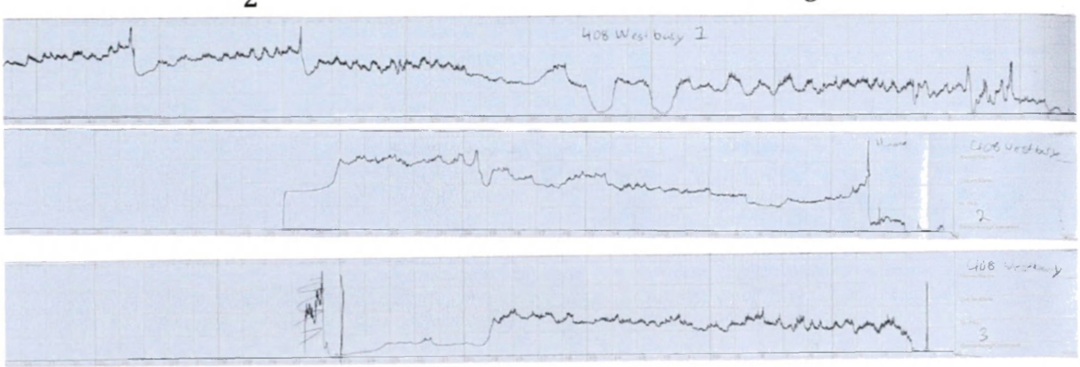
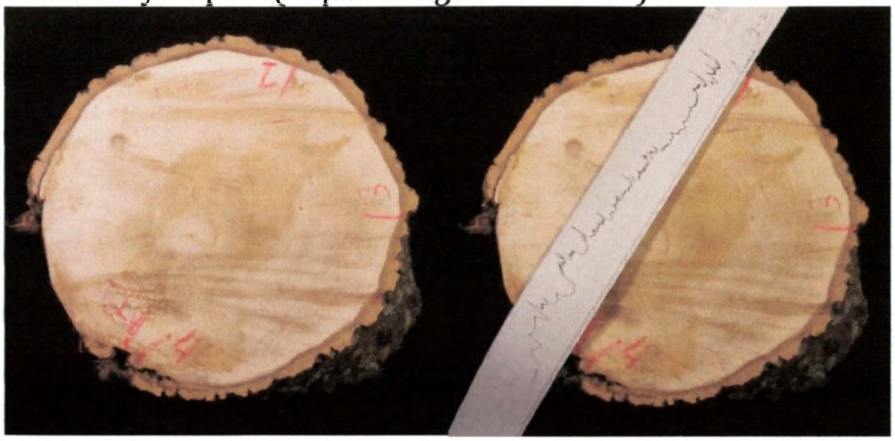


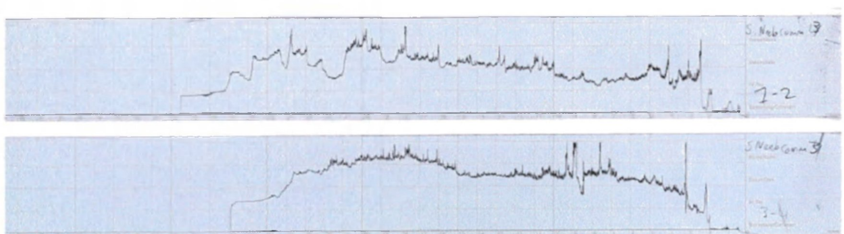
Resistograph Scans 1-3

Lombardy Poplar (*Populus nigra* cv. Italica)

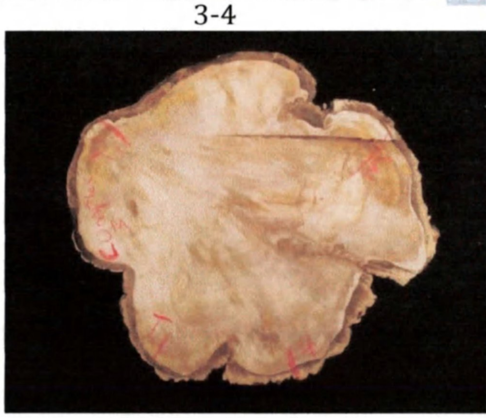


South Neebing Community Centre 3 1-2

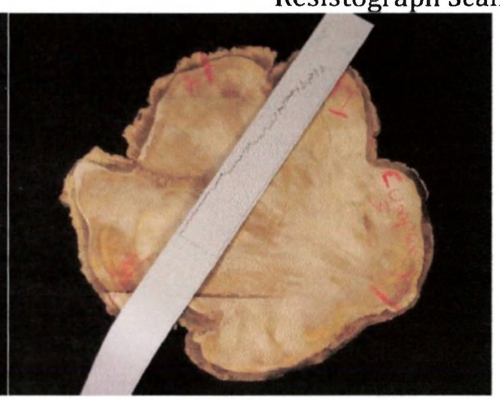
3-4



Resistograph Scans 1-4



420 Winnipeg Ave-2



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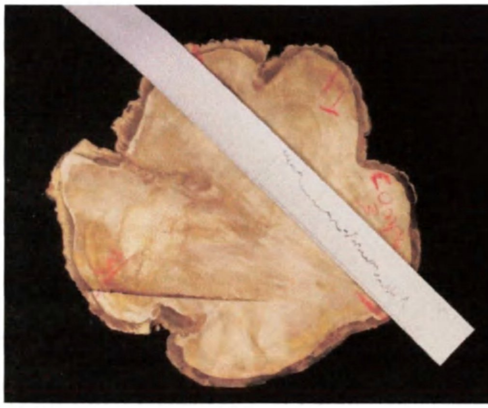

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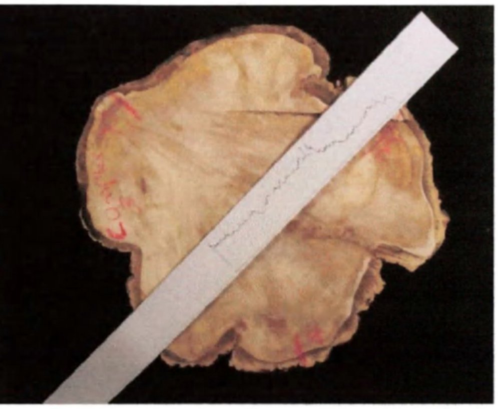

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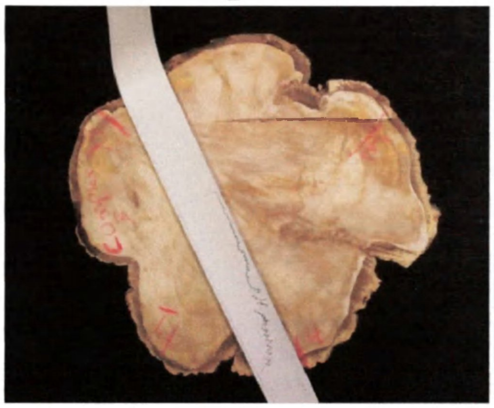

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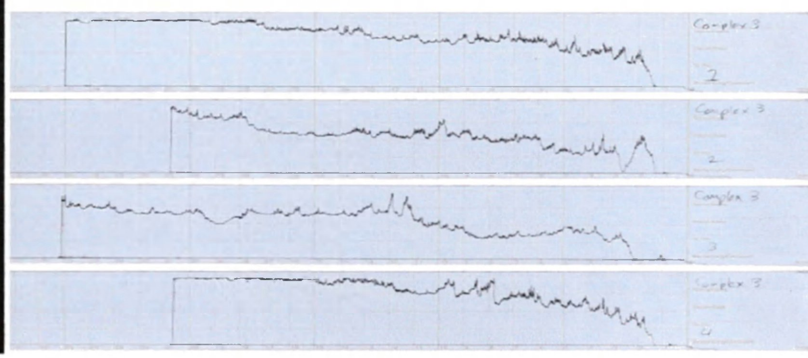
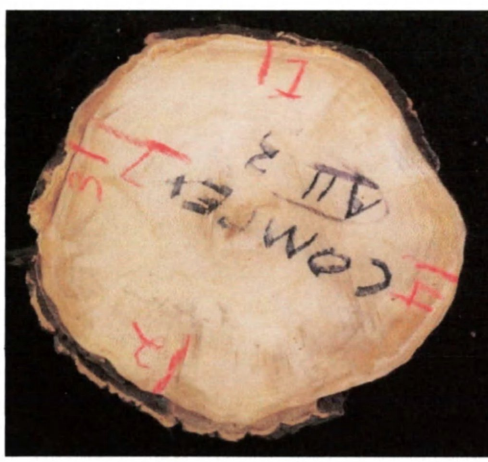
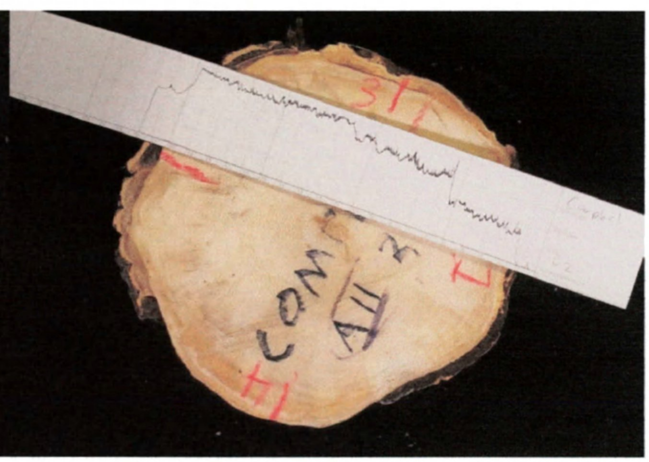


Resistograph Scans 1-4



420 Winnipeg Ave-1



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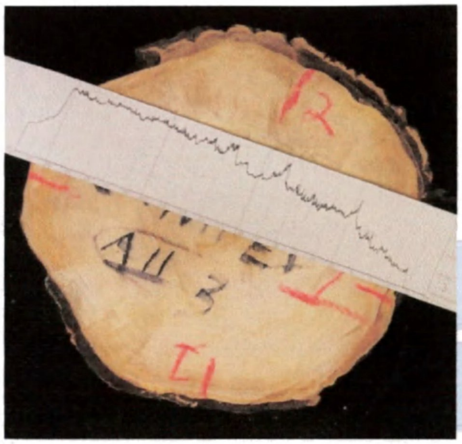

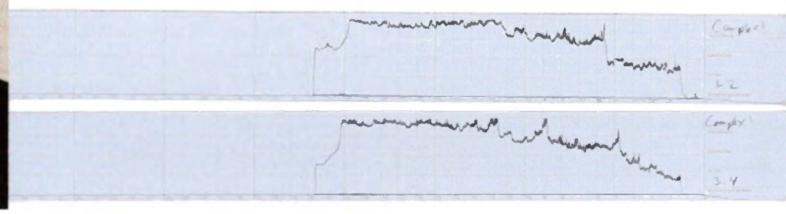

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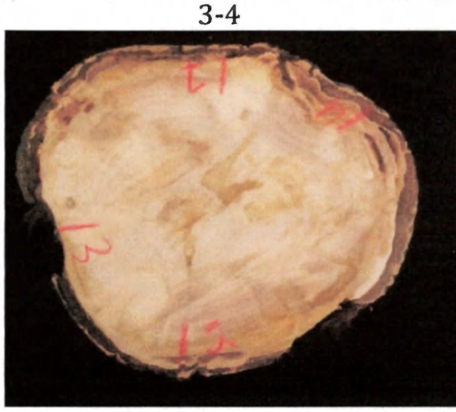
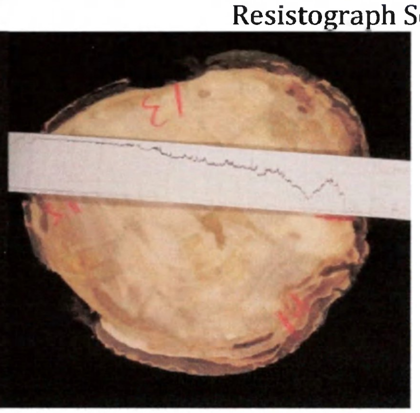
Resistograph Scans 1-4



420 Winnipeg Ave-3



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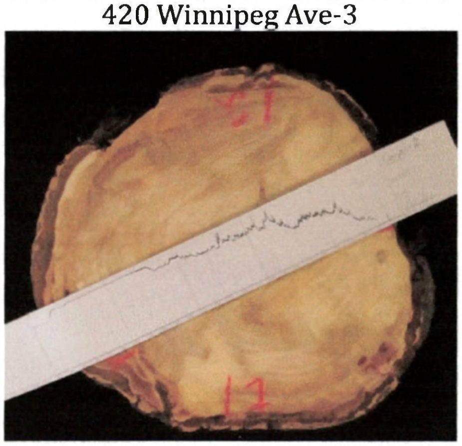
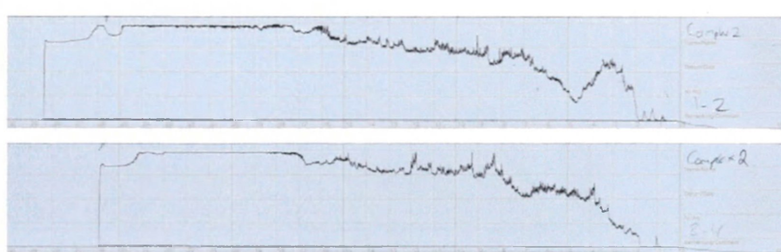
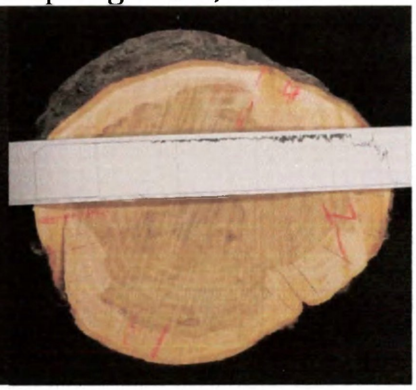




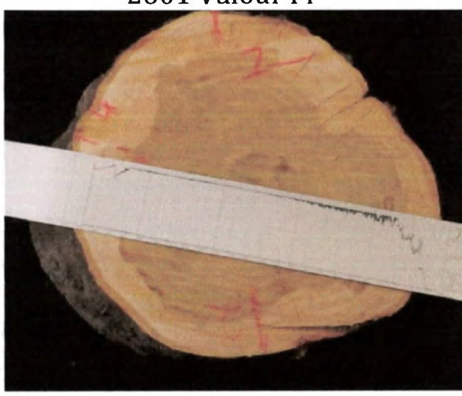
3-4

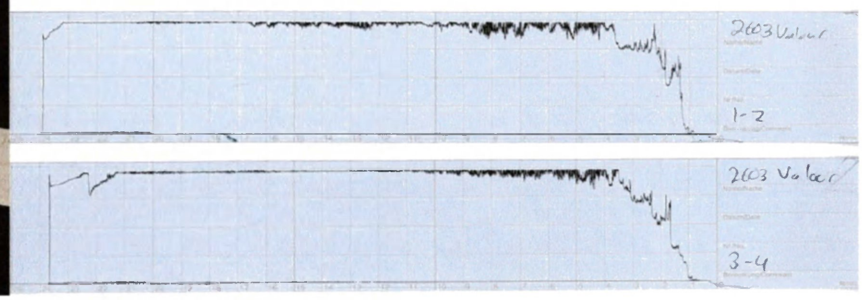
Resistograph Scans 1-4

Flowering Crab Apple (*Malus* x 'Spring Snow, *Malus* x 'Pink Spire)



