EXAMINATION OF SPECIES OF WOOD DECAY FUNGI PRESENT ON HAZARD STREET TREES IN THUNDER BAY, ONTARIO

By

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Major Advisor

Second Reader

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ABSTRACT

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Keywords: butt rot, generalist, hazard tree, heart rot, host specificity, opportunistic pathogen, sap rot, urban forest, wood decay

Urban forests are an integral component in modern day urban infrastructure. Forests systematically planted in unnatural growing conditions are predisposed to injury, deficiency and disease, therefore requiring regular maintenance. Species of wood decaying fungi are the most significant threat to the structural integrity of urban trees. These organisms are capable of colonizing suitable host trees, most commonly through wounds on the stem, branches or roots of trees in distress. Once established, wood decaying fungi can enzymatically break down wood components into easily digestible compounds. Overtime, infected trees can become structurally weakened and hazardous, resulting in branch breakage and stem failure. In this study, urban street trees were examined in Thunder Bay, Ontario for the presence of fungal fruiting bodies, with the purpose of identifying the hazard severity and host specificity among trees colonized by wood decaying fungi. The tree species, condition, location, size and species of decay fungi were recorded. A total of 102 infected trees were recorded, with 117 different occurrences of decay fungi. There were 19 different species of decay fungi identified and 12 different tree species infected. The three most commonly infected tree species included silver maple, white birch and Manitoba maple whereas the three most frequently occurring species of decay fungi were *Cerrena unicolor, Pholiota squarrosa* and *Pholiota aurivella*. The study found that the canopy cover of silver maple in Thunder Bay will likely decline significantly in the future as a result of an excess of overly mature trees susceptible to the opportunistic pathogen, *Cerrena unicolor*. Street trees only colonized by *Pholiota squarrosa* are less likely to become a hazard tree as opposed to trees infected with multiple species of decay fungi. Street trees found with fruiting bodies of *Chondrosterum purpureum* likely contain large portions of progressive sapwood decay and should be viewed as being a high-risk hazard.

CONTENTS

TABLES

FIGURES

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Leonard Hutchison for suggesting the topic and for providing valuable insight, guidance and editing for this thesis, as well as Shelley Vescio for kindly taking the role as a second reader. I thank the urban forestry class of 2017, which provided additional data and the Faculty of Natural Resources Management.

INTRODUCTION AND OBJECTIVE

It is compelling to realize that 80% of Canada`s population lives in 1% of the country`s total forest cover (Tree Canada 2008). This 1% represents millions of trees that make up the urban forest. With approximately 10% of the world`s forest cover, Canada is a forest nation from a global perspective (Tree Canada 2017). As the primary interface between urbanized and natural landscapes, urban forests influence people in their day-to-day life. Therefore, urban forests must be intensively managed in order to maintain this connection with the majority of the population (Miller 1988). Urban forests are under constant threat from biotic and abiotic factors. Disease accounts for approximately 40% of the total forest loss in Canada. Forest disease can be found most prevalent in forests growing in ecologically inappropriate areas. Urbanized forests are exclusively comprised of trees systematically planted in sites of adverse growing conditions. In turn, urban street trees have an increased susceptibility to injury, deficiency and stress. Therefore, the urban forest is predisposed to opportunistic disease.

Appropriate management and inspection of urban street trees has become standard practice in most municipalities to combat street tree disease (Pokorny 2003). One of the highest prevailing group of pathogens are wood decay fungi, which can cause structural instability in urban trees (Schwarze 2008, Glaeser 2016, Luley 2005). As a result, the tree can become hazardous to people and property from falling branches or topping over (Pokorny 2003). In addition, urban tree mortality can result in significant loss of the economic, environmental and social value trees hold for a community on the urban landscape (Miller 1988). This thesis will examine species of wood decay fungi found on street trees in the municipality of Thunder Bay, Ontario. Collected data include species identification of the wood decay fungi found, along with the corresponding host tree species, size condition and location. The objective of this thesis is to determine fungal host selection patterns, focusing on host specificity and the hazard severity of different species of wood decaying fungi. It is hypothesized that wood decaying fungi infecting living urban trees are generalists in behavior, attacking a wide range of host species, specifically targeting overly mature trees with mechanical injury. In addition, the hazard severity among street trees is equally dependent on host health and the causal agent.

LITERATURE REVIEW

Under appropriate growing conditions and successful urban forest management, urban streets can maintain high frequencies of mature trees in comparison with naturally growing trees in an unmanaged forest (Miller 1988). As urban trees age, their susceptibility to pathogenic activity increases, becoming stressed and naturally weak. In addition, urban trees often become highly stressed throughout their life due to the urban landscape`s insufficient growing characteristics. Therefore, streets lined with large and mature urban trees can become an epicentre of hazardous trees in the future, caused by various wood decaying fungi (Pokorny 2003, Schwarze 2008, Luley 2005)

Fungi are structurally comprised of vegetative filamentous growths known as hyphae. Hyphae are tube-like structures exhibiting polarized growth and, when collected together, form mycelium (Peberdy 1980). Wood decay, caused by pathogenic fungi is the main causal agent of urban tree risk (Fink and Schwarze 2008, Schwarze 2008). Wood decaying fungi produce hyphae, which mechanically penetrate into the cell walls of wood. Hyphae can secrete enzymes to chemically break down the cell wall structure into components that can be easily digested by fungal hyphae (Karim *et al*. 2016). The majority of wood decay fungi are saprophytic in nature, only 5% of all known species will attack and decay living host trees. Furthermore, most decay fungi are strictly confined to infect and decompose the heartwood of a tree.

The heartwood of a tree provides the greatest structural stability and is located in the centre as a pillar of highly rigid and strong wood. Heartwood is composed of inner xylem cells that are continually pushed into the centre core of the tree as new rings of sapwood develop (Smith 2018). These xylem cells incorporate themselves into the heartwood, becoming inactive and die as the tree continues to grow new rings of wood

(North Carolina Forestry Association 2018). Heartwood cells are, therefore, not living and unlike living cells, do not possess any active defence mechanism. Heartwood pores are very low in moisture as straw like cells that once transported water and nutrients when living, are now filled with organic material when dead (Smith 2018). These conditions are more suitable for fungal growth compared to the surrounding sapwood. Although heartwood cells are more susceptible to decay, injuries to the sapwood promote access for pathogenic infection to the heartwood. Even if decay occurs in the heartwood of a living tree, this does not automatically confirm the tree is hazardous.