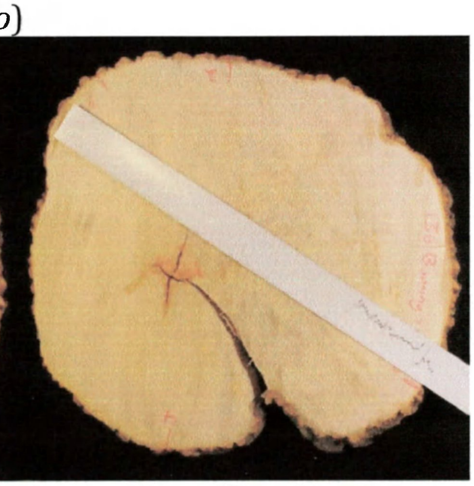
2601 Valour Pl 1-2



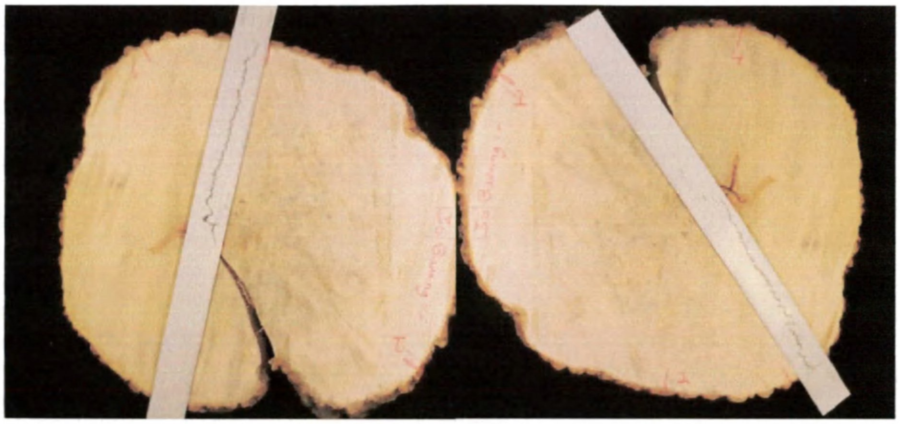


3-4 Resistograph Scans 1-4

Manitoba Maple (*Acer negundo*)



136 Banning St 1



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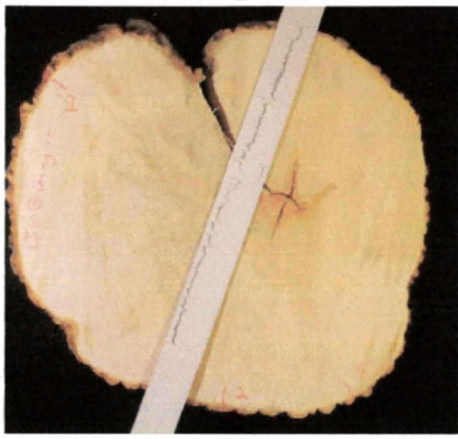

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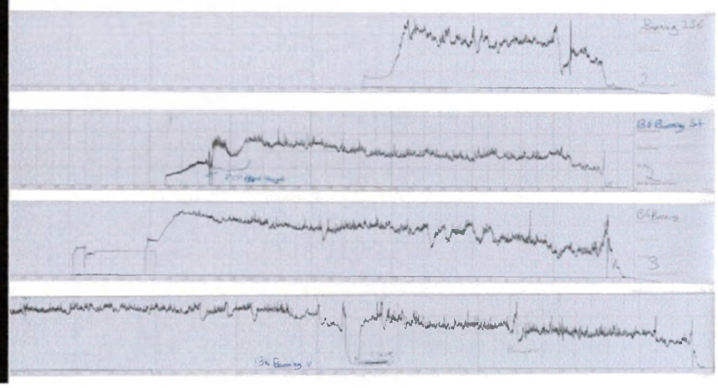
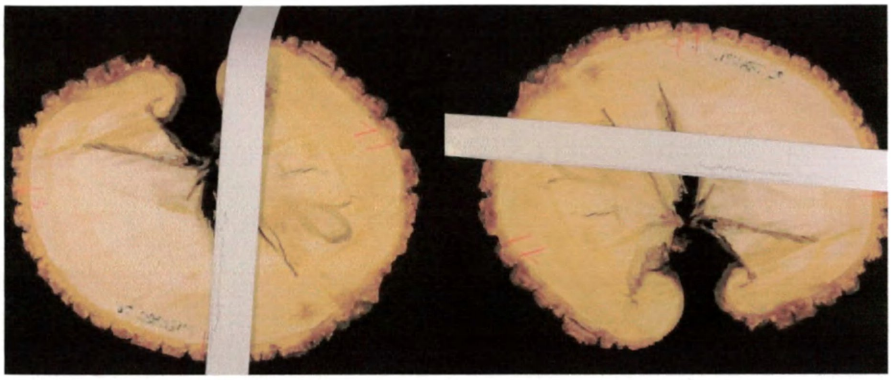


Resistograph Scans 1-4

14 Wishart Ct 1



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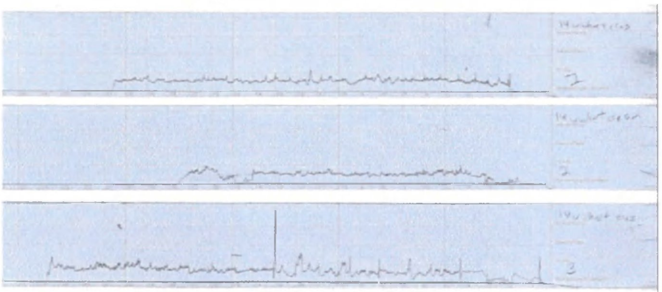
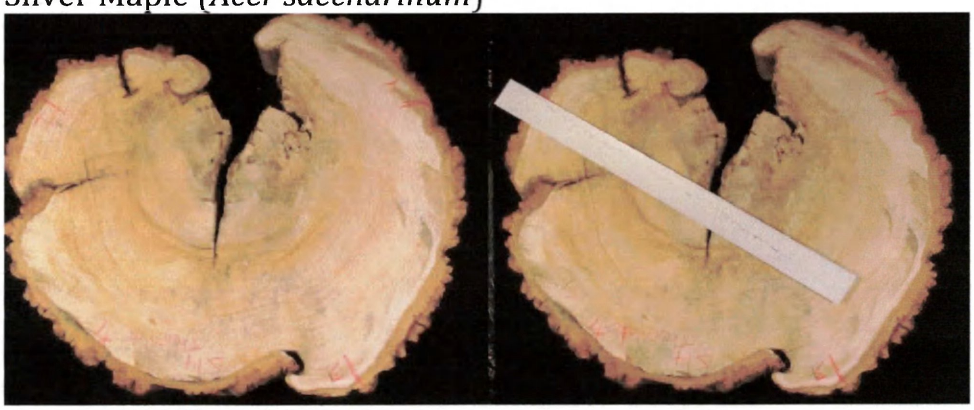
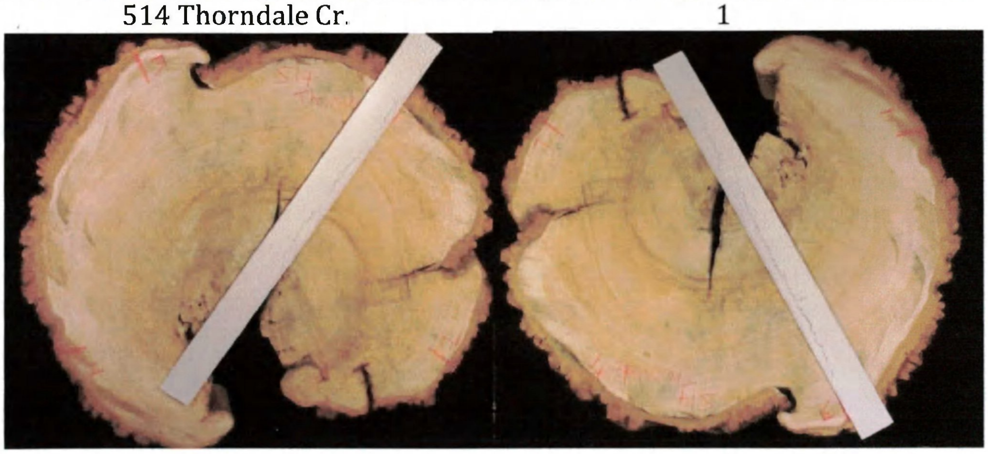


Resistograph Scans 1-3

Silver Maple (*Acer saccharinum*)



514 Thorndale Cr. 1



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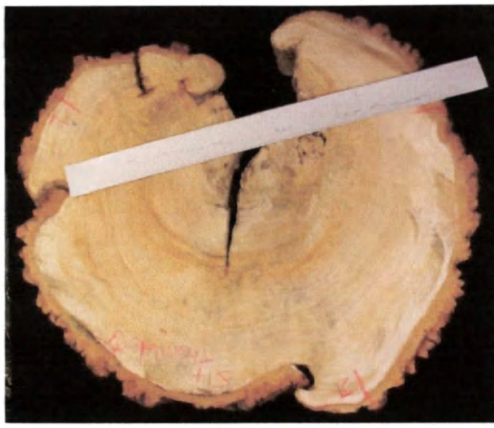

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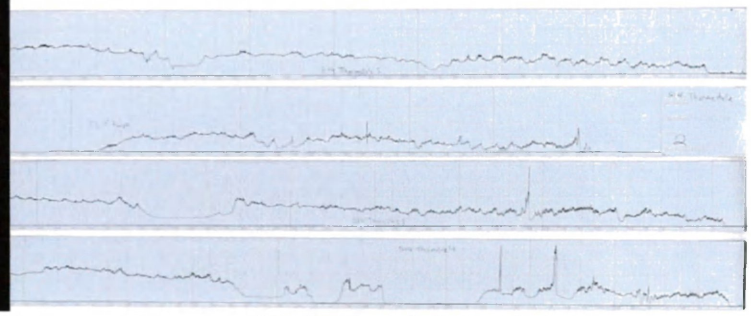
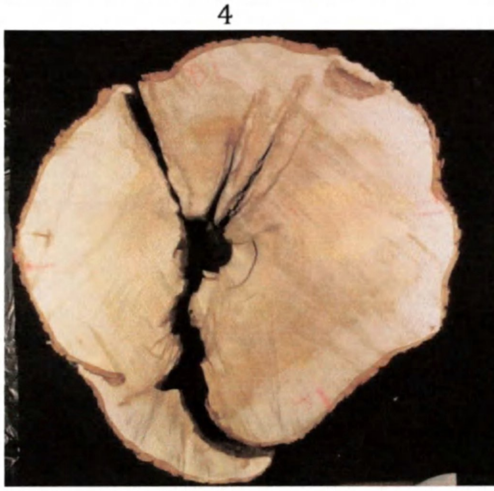
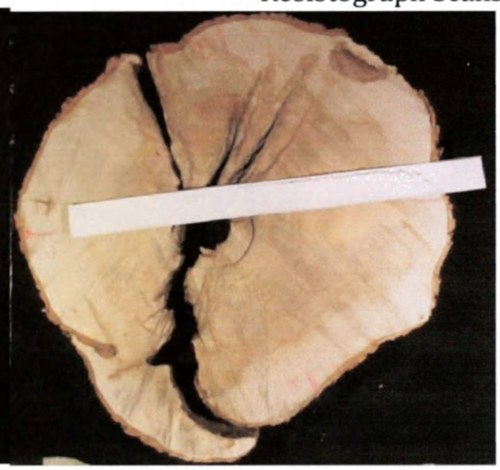


Resistograph Scans 1-4



Mnt. View Cemetery 1



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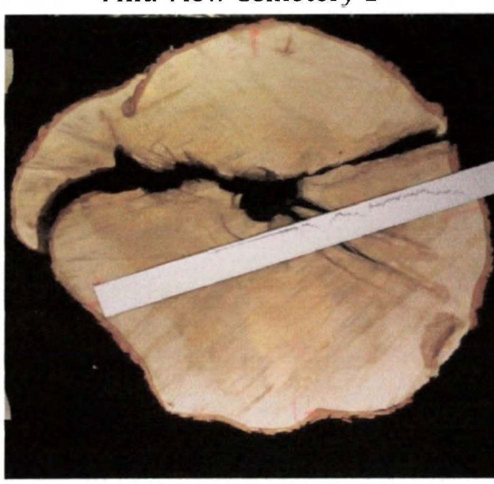

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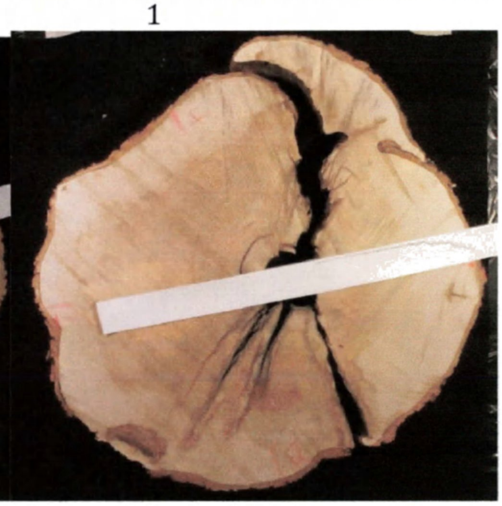

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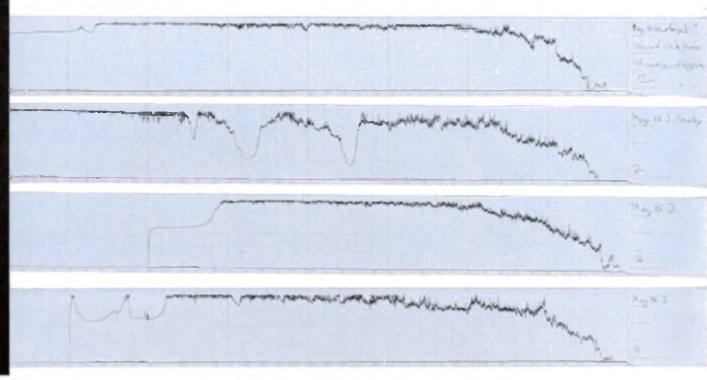
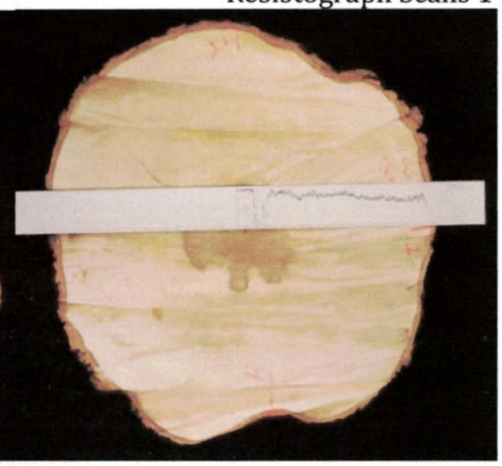


Resistograph Scans 1-4

166 Peter St



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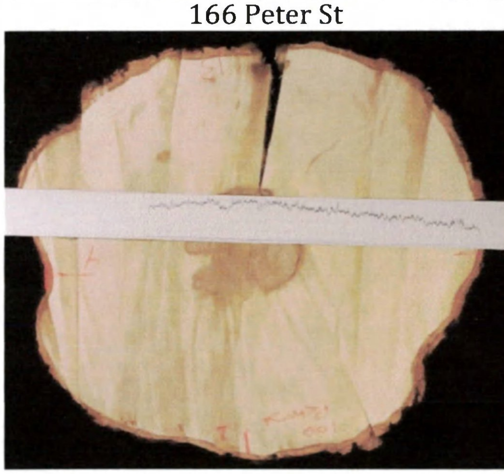

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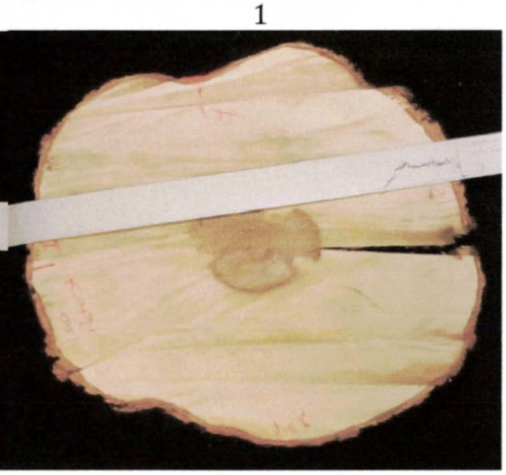

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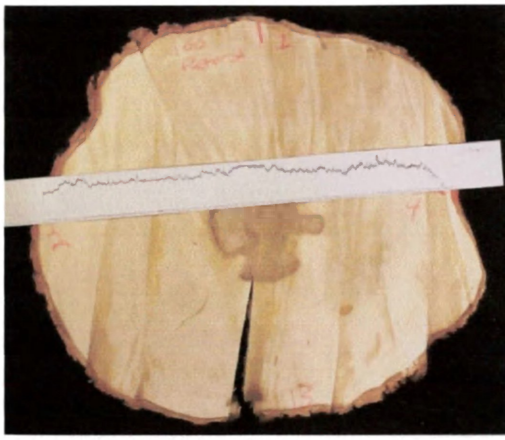