A tree containing heartrot can still be considered structurally sound, provided that the living sapwood is not infected. Pokorny (2003) outlines the basic rules for diagnosing a hazard tree: the stem must have openings that exceed 30% of the stem circumference, openings are under 30% of the stem circumference but sound wood is less than 2cm for every 6cm of stem diameters and a stem possessing a solid exterior but sound wood is less than 1cm for every 6cm in stem diameter. Diagnostic tests can be aided with the use of a shigometer or resistograph to calculate the amount of sound wood in a stem.

Sapwood is composed of living xylem cells that have been recently produced and formed into outer ring layers of wood. The main function of sapwood cells is to transport, store and conduct water and nutrients through the vascular system of the tree. All xylem cells are living and thus contain high moisture content that is unsuitable for fungal hyphae growth (Bamber 1987). Unlike heartwood, sapwood posses an important active defence mechanism known as compartmentalization of decay in trees (CODIT).

Compartmentalization of decay in trees refers to a very important wound reaction process first observed and described by Dr. Alex Shigo, a plant pathologist with the

United States Forest Service (Shigo 1984). Trees, particularly in an urban setting are prone to wounds and damages from a variety of sources such as storms, animals and people. Compartmentalization or CODIT is an active defence mechanism in trees that create boundaries (walls) by altering cell structure to compartmentalize the wounded area, slowing or eliminating disease from spreading into the rest of the tree (Shortle & Dudzik 2012). There are four boundaries that take place in the CODIT process, each differing in function and structure. Each wall is numbered; increasing in its strength to retard the movement of decay organisms, wall 4 representing the strongest resistance to the spread of decay (Shigo 1984, Shigo & Marx 1977). The first wall consists of xylem cells that immediately begin to close pits and plug the conducting elements. Xylem run longitudinally within the tree, limiting the vertical extension of decay above and below the entrance of decay (injury). The more rapid a tree can plug elements, the shorter the compartment will form. The second wall is provided by the tree`s growth rings, continuous around the entire tree. Invading organisms are hindered by the transition between growth rings. Organisms like decay fungi progress slowly travelling laterally through the tree as compared to longitudinally up or down the stem. Wall 3 is the strongest wall present at the time of injury, as wall 4 forms as a response to an injury that has occurred. This wall is made of ray cells that run vertically like xylem but are discontinuous in elongate sheets, transporting saps (Shigo & Marx 1977). Ray cells are high in starch, which can impede the spread of foreign organisms. The fourth wall forms as a reaction zone from the cambium, extending longitudinally and tangentially around the tree just above the outer most growth ring. The zone will encompass the injury and become localized depending on the injury`s size and severity. After this zone forms, it will remain within the tree, compartmentalizing the invading organism from spreading outside the protection zone. However, any stored starches or sugars remaining inside the compartmentalized area will be unavailable to the tree, as they cannot pass through the fourth wall (Gilman 2015). In addition, the compartmentalized area can be prone to ring and radial cracks which can form from callused tissue around wounds. Cracking, like decay fungi, can significantly weaken the integral structure of a tree and can cause breakage (Pokorny 2003). Compartmentalization is an essential process for a tree`s survival. Yet, some species are much weaker compartmentalizers than others. For instance, *Acer saccharinum* is a poor compartmentalizer whereas *Acer saccharum* is relatively strong in developing a zone of protection. Other species such as *Salix*, *Betula*, *Prunus*, *Malus* and *Celtis* are also fairly poor at compartmentalizing injuries (Gilman 2015).

Decay rarely occurs in the sapwood of a living host tree due to its physiological function. However, some exceptions do exist among species of wood decay fungi, which can specialize in degrading the sapwood of a host. Species such as *Cerrena unicolor, Chondrostereum purpreum* (Pers.) Pouzar and *Schizophyllum commune* Fr. are able to degrade the sapwood of a host tree. The presence of sap rot indicates that a portion of the bark and cambium are dead, where decay can progress rapidly into the host stem. Therefore, hosts colonized by fungi that cause sap rot should have an elevated hazard severity (Luley and Kane 2009).

Decay fungi have three general colonization strategies to infect a tree: airborne spores infecting through a broken branch stub or wound in a branch or stem, migratory mycelium in the soil infecting through roots, and wood boring insects vectoring spores into trees. Most opportunistic species rely on the production of spores either through sexual or asexual production. Spores are released from fruiting bodies into the air, becoming widely dispersed and establishing themselves on newly exposed woody substrates. The most common infection sites for stem fungi are injuries to a host tree`s branches within the crown (Schwarze *et al.* 2000). Mechanical injuries in the urban landscape, such as pruning operations or injuries are commonplace for fungal colonization and eventual fruiting body development. Less commonly, fungi can colonize hosts through migratory mycelium in the soil. This can occur when mycelia come in contact with the root structure of host trees. Infection from tree roots causes butt rot at the base of the stem (Dix & Webster 1995). In urban environments, trees planted in close proximity can expedite fungal colonization by migratory mycelium. The root structures of individual hosts can be grafted together, facilitating root contact and infection. Furthermore, roots of urban trees are frequently exposed and damaged by external actions, promoting root and butt rot. The least common colonization strategy observed is through the vectoring by insects. Decay fungi are vectored by members of the genus *Sirex*, commonly referred to as the wood wasps. Wood wasps lay eggs into tree bark, which can inadvertently deposit asexual spores that have been transported from a previous infected host. Wood decaying pathogens such as *Stereum* and *Amylostereum* have frequently demonstrated this strategy (Schwarze *et al.* 2000). Fungal hyphae provides suitable conditions for wood wasp incubation and a source of food for larvae. Therefore a symbiotic relationship between the fungus and insect is highly possible.