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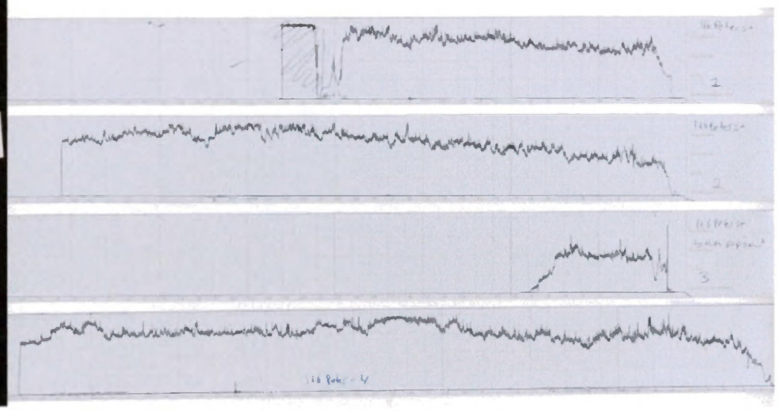
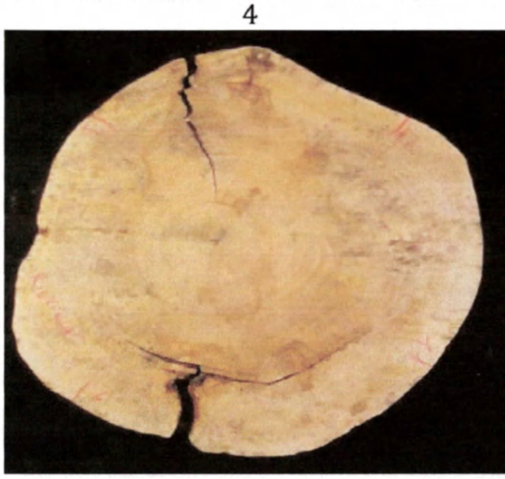
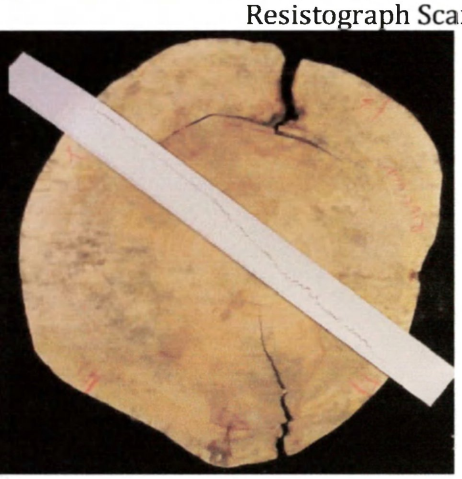


Resistograph Scans 1-4



Riverveiw Dr-1



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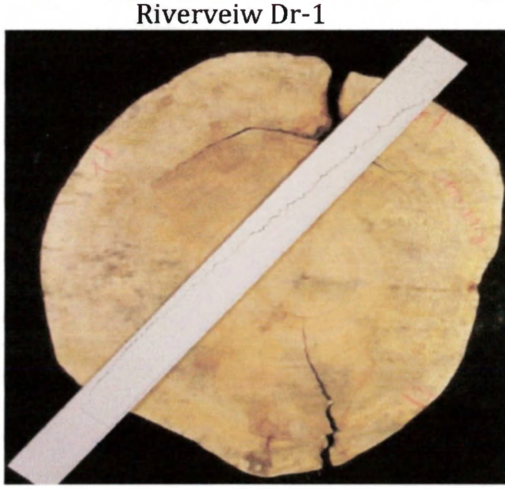
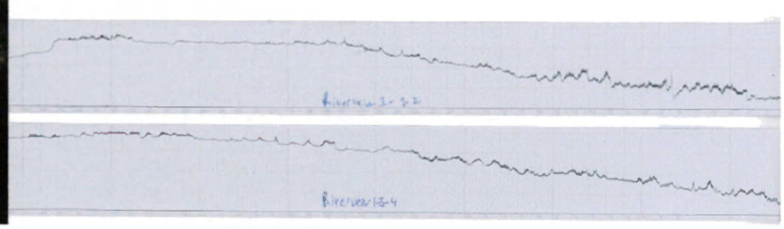




3-4

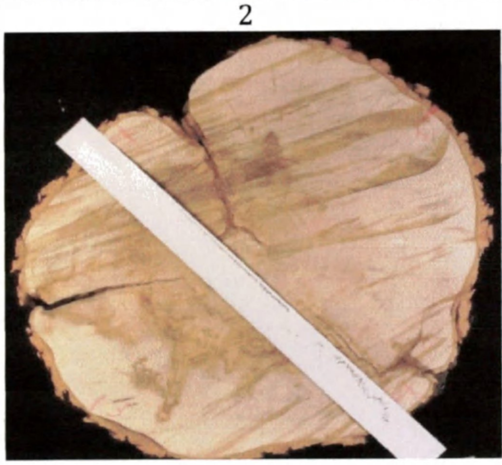
Resistograph Scans 1-4

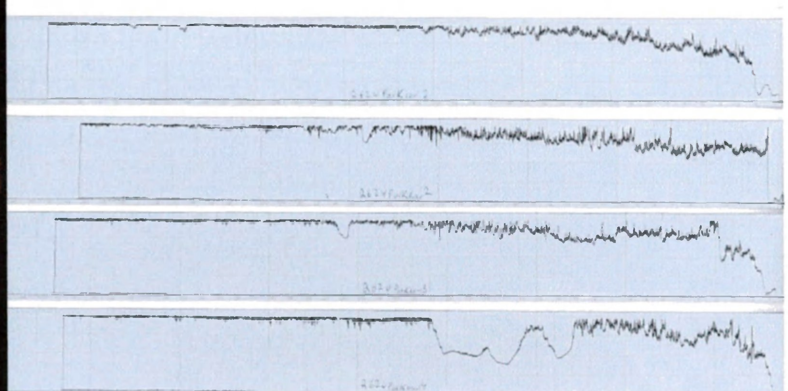
2624 Park Row

1

2

3





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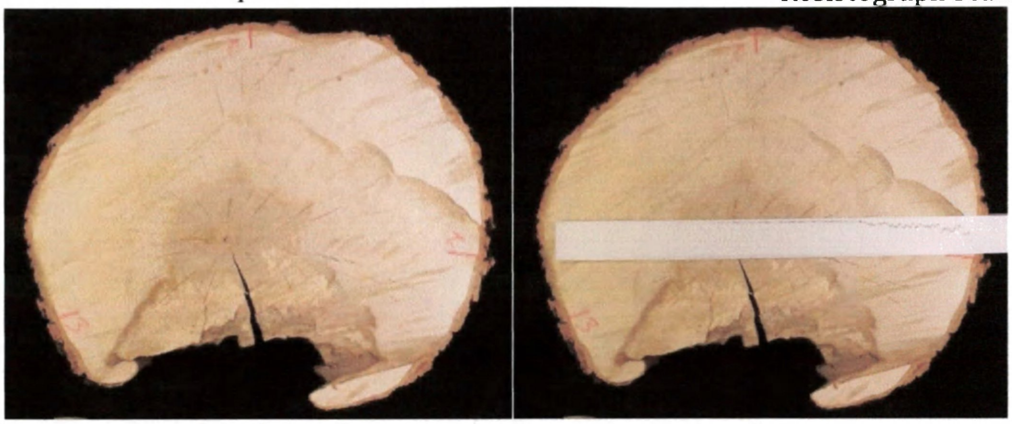
Resistograph Scans1-4

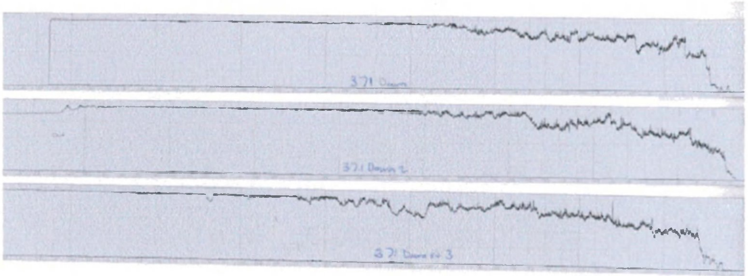


371 Dawn St

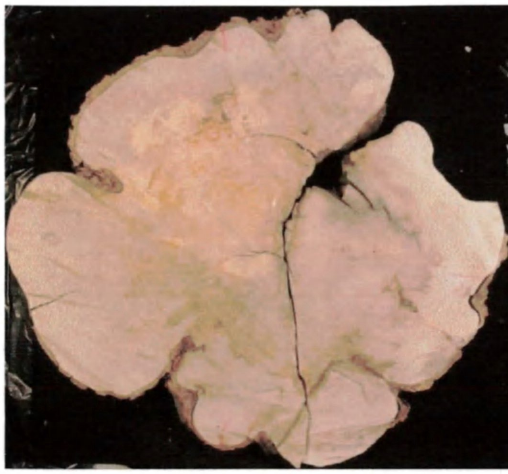
1

2

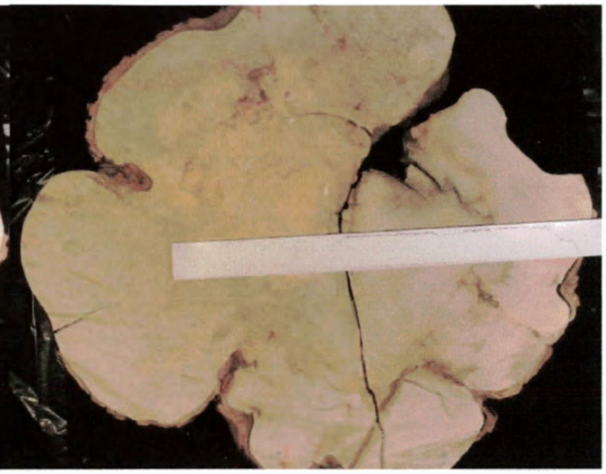
3



Resistograph Scans 1-3



526 Wiltshire Cr



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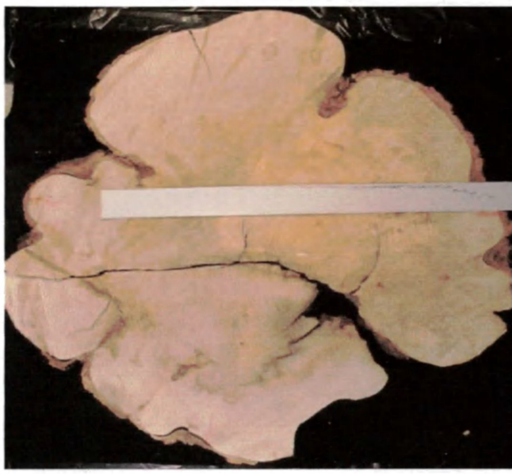

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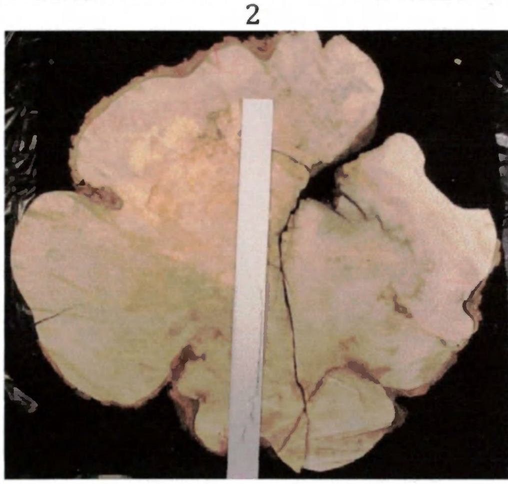

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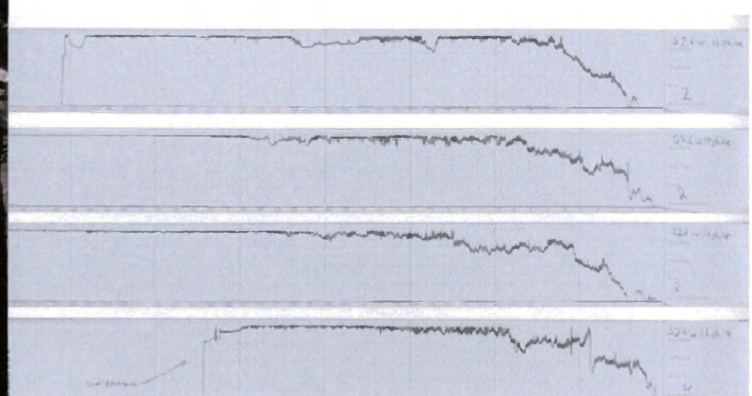
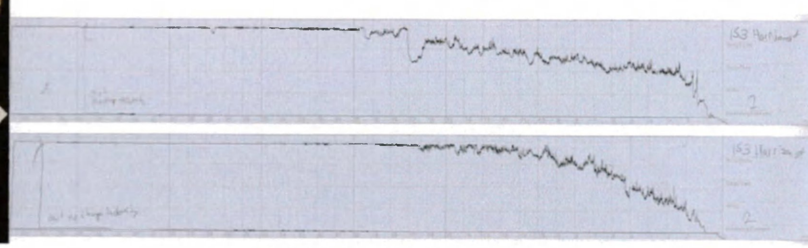


Resistograph Scans 1-4

153 Harrison St

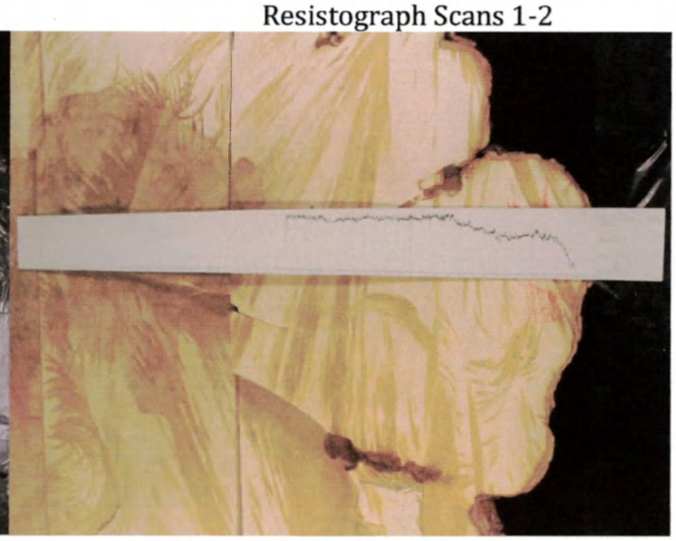
1

2



Resistograph Scans 1-2

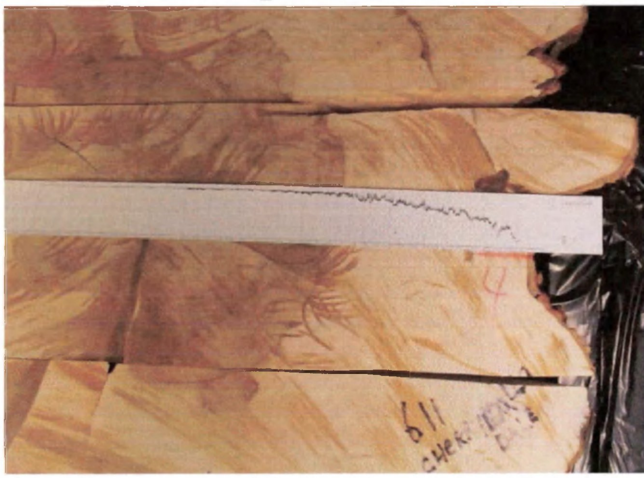
611 Cherrydale Pl



1

2

3



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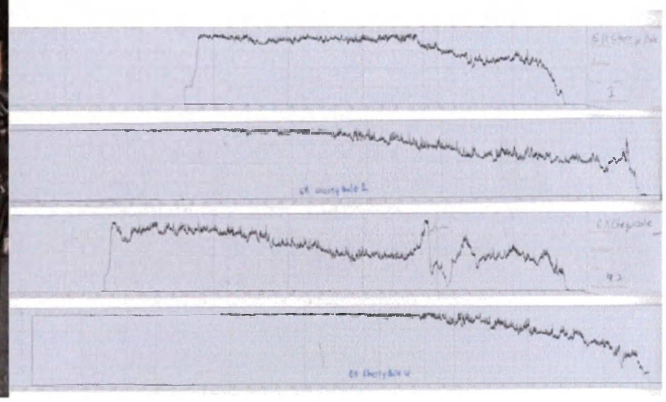
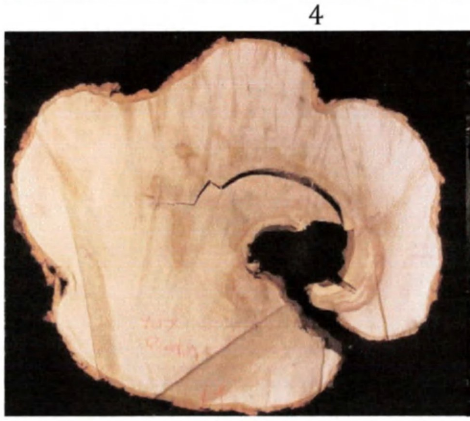
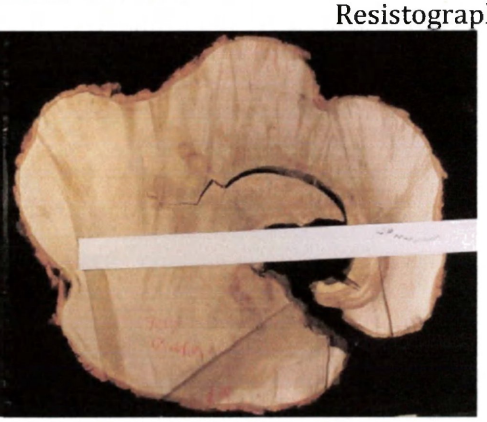