Depending upon the structure of wood that is decayed, wood rot can be classified into three groups, brown rot, white rot and soft rot (Schwarze *et al.* 2000). Brown rot is a common type of rot typically found on coniferous tree species. This rot type strictly decays cellulose and hemicellulose in the cells, leaving lignin intact. This type of rot produces a cracked, dried appearance on the decayed wood. Approximately 6% of all decay fungi (Dix and Webster 1995, Goodell *et al.* 2008) cause brown rot. This type of rot is caused by members of the Basidiomycota, such as species of *Daedalea*, *Gloeophyllum, Fomitopsis* and *Laetiporus.*

Unlike brown rot, white rot can be more severe because it has the ability to enzymatically degrade cellulose, hemicellulose and lignin in the wood of a host tree (Dix and Webster 1995), causing a spongy and stringy bleached decay that is moist to the touch. White rotting fungi represent 94% of all decay fungi, attacking mostly hardwoods but some softwood trees (Goodell *et al.* 2008). Most members belong to the Basidiomycota, however, some Ascomycota can cause white rot as well. Common white rotting fungi include *Ganoderma*, *Pholiota*, and *Trametes*.

Species of soft rot fungi are more selective in host decay, preferring wood with distinctively higher moisture content (Worrall *et al.* 1991). Soft rot wood degradation is less understood, although species that cause this type of decay produce enzymes similar to that produced by brown and white rotting fungal groups (Goodell *et al*. 2008). Degradation of the wood only occurs within a confined area because degradation enzymes diffuse not far from the hyphae. Therefore, cavities and pits form, making soft rot less easily identifiable. Soft rotting fungi belong to the Ascomycota, with notable fungi such as *Chaetomium* and *Cladosporium*, being involved (Worrall et al. 1991).

The extent and severity of tree decay varies greatly among different decay fungi and their host species. Therefore, it is crucial to examine different species of fungi that thrive in urban communities and the severity of damage they cause to an attributed tree host (Luley 2005). A study by Terho *et al.* (2007) examined decay fungi occurrence on 194 living trees in the city of Helsinki, Finland. Results suggested that the most frequent species of decay fungi that caused extensive stem decay were *Cerrena unicolor* and *Inonotus obliquus* (Ach. Ex Pers.) Pilat on *Betula* species as well as *Ganoderma applanatum* (Pers.) Pilat and *Phellinus igniarius* (L.) Quel. on *Acer* and *Tilia* tree species (Terho *et al*. 2007). Despite a total of thirteen species of decay fungi observed in the study, these four species mentioned were the most prevalent with regards to damage and predictability on the three common host genera.

MATERIALS AND METHODS

Species of decay fungi and their associated wood decaying properties on host street trees were studied in this examination. This study was carried out in the municipality of Thunder Bay. Collected data were strictly obtained from municipally-owned trees. Data were collected in the fall season, between the months of September and October of 2017. The method of data collection involved sampling areas of high street tree densities, examining trees that contained fruiting bodies of wood decaying fungi. Candidate trees were recorded by visual identification of decay fungus fruiting bodies. Once a candidate tree was found, data pertaining to the species of decay fungus, tree species, condition, location and size (dbh) were recorded. To supplement data, Chapter 4 of Kurtis Barker`s Masters' thesis (Barker 2014) was utilized, originally containing 101 trees that were positively identified as having a fruiting body of a decay fungus. These trees were reevaluated for the purpose of this study. Candidate trees were not considered viable data if the tree was removed. However, candidate trees that were lacking fruiting bodies but once identified in the past, were considered viable data. Trees that once had positive identification of fruiting bodies will still contain decayed wood regardless of fruiting body presence afterward.

In preparation for data collection, zip-lock bags were used to store any fungal species that required further research for identification. A small pocketknife was used to collect fungi. Specimens of fruiting bodies were removed from the tree in a way that would minimize any adverse effects to tree health. The knife was sanitized with rubbing alcohol after individual uses to avoid spreading infection. In the event that a fungal species could not be identified in the field, specimens were taken to Dr. Hutchison in the

Faculty of Natural Resources Management for confirmation. All data were recorded and organized with Microsoft`s excel spreadsheets.

RESULTS

In total, 102 trees were identified with the presence of fruiting bodies of wood decaying fungi, and of these, 62 trees were previously identified by Masters student Kurtis Barker in 2013. Previously identified trees recorded in his examination remain standing as of 2017. The remaining 40 trees were identified in collaboration with Dr. Hutchison and the Urban Forestry class of 2017 in the Faculty of Natural Resources Management at Lakehead University. All trees recorded were located within the City of Thunder Bay, growing on public property (Figure 1). Trees growing on private property were excluded from this examination. Of the 102 trees identified, 117 occurrences of wood decay fungi were found.