Resistograph Scans 1-4



407 Dublin Ave



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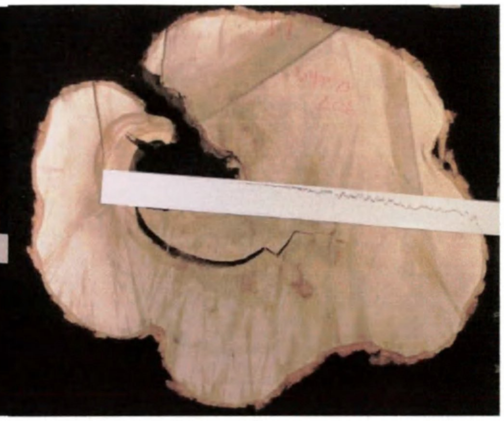

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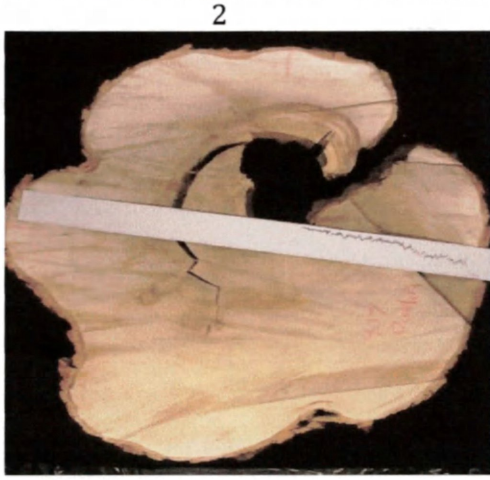

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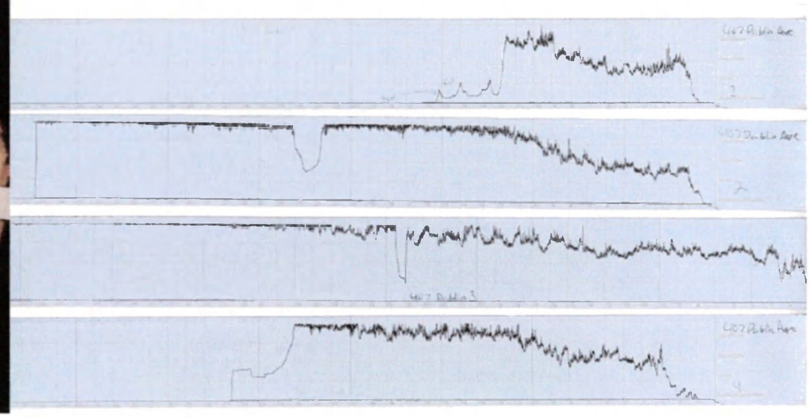
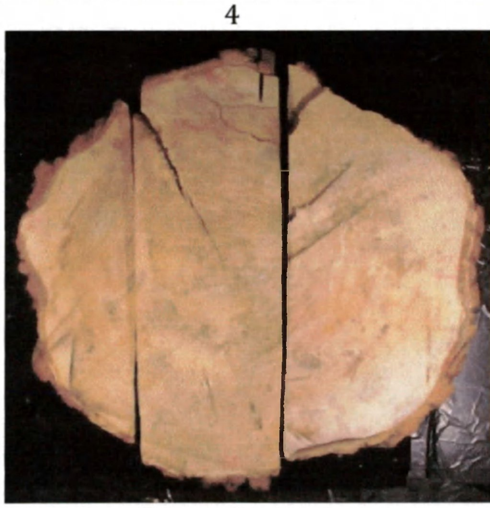
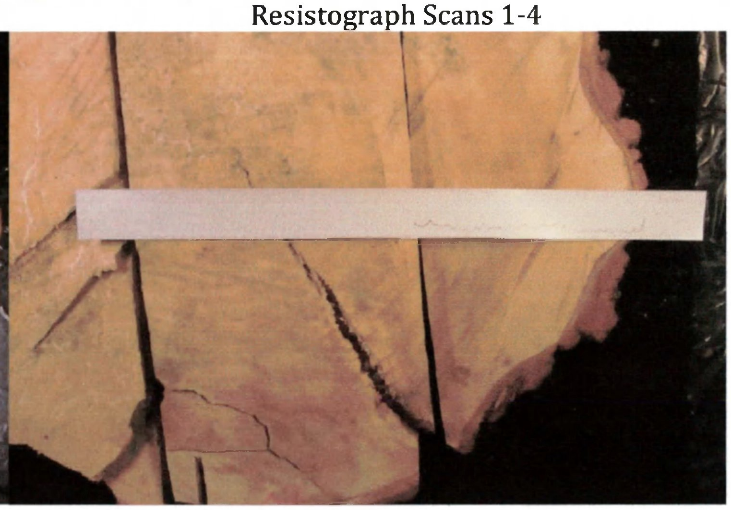


Resistograph Scans 1-4



Riverveiw Dr-2



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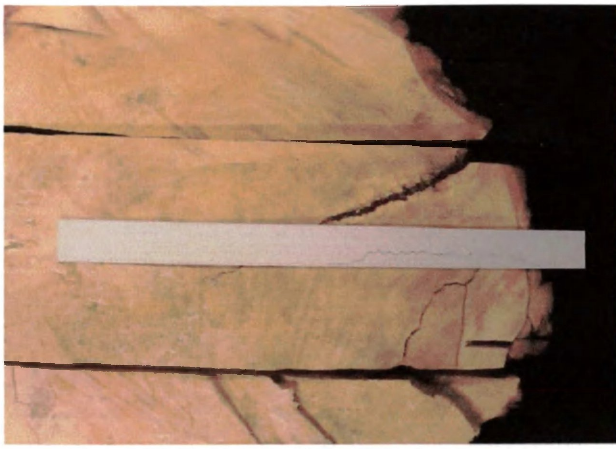

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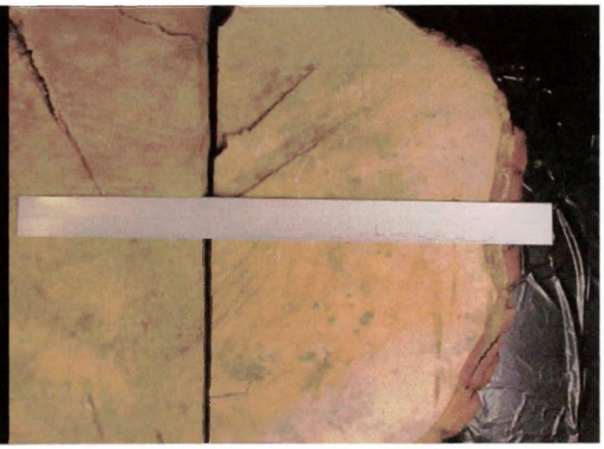

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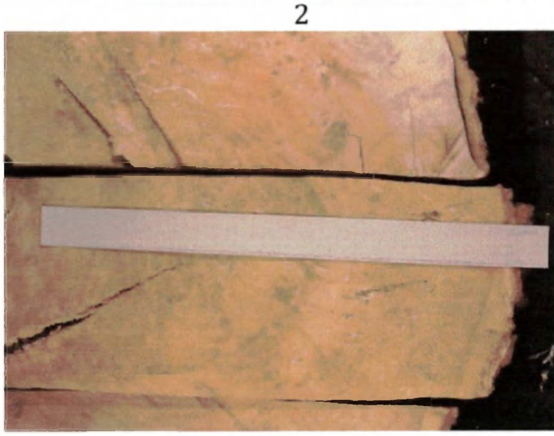

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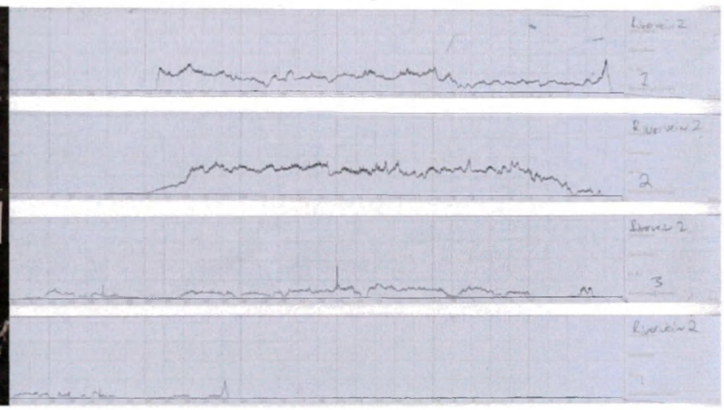
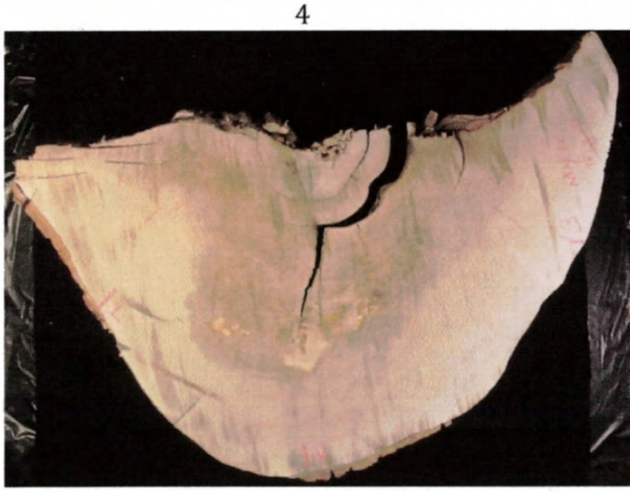
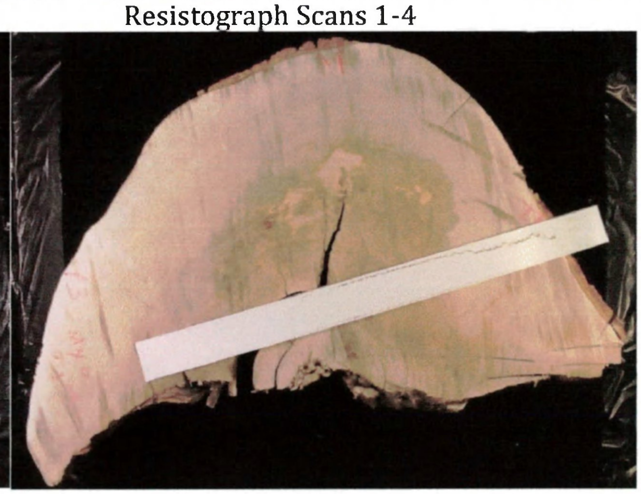


Resistograph Scans 1-4



Mnt. View Cemetery 2



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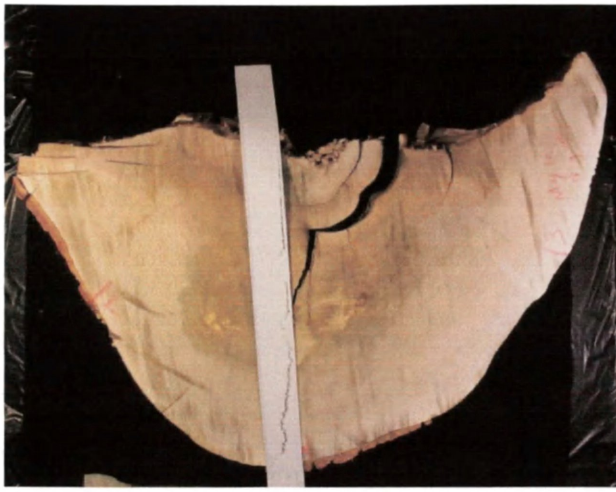

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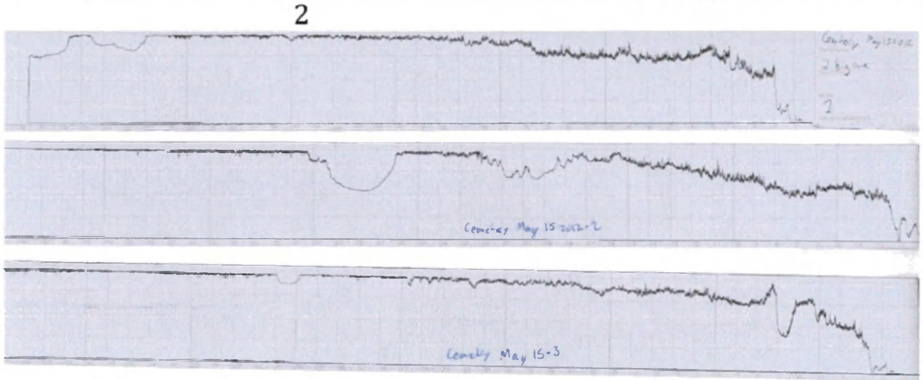

Resistograph Scans 1-3

104 Keystone Ct

1

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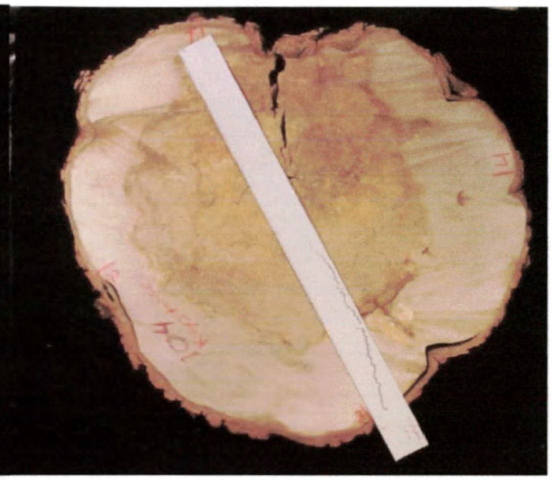

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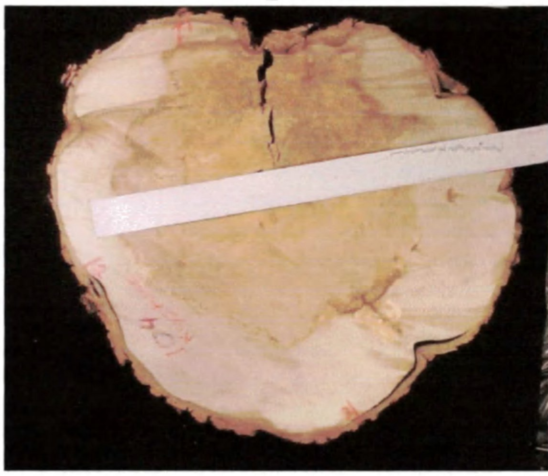

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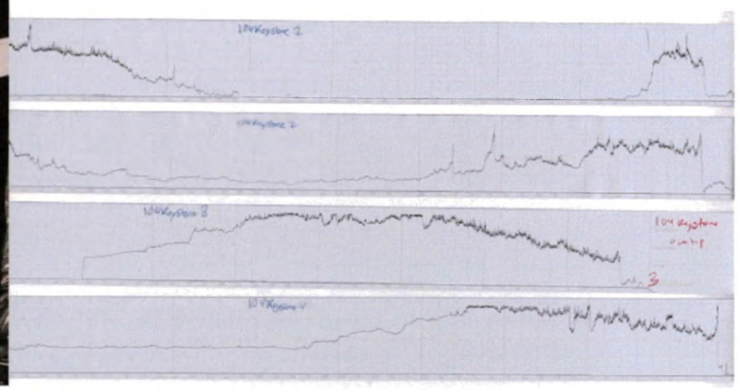
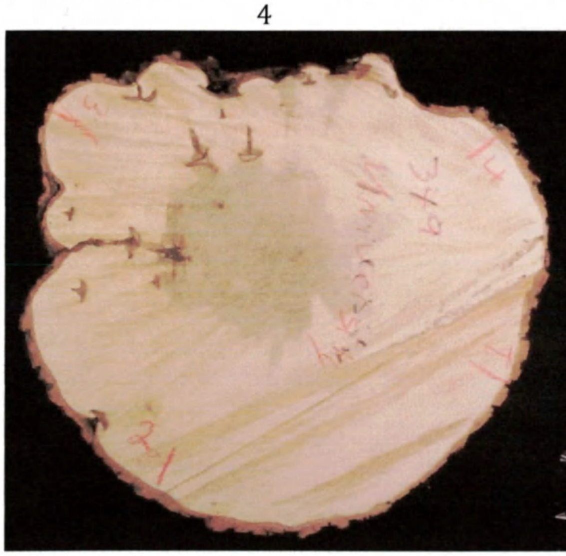
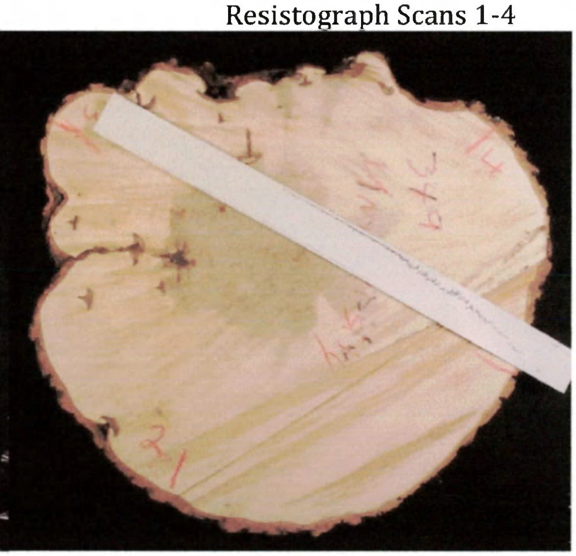


Resistograph Scans 1-4



349 University Dr



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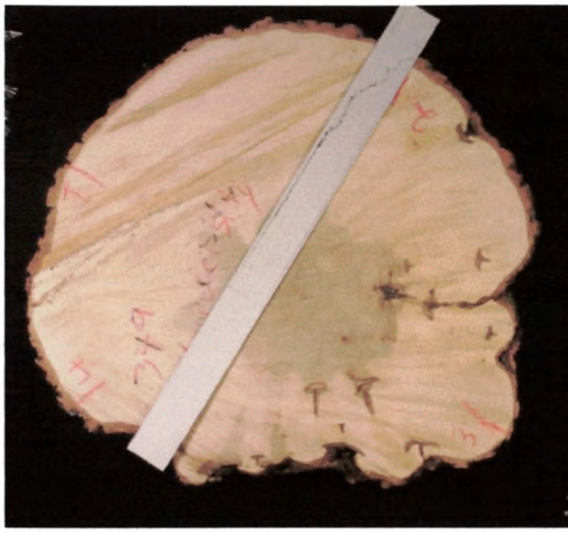

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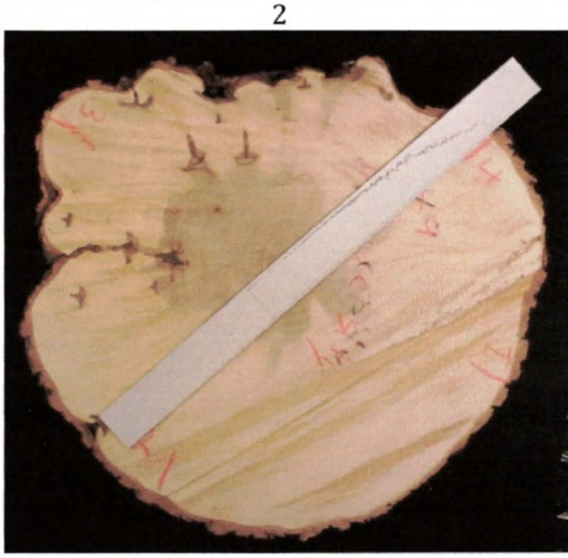

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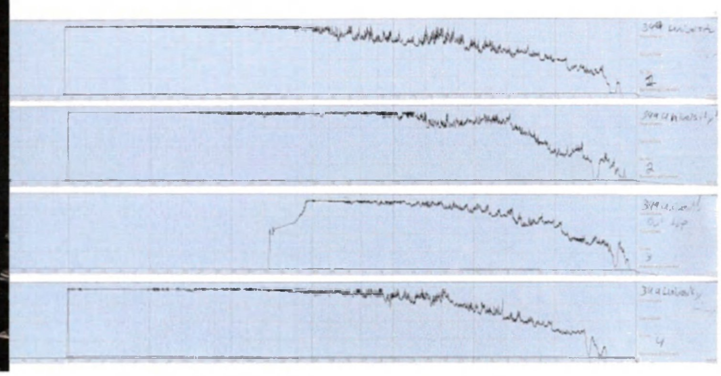
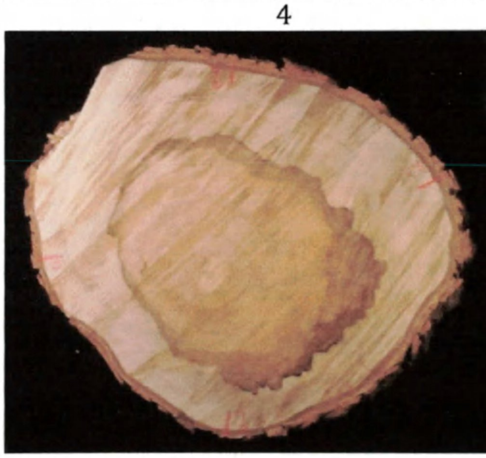
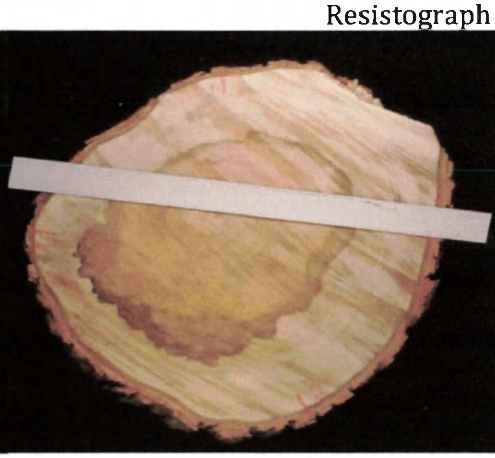


Resistograph Scans 1-4



607 Avondale Pl



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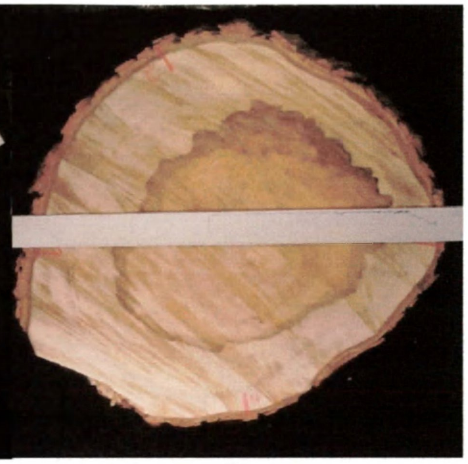

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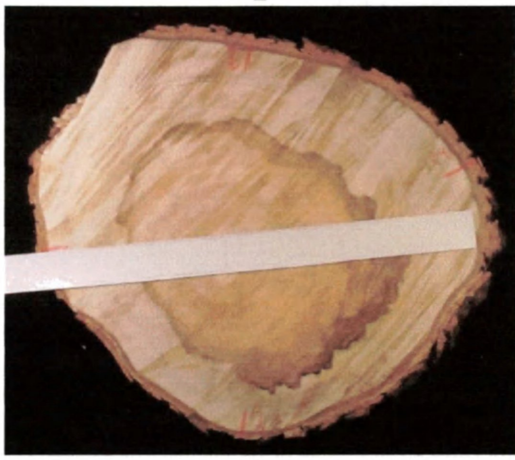

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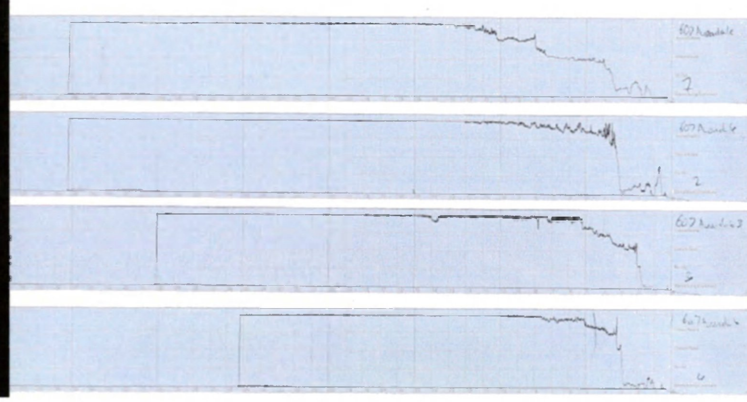
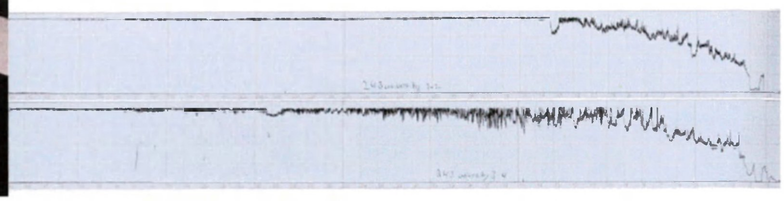


Resistograph Scans 1-4

243 University Dr

1-2

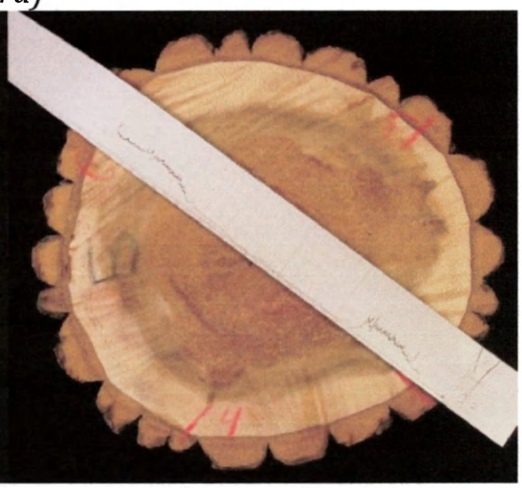
3-4



Resistograph Scans 1-4

Balsam Poplar (*Populus balsamifera*)

Birch Point Tree-10



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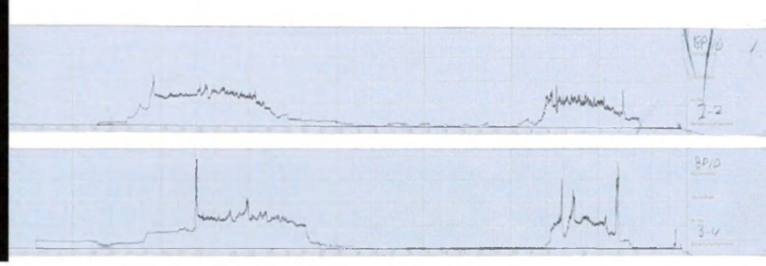
3-4

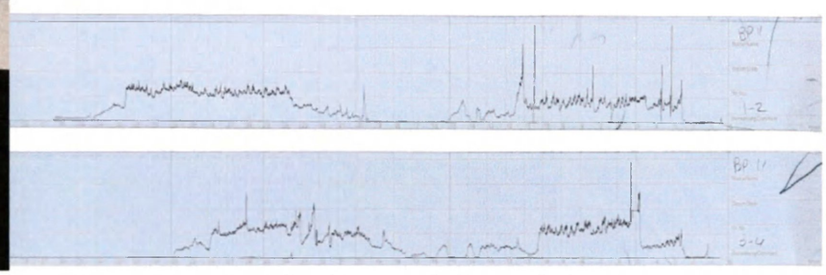


Resistograph Scan 1-4

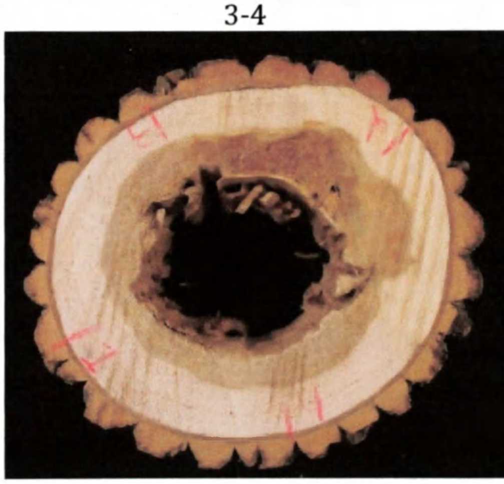
Birch Point Tree-11

1-2

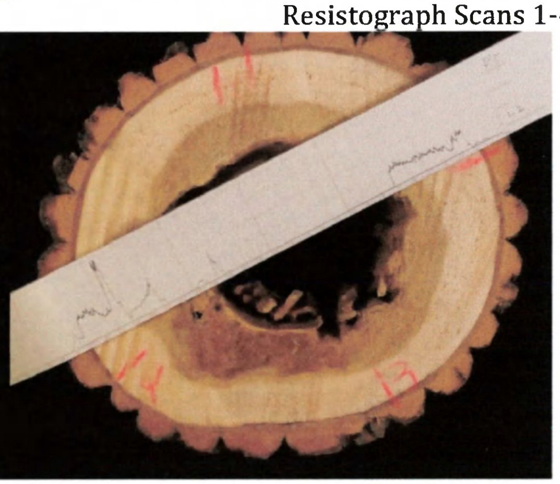
3-4



Resistograph Scans 1-4



Birch Point Tree-8



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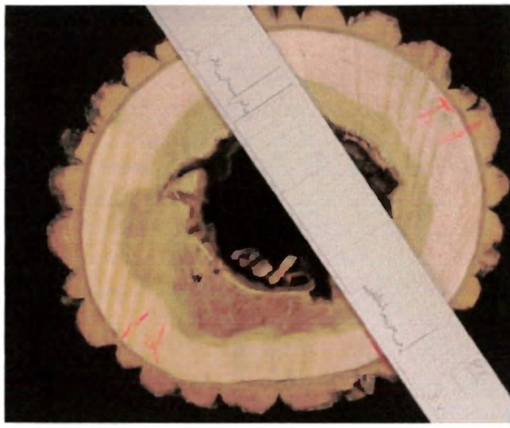