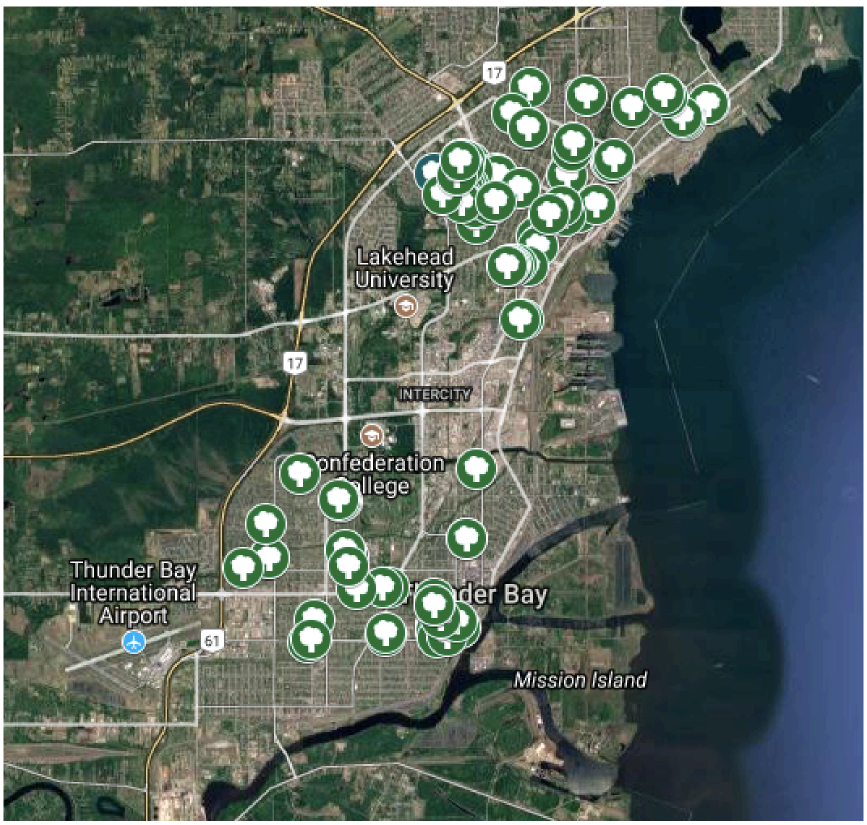

Figure 1. Location of 102 trees with fruiting bodies in the City of Thunder Bay

The locations of identified trees can be separated into two distinct regions – Thunder Bay North and Thunder Bay South. Both regions are highly populated and characterized by residential areas and suburban communities, containing a high density of urban street trees. Consequently, the majority of infected trees identified were found in these two regions. The Thunder Bay intercity, located between the North and South Wards is mainly commercial land, with fewer and less significant urban trees. Therefore, no street trees were examined in the intercity area.

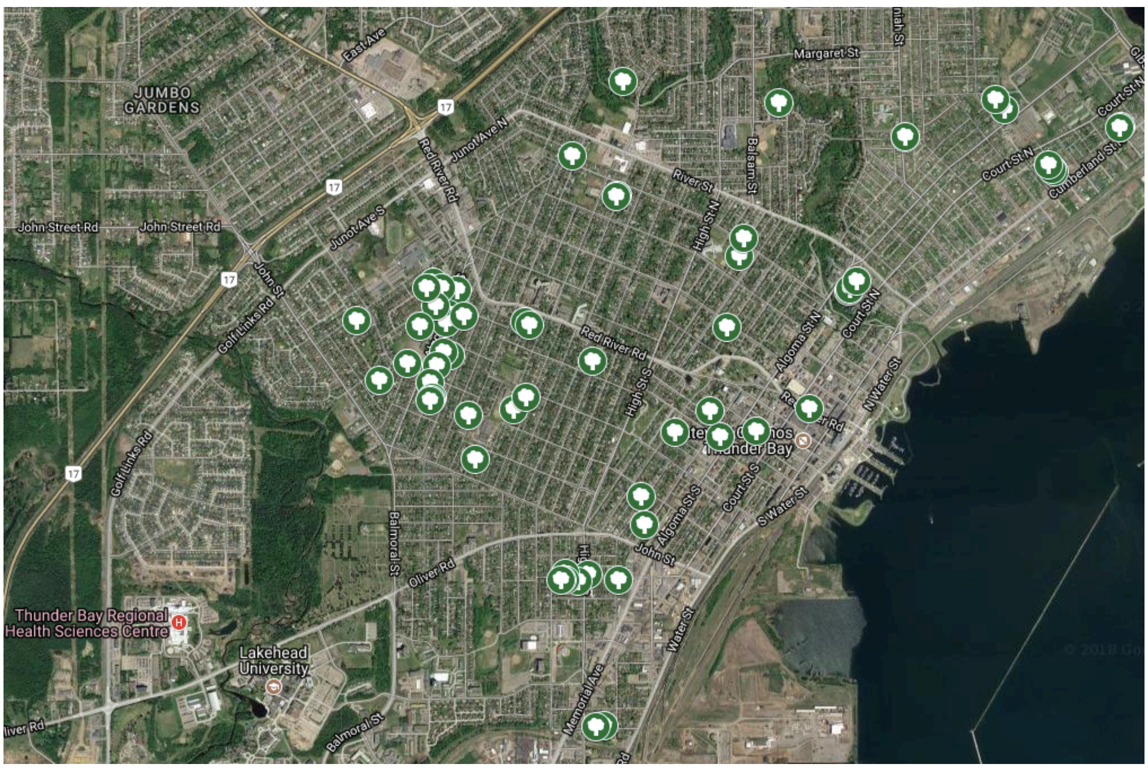

Figure 2. Trees identified in the North Ward of Thunder Bay

There were 60 trees identified in the North Ward (Figure 2). All trees were located north of Lakehead University, recorded on 28 residential streets. Notable areas of high disease occurrence included Algonquin Avenue, Kenogami Avenue and Oak Avenue situated around Algonquin Avenue Public School. Emmerson Avenue and Queen Street were also notably significant areas of street tree disease.