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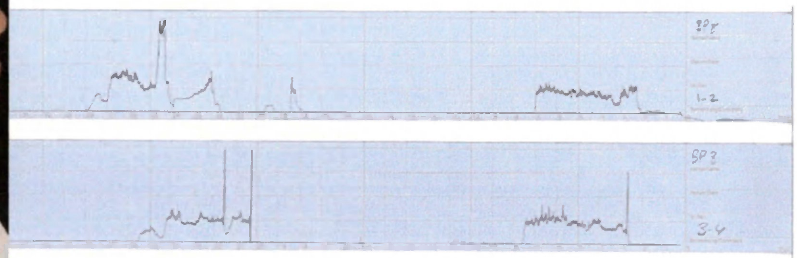
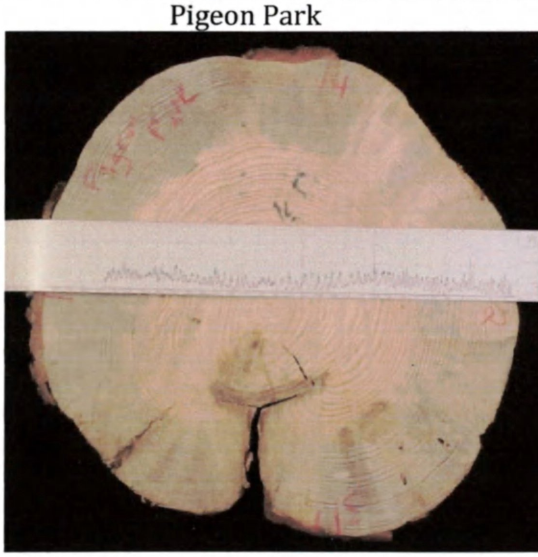


Resistograph Scans 1-4

Jack Pine (*Pinus banksiana)*

Pigeon Park

1



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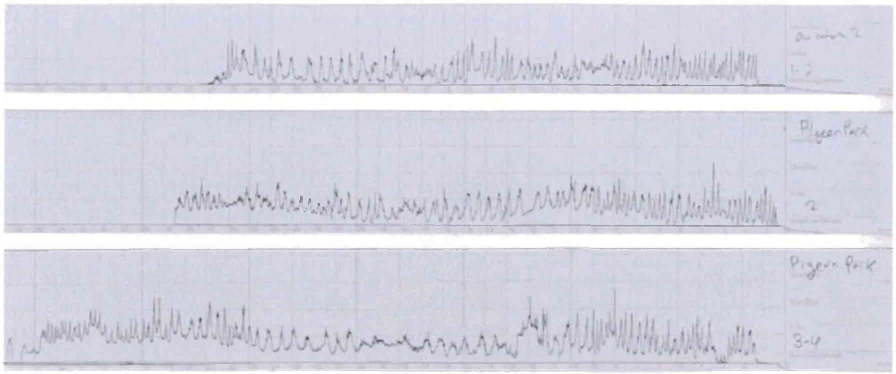
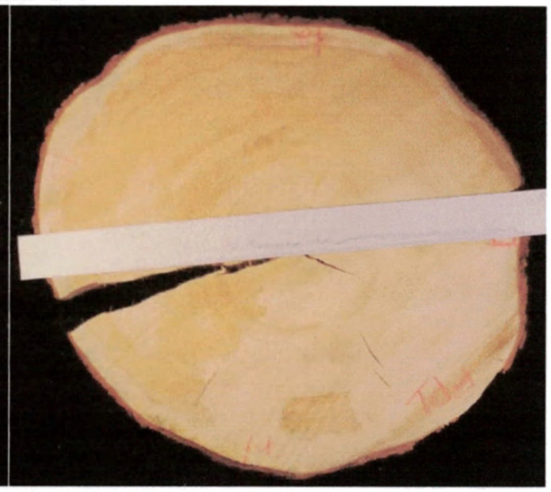


Resistograph Scans 1-4

Birch Point Tree-1



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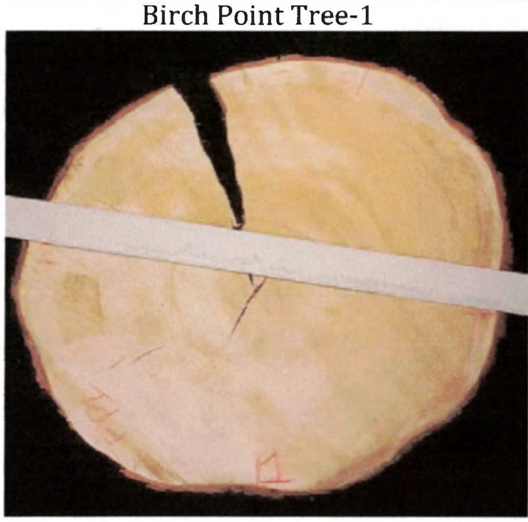

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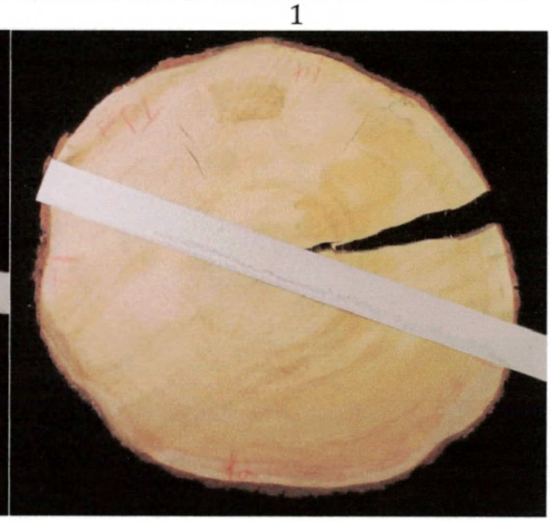

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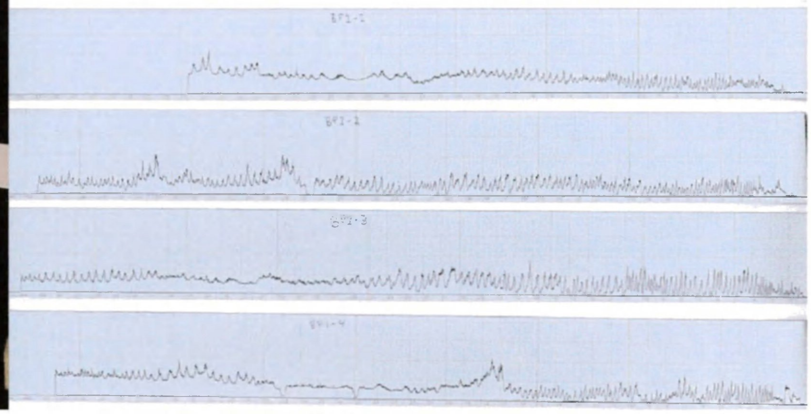
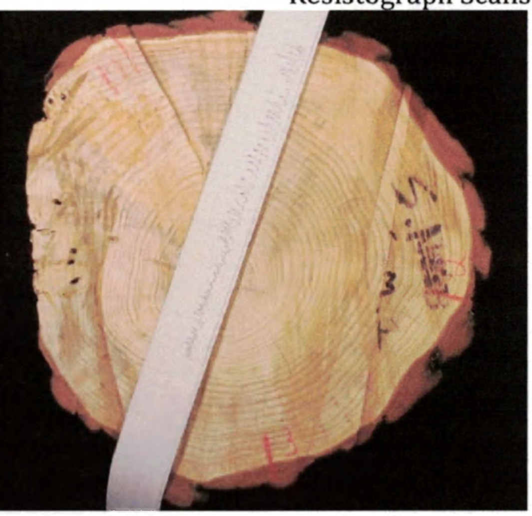


Resistograph Scans 1-4

South Neebing Community Centre-1



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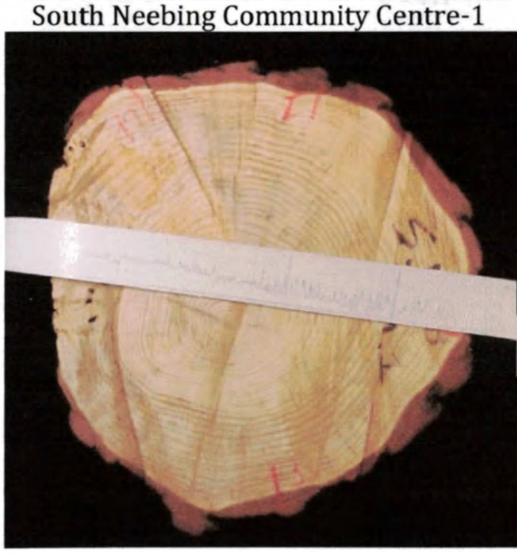

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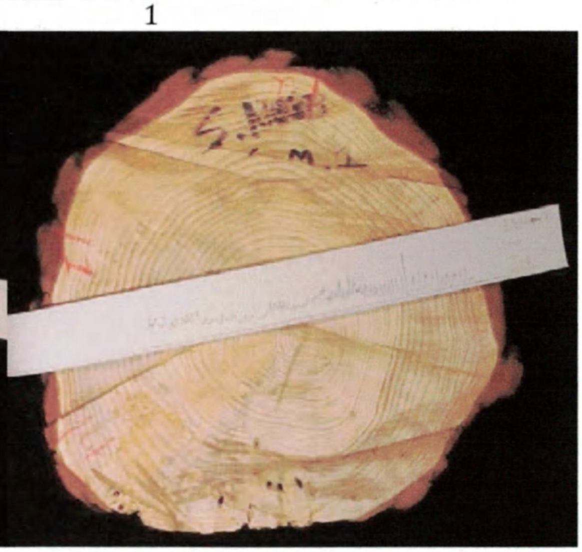

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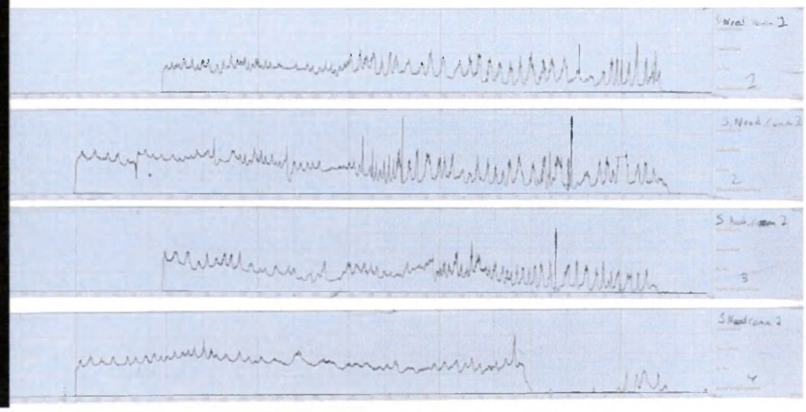

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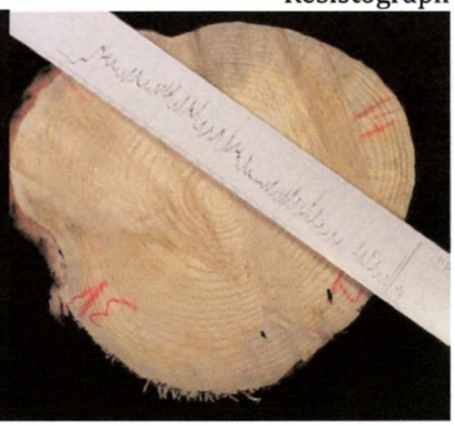
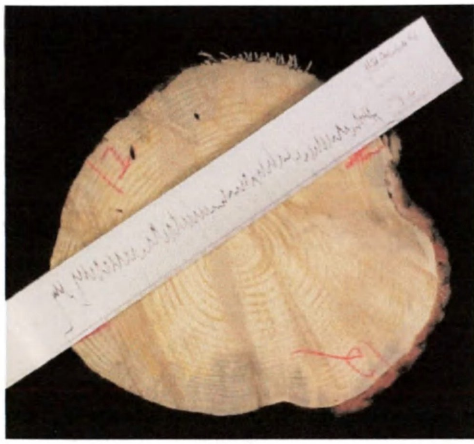
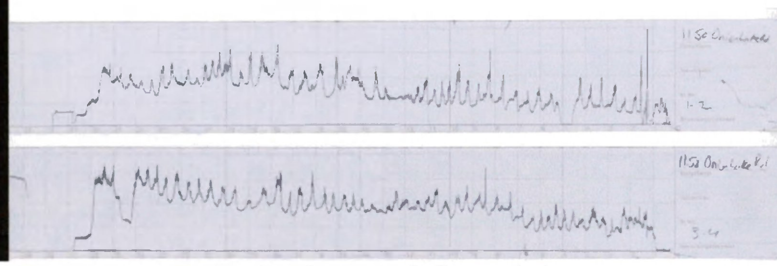
Resistograph Scans 1-4



1150 Onionlake Rd

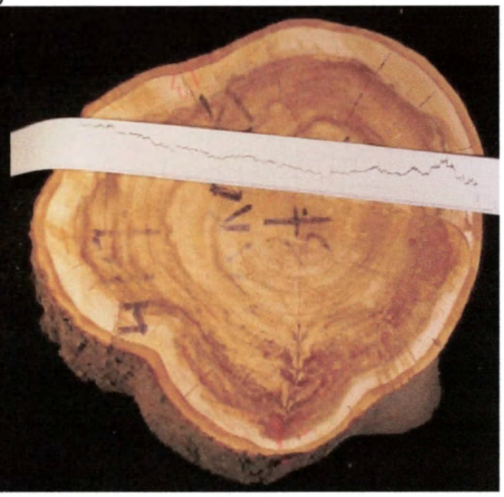
1-2



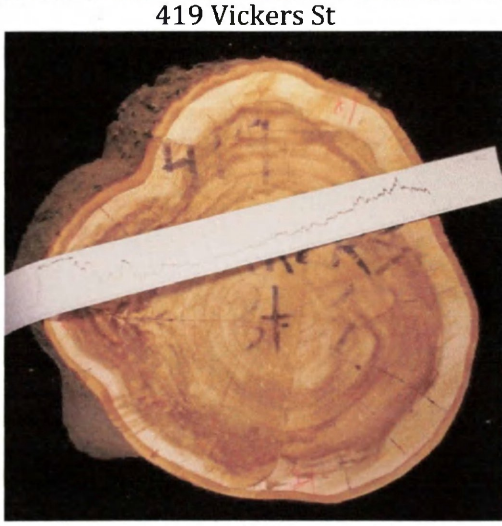


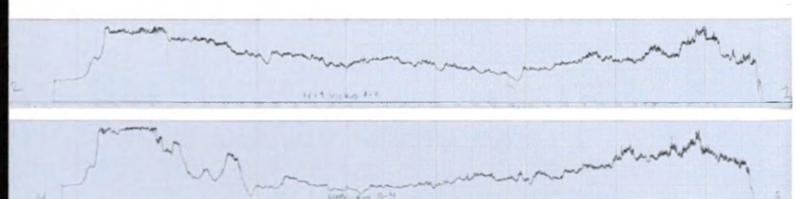
3-4 Resistograph Scans 1-4

Chokecherry (*Prunus virginiana*)

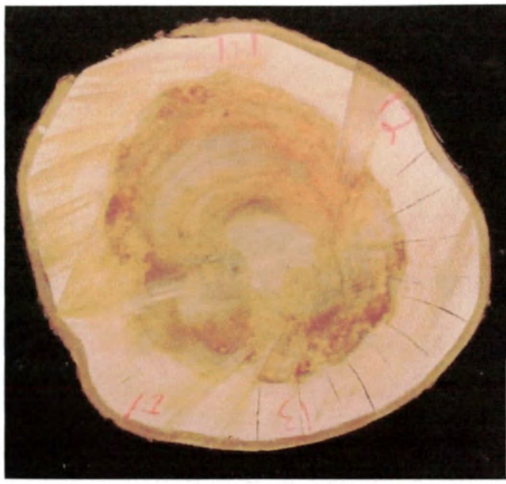


419 Vickers St 1-2

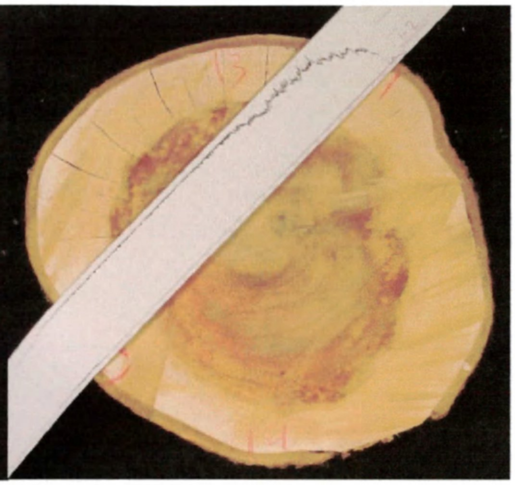




3-4 Resistograph Scans 1-4



253 May St W



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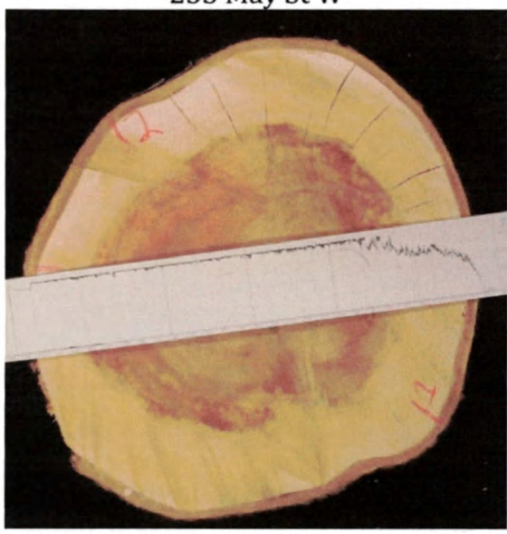

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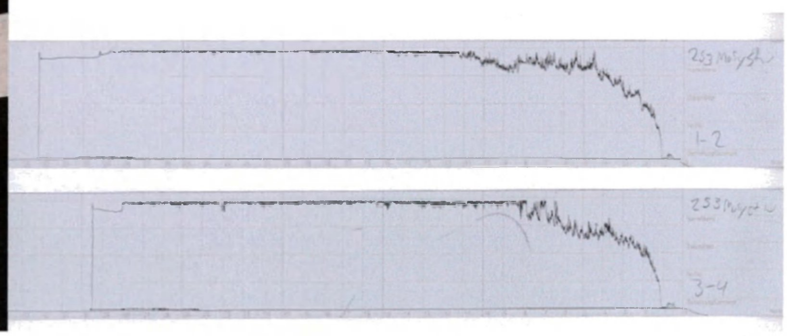
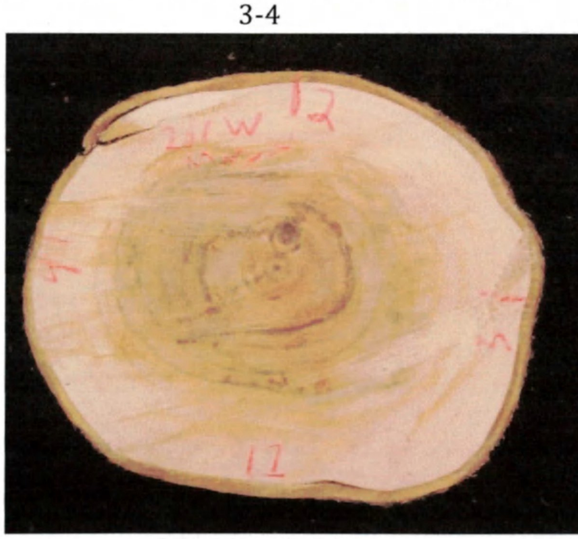
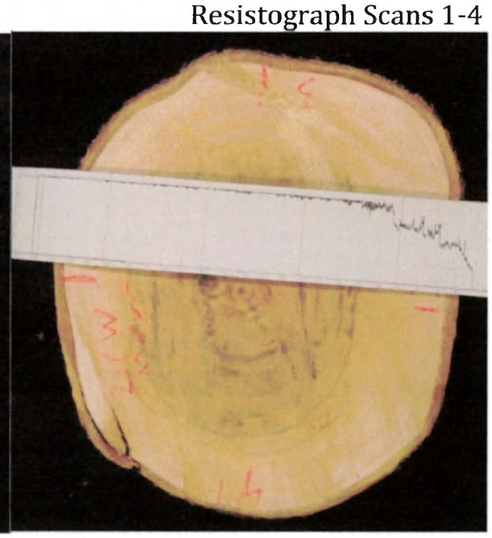


Resistograph Scans 1-4



261 Mary St W



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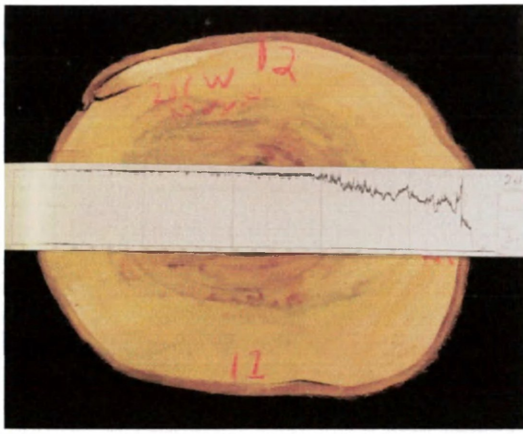

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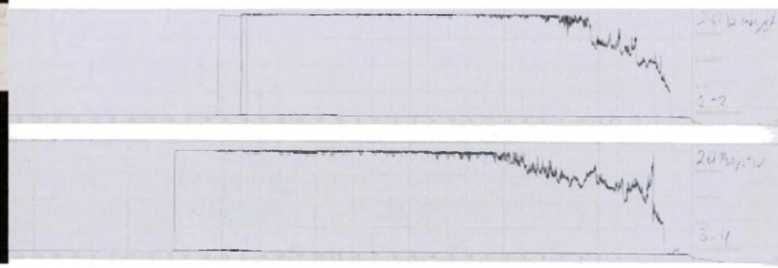
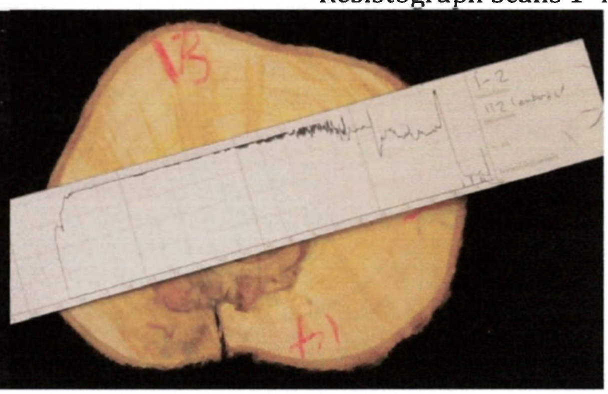


Resistograph Scans 1-4

112 Lombard Ct



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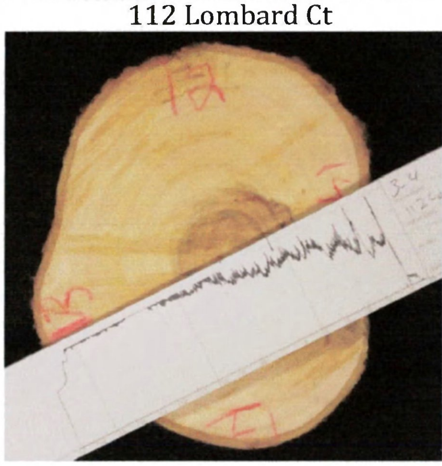

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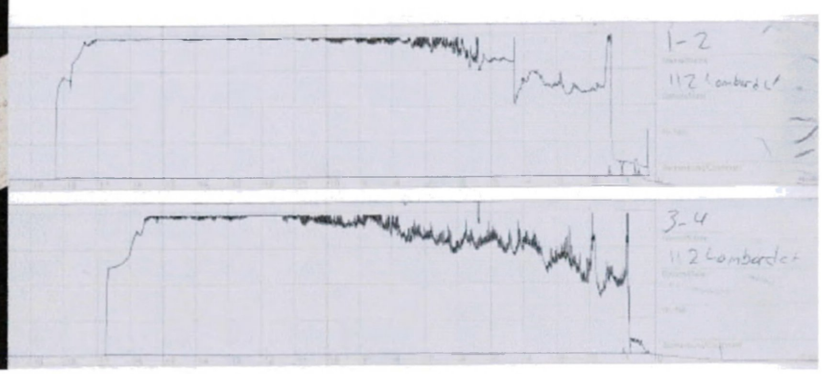
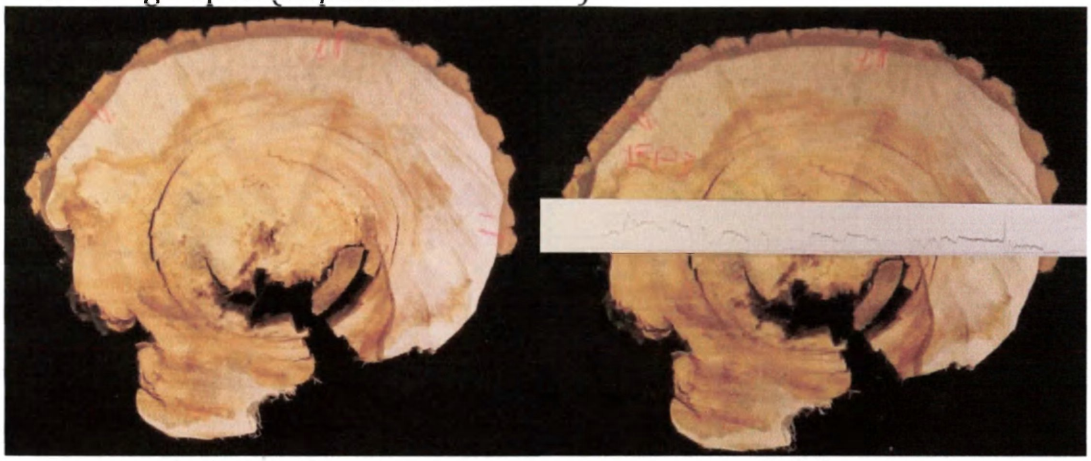


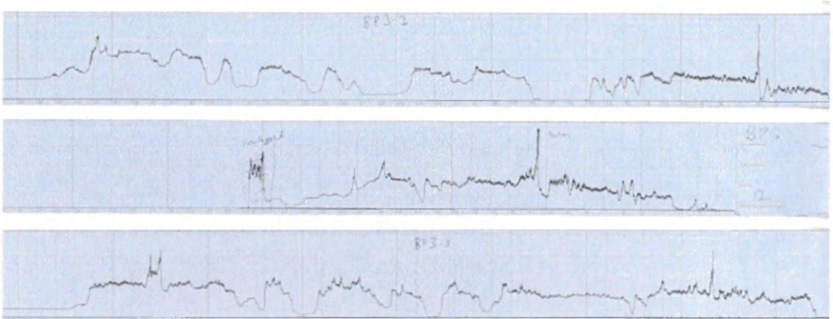
Resistograph Scans 1-4

Trembling Aspen (*Populus tremuloides*)



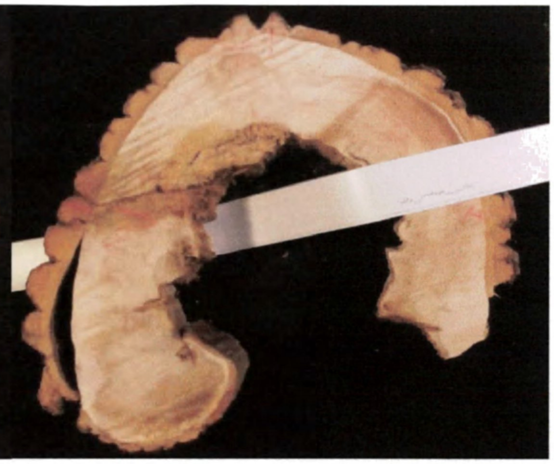
Birch Point Tree-3 1-2

2 3



Resistograph Scans 1-3

Birch Point Tree-5



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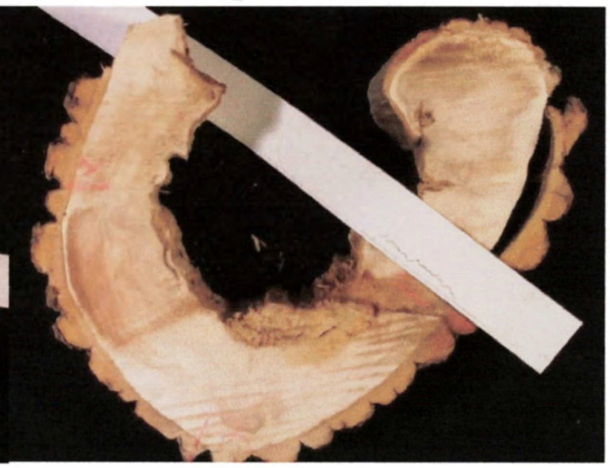

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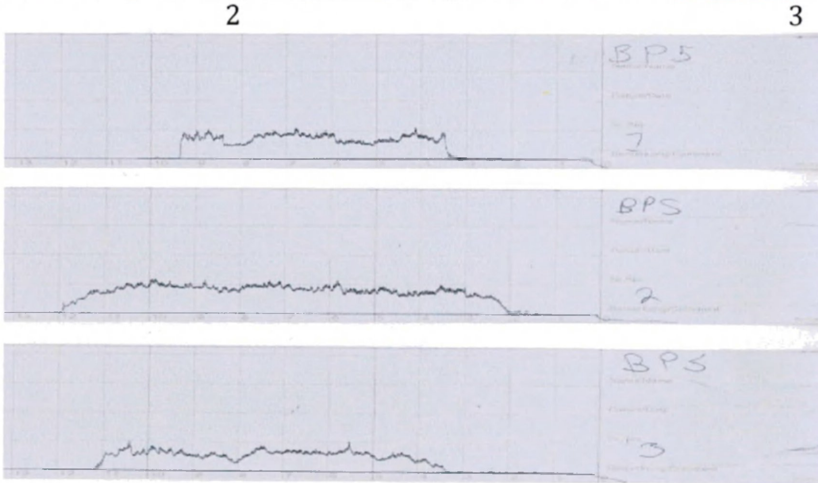
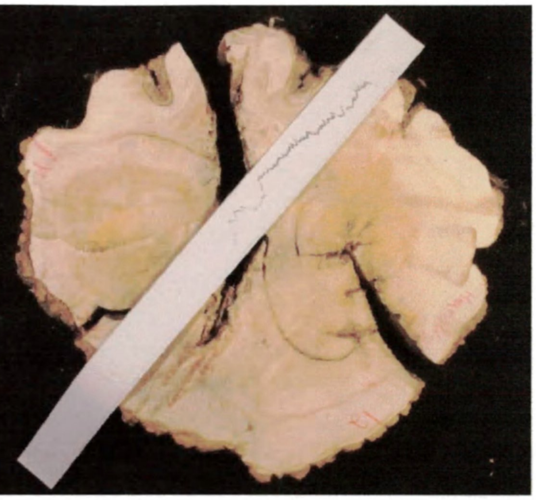


Resistograph Scans 1-3

Harold St



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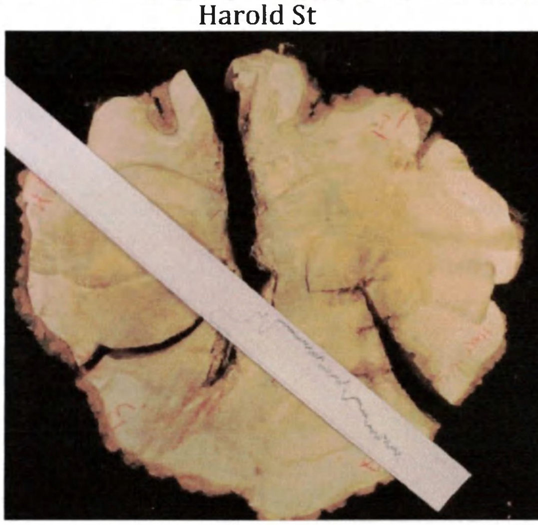

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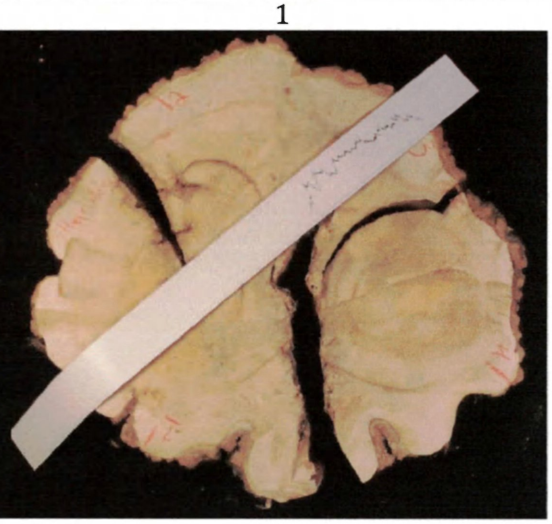