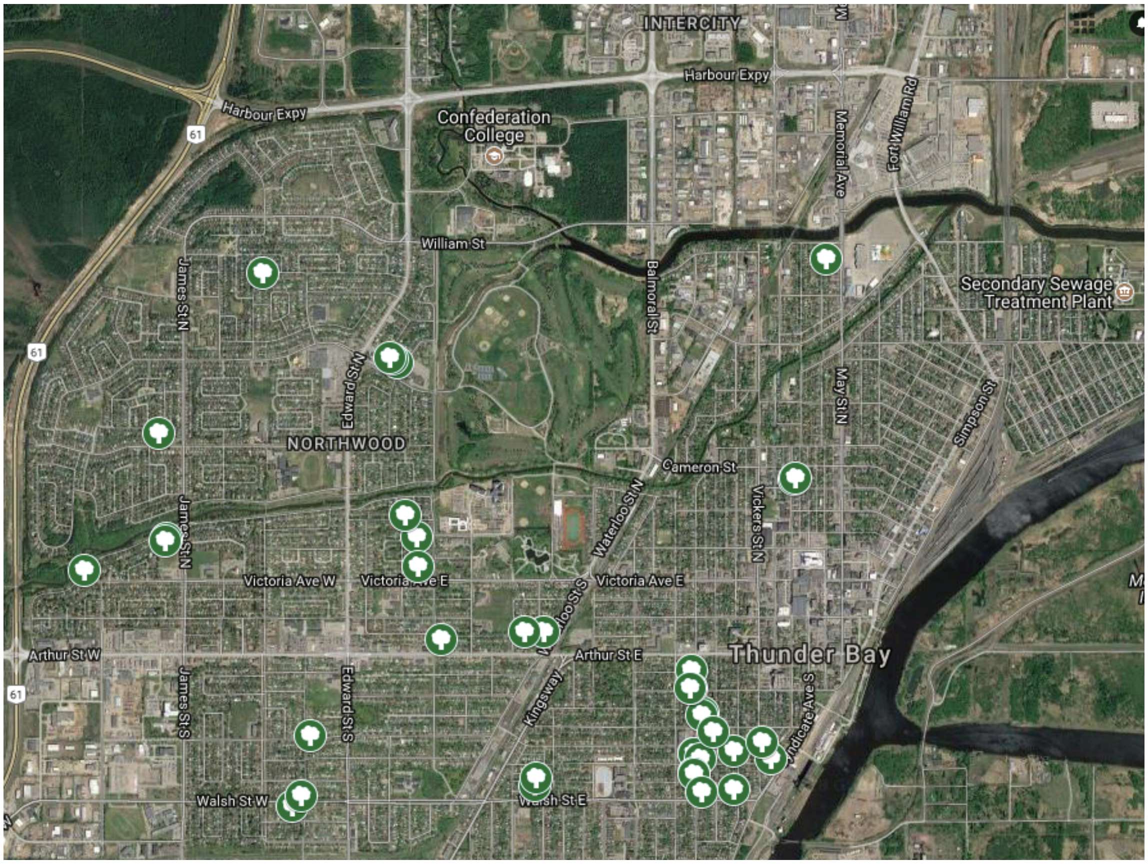

Figure 3. Trees identified in the South Ward of Thunder Bay

There were 42 trees identified in the South Ward (Figure 3). All trees were located south of Confederation College, recorded on 18 residential streets. Results were more spatially sporadic compared to the North Ward, however a high-density area was identified southeast of Vickers Park, including Norah Street, Walsh Street and Catherine Street.

Table 1. Occurrence of decay fungi and average size of tree species infected

Species	Number of Individual trees infected	Average DBH (cm)
Silver Maple	55	73.4
White Birch	19	53.5
Manitoba Maple	8	72.0
Green Ash	4	56.7
Linden	4	38.0
Red Maple	3	35.3
Red Oak	3	42.3
Flowering Crab Apple	2	27.5
Lilac	1	20.0
Mountain Ash	1	22.1
Balsam Poplar	1	19.6
White Spruce	1	44.2
Total	102	41.9

Table 1 displays the occurrence of decay fungi and average size of tree species. A more in-depth analysis can be seen in Table 3. In total, there were 12 different tree species recorded. The most common tree species infected was silver maple (*Acer saccharinum* L.), which comprised 55% of all infected trees recorded, totaling 55 infected trees. White birch (*Betula papyrifera* Marsh.) was the second most commonly infected tree, at 19 trees and Manitoba maple (*Acer negundo* L.) was the third highest in occurrence with eight infected trees. Green ash (*Fraxinus pennsylvanica* Marsh.) and linden (*Tilia cordata* Mill.) followed with four infected trees each. The remaining seven tree species recorded three or less individual infections.

Table 2. Occurrence of decay fungi species

Decay fungus	Count of Occurence	Percentage of total count
Cerrena unicolor	29	25
Pholiota squarrosa	15	13
Pholiota aurivella	14	12
Hypsizygus tessulatus	14	12
Ganoderma applanatum	10	9
Chondrostereum purpureum	6	5
Piptoporus betulinus	5	4
Irpex lacteus	5	4
Panus serotinus	4	3
Fomes fomentarius	4	3
Trametes versicolor	2	2
Daldinia concentrica	2	2
Bjerkandera adusta	1	1
Schizophyllum commune	1	1
Phaeolus schweinitzii	1	1
Inonotus obliquus	1	1
Volvariella bombycina	1	1
Coprinus micaceus	1	1
Stereum sp.	1	1
Total	117	100

Table 2 displays the occurrence of decay fungi by species. In total, 19 different species were identified, accounting for 117 individual infections. The most commonly occurring decay fungus in the study area was *Cerrena unicolor* (Bull.) Murrill. accounting for 29 out of the 117 infections. *Pholiota squarrosa* (Vahl) P. Kumm. was the second most common species identified, followed by *Pholiota aurivella* (Batsch) P. Kumm. and *Hypsizygus tessulatus* (Bull.) Singer. with each occurring 14 times. The next most frequently occurring species were *Ganoderma applanatum* (Pers.) Pat. and *Chondrostereum purpureum* (Pers.) Pouzer with ten and six occurrences respectively. Thereafter, both *Piptoporus betulinus* (Bull.) P. Karst. and *Irpex lacteus* (Fr.) Fr. shared five occurrences. Similarly, *Panus serotinus* (Pers.) Kuhner. and *Fomes fomentarius* (L.) Fr. occurred four times each. The remaining nine species occurred two times or less.

Table 3. Occurrence of wood decay fungi associated with tree species and average tree DBH

Tree Species and Associated Fungi	Tree Count	Decay fungus Count	Average DBH
Silver Maple	**55**	**64**	**73.4**
Cerrena unicolor		18	76.2
Pholiota aurivella		13	82.3
Hypsizygus tessulatus		11	83
Ganoderma applanatum		6	81.2
Pholiota squarrosa		4	64.4
Panus serotinus		4	81.7
Chondrostereum purpureum		2	106.9
Daldinia concentrica		2	51.4
Trametes versicolor		1	54
Volvariella bombycina		1	66
Coprinus micaceus		1	77.7
Fomes fomentarius		1	57.9
White Birch	**19**	**23**	**54.5**
Pholiota squarrosa		5	56.4
Cerrena unicolor		4	51.4
Piptoporus betulinus		5	55.5
Fomes fomentarius		3	53.4
Chondrostereum purpureum		2	47.1
Irpex lacteus		1	44
Pholiota aurivella		1	72.5
Inonotus obliquus		1	60.3
Bjerkandra adusta		1	49.9
Manitoba Maple	**8**	**8**	**72**
Cerrena unicolor		4	74
Hypsizygus tessulatus		2	51.1
Chondrostereum purpureum		1	83.9
Stereum		1	79