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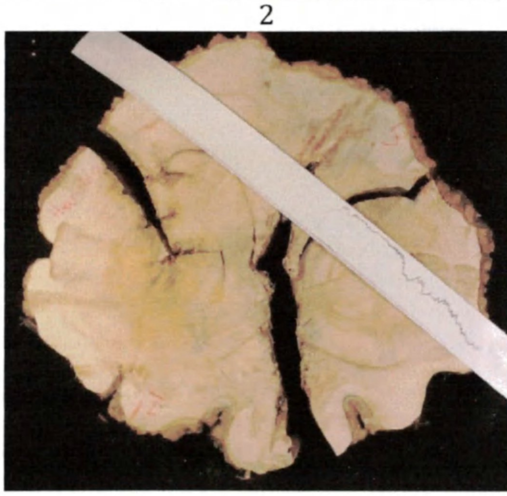

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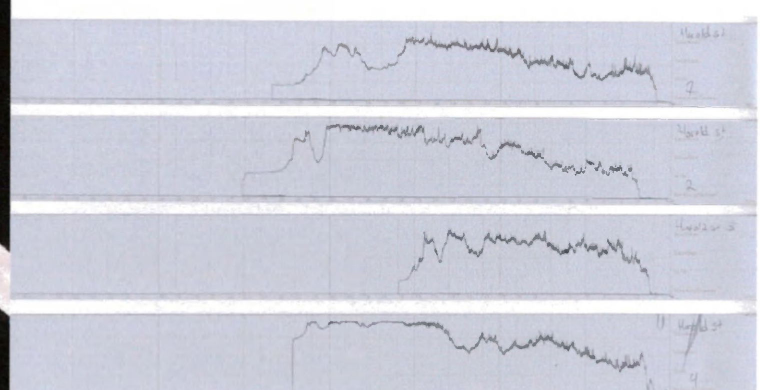
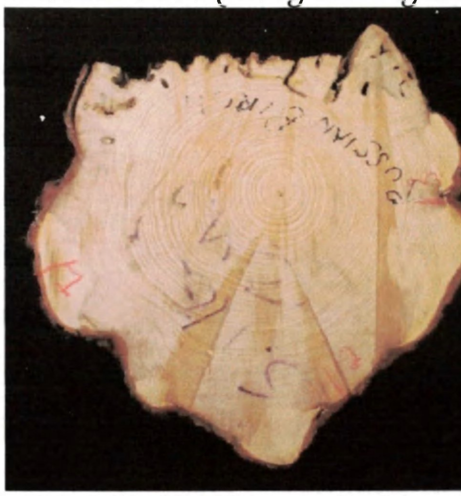
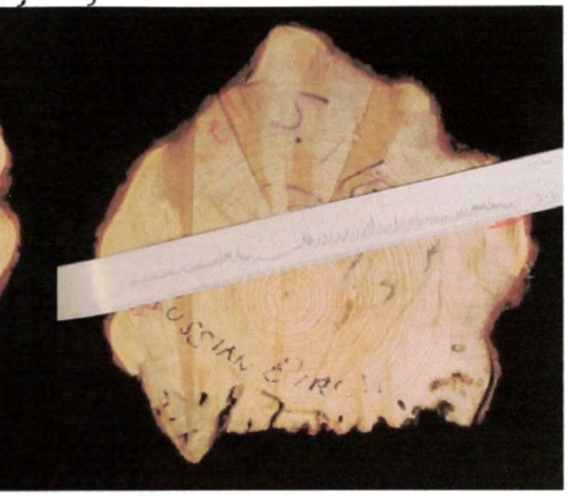
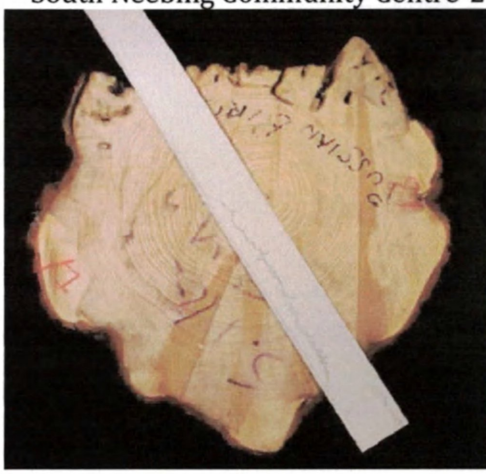
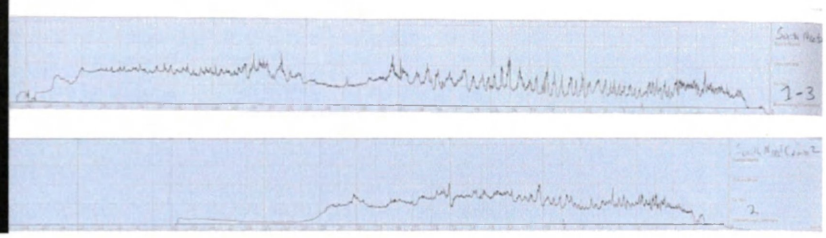


Resistograph Scans 1-4

Russian Olive (*Elaegnus angustifolia*)

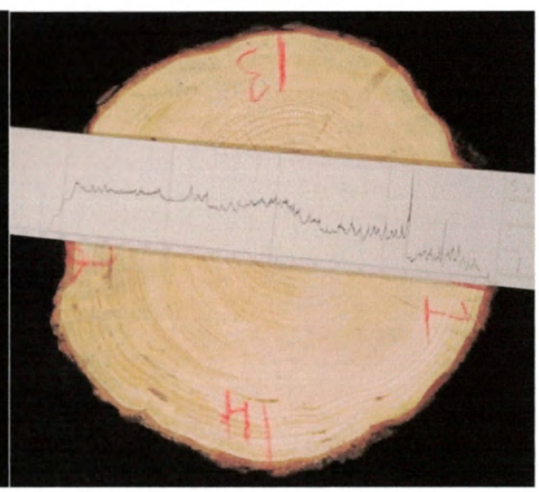



South Neebing Community Centre-2 1-3

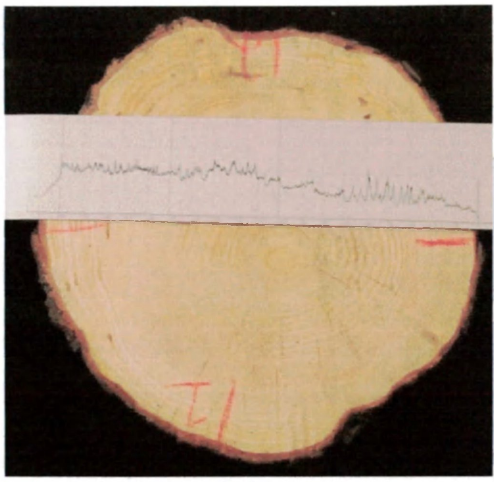



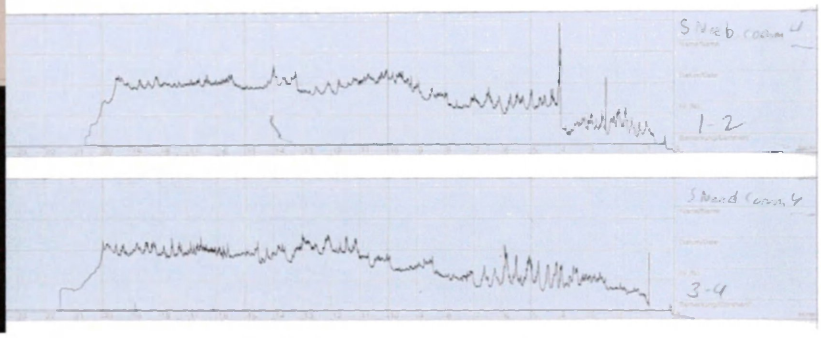
2 Resistograph Scans 1-3

Black Spruce (*Picea mariana*)

South Neebing Community Centre-4 1-2

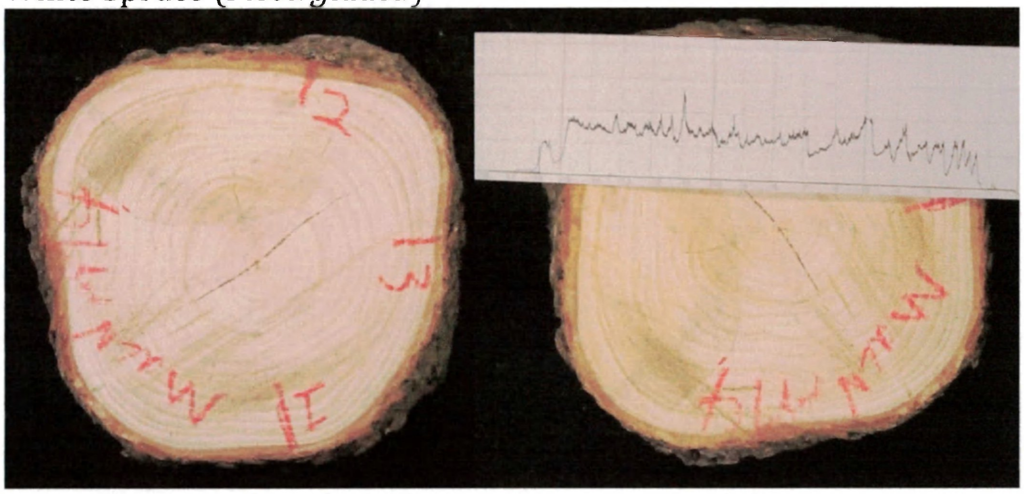




3-4

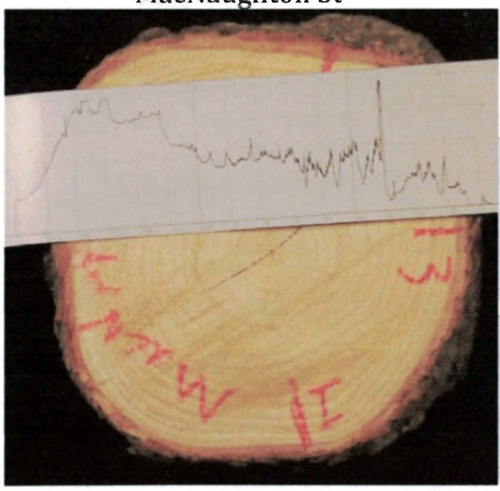
Resistograph Scans 1-4

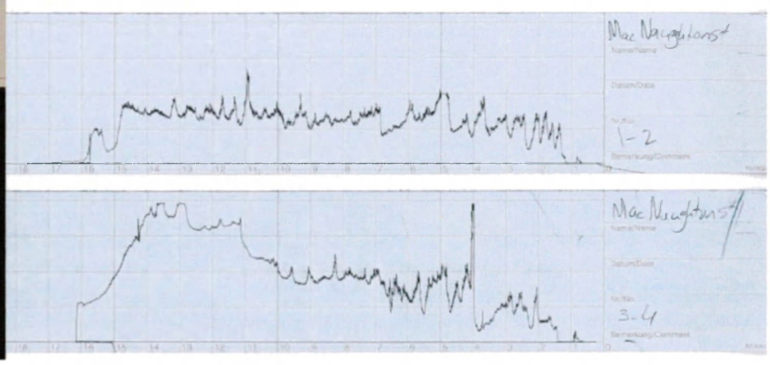
White Spruce (*Picea glauca*)



MacNaughton St

1-2

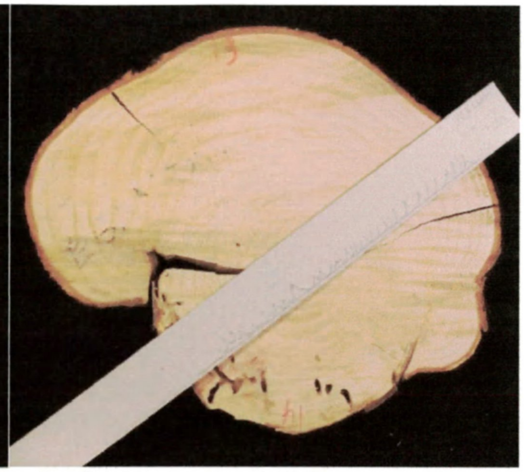




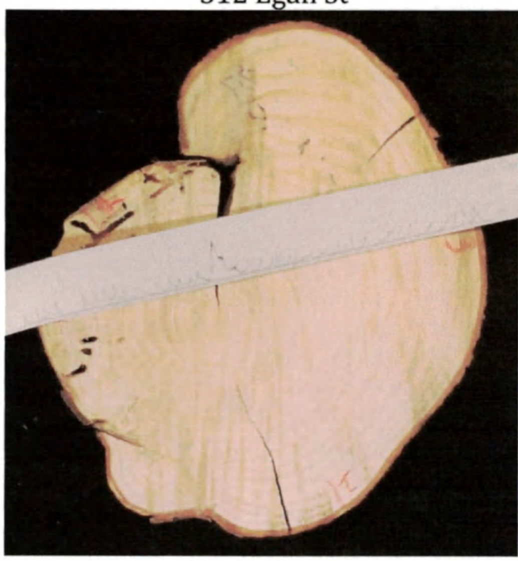
3-4

Resistograph Scans 1-4

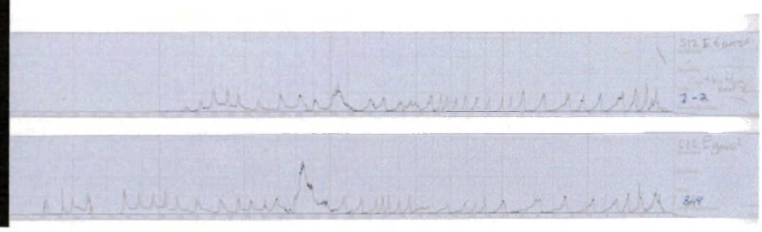
512 Egan St



1-2



3-4



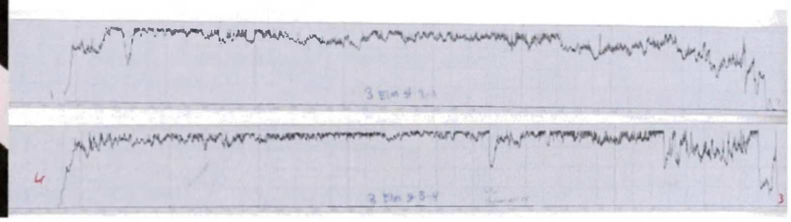
Resistograph Scans 1-4

American Elm (*Ulmus americana)*

119 Elm St

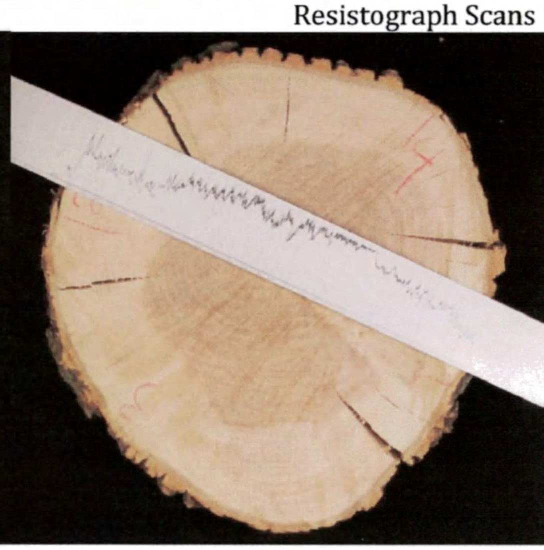
1-2

3-4



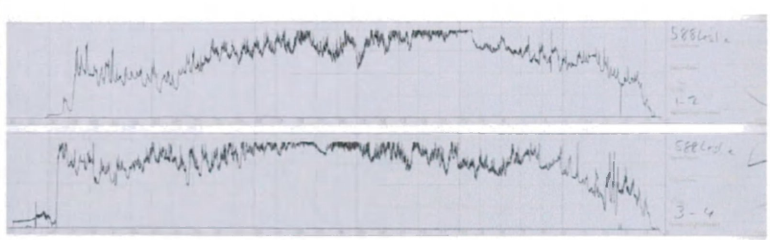
Resistograph Scans 1-4

588 Leslie Ave



1-2

3-4



Resistograph Scans 1-4