Tree Species and Associated Fungi	Tree Count	Decay fungus Count	Average DBH
Green Ash	**4**	**5**	**56.7**
Pholiota squarrosa		3	64.1
Ganoderma applanatum		1	69
Hypsizygus tessulatus		1	37
Linden	**4**	**4**	**38.0**
Pholiota squarrosa		2	74.7
Irpex lacteus		1	26
Schizophyllum commune		1	13.2
Red Oak	**3**	**3**	**42.3**
Ganoderma applanatum		2	47.8
Trametes versicolor		1	36.8
Red Maple	**3**	**3**	**35.3**
Irpex lacteus		2	47.2
Cerrena unicolor		1	23.3
Flowering Crab Apple	**2**	**2**	**27.5**
Cerrena unicolor		1	24
Pholiota squarrosa		1	31
Lilac	**1**	**2**	**20**
Irpex lacteus		1	20
Ganoderma applanatum		1	20
Mountain Ash	**1**	**1**	**22.1**
Cerrena unicolor		1	22.1
Balsam Poplar	**1**	**1**	**19.6**
Chondrostereum purpureum		1	19.6
White Spruce	**1**	**1**	**44.2**
Phaeolus schweinitzii		1	44.2
Total	**102**	**117**	**41.9**

In some cases, the same infected tree was host to more than one species of decay fungus, therefore, there were 15 additional decay fungi identified compared to the number of trees infected. Thirteen trees hosted two species of decay fungi and one tree was found to host three separate species of fungi. Of the three most commonly infected tree species, *Cerrena unicolor* was the most frequent decay fungus found on silver maple and Manitoba maple, whereas white birch was most commonly infected with *Pholiota squarrosa*. In terms of size, the average diameter at breast height (DBH) of all trees recorded was 42.1cm. The largest tree species on average being silver maple at 73.4cm and the smallest species being balsam poplar (*Populus balsamifera* L.) at 19.6cm. Silver maple and white birch were the only tree species that occasionally hosted more than one species of decay fungus.

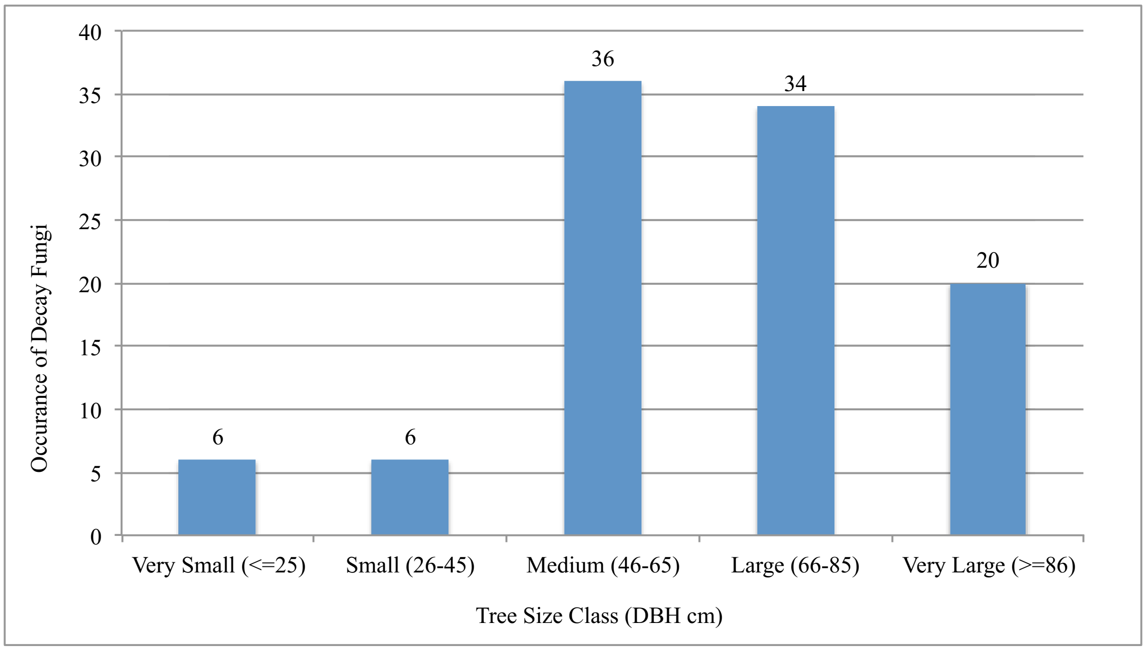

Figure 4. Occurrence of wood decay fungi based on tree size class

The majority of trees infected in this examination were medium to large in size (Figure 4). In fact, only 12 out of the 102 infected trees were 45cm or less in DBH. The smallest individual tree was measured at 19.6cm. The most commonly encountered tree size classes were between 46-65cm and 66-85cm in DBH, accounting for 70 trees. Trees that were 86cm or larger were exclusively silver maple or Manitoba maple, with the largest individual tree being measured at 114.6cm DBH.

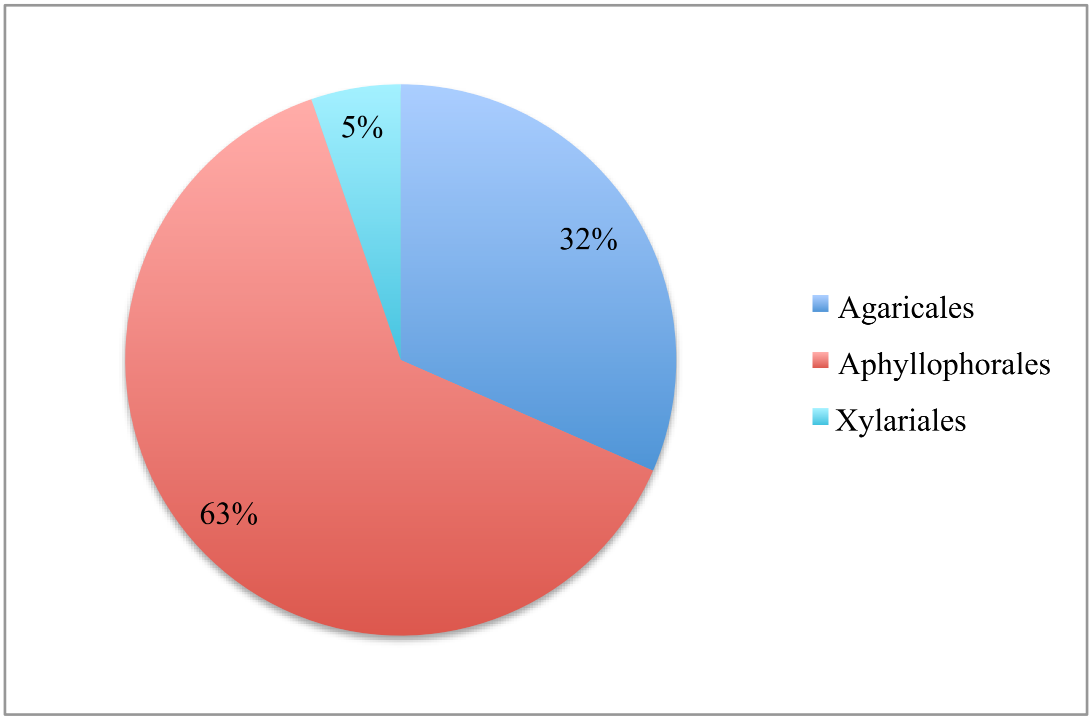

Figure 5. Occurrence of identified taxonomic Order based on 19 individual fungal species

Figure 5 displays the occurrence of taxonomic Orders based on the total number of fungal species identified. Out of the 19 individual fungal species identified, three different taxonomic Orders were represented. Twelve out of the 19 fungal species belong to the Order Aphyllophorales (bracket fungi) (63%) while six belong to the Order Agaricales (gilled mushrooms) (32%). Both of these Orders belong to the Basidiomycota and account for 95% of the species encountered. Only one species (*Daldinia concentrica*) belonged to the Order Xylariales with the Ascomycota and accounted for 5%.

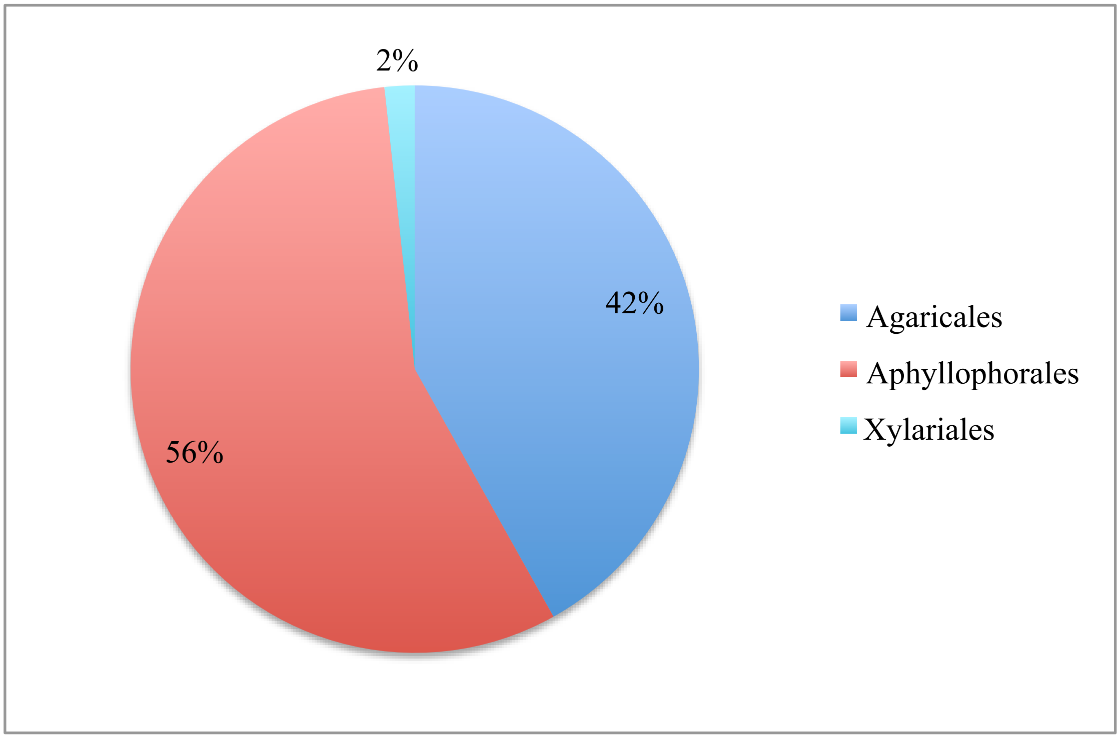

Figure 6. Occurrence of taxonomic Order based on total decay fungus count

In contrast to Figure 5, Figure 6 displays the occurrence of taxonomic Orders based on the total number of fruiting bodies found (117 identified specimens). As seen, Agaricales and Aphyllophorales comprise the vast majority of all fungal fruiting body occurrences. The Order Xylariales had one species identified that only occurred twice throughout the examination.

DISCUSSION

When examining the different effects of fungal decay on street-tree hosts, it is essential to understand that different species of wood decaying fungi are capable of causing different types of decay. The severity of damage caused is specific to the infecting species of decay fungus and host tree characteristics. In regards to the type of decay, two fungi identified including *Piptoporus betulinus* and *Phaeolus schweinitzii* (Fr.) Pat. cause brown rot. This type of rot is common among decaying conifer trees, but can still be found in various hardwoods. These brown rot fungi were confined to white birch (*P. betulinus*) and white spruce (*P. schweinitzii*), occurring only six times in total. Although less common in this study, brown rot can still cause damage to host trees and will be discussed further in detail. The remaining species of decay fungi identified in this study cause white rot, the most common type of rot among all fungus species. The type of decay does not define a decay fungus pathogenesis, as some decay fungi are characterized as opportunistic, ruderal strategists that quickly colonize a host in distress and are short lived. Others can be classified as stress-tolerant pathogens, which specialize in specific host conditions, yet others are naturally combative, long living pathogens that colonize a host and live over a long period of time. All of which cause varying degrees of decay severity, and must be treated independently in order to identify how hazardous a street tree is or will become.

Silver maple was the most commonly infected tree in the examination. The three most frequent decay fungi being *Cerrena unicolor*, *Pholiota aurivella*, and *Hypsizygus tessulatus*. Despite being found occurring on 6 different tree species and representing approximately 25% of all occurrences, *Cerrena unicolor* was exceedingly high in silver maple infections. Furthermore, *Pholiota aurivella*, and *Hypsizygus tessulatus* were found more often on silver maple than any other host. This may be due in part to the City of Thunder Bay`s tree species diversity. As of 2011, 18% of the City`s tree population was silver maple (Davey Resource Group 2011). This amount exceeds the standard principle of no more than 10% of one species in a given urban forest. Additionally, silver maple was the largest tree in average size (73.4cm) during the study. With an overly large, aging silver maple population, Thunder Bay is susceptible to a rapid decline in silver maple canopy cover due to the hazards they may pose to the public. However, in order to assess the hazard severity, host specificity is an important property to analyze.

Cerrna unicolor is an aggressive unspecialized opportunist, belonging to the Order Aphyllophorales. This fungus typically prefers wood environments with a high oxygen content. The fungus is found to attack a variety of northern hardwood hosts, with no specific host preference, typically found among maple and birch (Enebak & Blanchette 1989). However, it is highly associated with colonizing sapwood after initial tree wounding. Silver maple is notable for weak branch attachment and crotch development, causing frequent breakage specifically in urban environments (Hauer *et al*. 1993). These trees are predisposed to injury in urban environments from people and natural storms (ice, wind etc.). The high occurrence of *Cerrena unicolor* on silver maple can be attributed to the decay fungus` success as an opportunistic pathogen and to the poor health of the tree species. As a generalist, *Cerrena unicolor* does not prefer silver maple over other suitable hosts. Instead, the findings suggest that the fungus is the most successful opportunistic pathogen in Thunder Bay at colonizing silver maple through wounds.

Figure 7. Small fruiting bodies of *Cerrena unicolor* in silver maple wound

Figure 7 displays the typical infection of *Cerrena unicolor* during the study. The fungus produces very small fruiting bodies, generally scattered throughout the host trunk and was almost always associated with injuries to the tree`s periderm (i.e. frost cracking). Most infected maples appeared to be in a general state of health decline, commonly displaying stem breakage, callus formation and discoloration. These symptoms are quite indicative of *Cerrena unicolor.* Studies have shown that this fungus produces more pronounced callus tissue in silver maples compared to other common hosts like white birch. Zones of discolored xylem indicate repeated attacks by the fungus where columns of decayed wood can be twice the size of visible cankers in the periderm (Enebak & Blanchette 1989). Extensive white rot will take hold and can cause severe breakage in a tree that is predisposed by weak wood and formation. Overly mature silver maples will likely continue to weaken and break, increasing the need for pruning and tree maintenance within the City. In the near future, it is likely that the majority of silver maples infected with *Cerrena unicolor* in this study will become hazardous. The infected maples averaged 76.2cm in size; with continued canker development the trees will pose a great risk to adjacent property and the safety of people in the community.

Pholiota squarrosa and *Pholiota aurivella* were the second and third most common decay fungi found in the study. Unlike *Cerrena unicolor*, species of *Pholiota* are members of the Agaricales. This Order is characterized by a stipe, pileus and lamellae. Both *Pholiota* species found are very similar in appearance and pathogenicity. *Pholiota squarrosa* was the most common decay fungus for white birch, green ash and linden, whereas *Pholiota aurivella* was the second most common on silver maple. Fruiting bodies of *Pholiota squarrosa* were exclusively found near the base of the host tree (Figure 8), where it causes root and butt rot while *P. aurivella* is more frequently found on trunks and scaffold branches causing heart rot.

Figure 8. Fruiting bodies of *Pholiota squarrosa* infecting the buttress of a white birch

Tree hosts with butt rot are likely to break or fail at the tree`s base. In contrast, heart rotting fungi infect and decay the trunk and branches which can cause branch failure. Therefore, both types of rot are of equal concern when found on street trees. A German study (Schwarze *et al.* 2000) has shown that *Pholiota squarrosa* are generally saprophytic on street trees. Furthermore, the fungus is typically known to cause very slow wood degradation. Host trees that can potentially become hazardous are likely not only infected with *Pholiota squarrosa* (Schwarze *et al.* 2000). This indicates that the disease is not likely to cause butt breakage on its own. Only two trees were infected with *Pholiota squarrosa* and an additional disease in the study. These hosts include a white birch (Norah Street) and silver maple (Queen Street) additionally infected by *Fomes fomentarius* and *Cerrena unicolor*, respectively. In both cases, the host trees displayed rot of the buttress and trunk. As such, street trees infected with *Pholiota squarrosa* accompanied with an additional decay fungus have significantly increased hazard severity. Trees infected with multiple species of decay fungi that cause rot of the butt and trunk should be of special interest to the city forester. The host trees described on Queen and Norah are more hazardous as opposed to other hosts infected only with *Pholiota squarrosa* in the study.

(Source: Aboriculture Wordpress 2007)

Figure 9. Fruiting bodies of *Chondrostereum purpureum* infecting host trunk

Chondrostereum purpureum (Figure 9)*,* is a destructive wood decaying pathogen which has a wide host range (Setliff 2002), and causes a disease known as silver leaf disease when attacking members of the Family Rosaceae such as crab apples, plums, mountain ash and chokecherries (NRCan 2014). This fungus was less frequently found within the study, comprising 5% of the total decay fungus count, with six individual occurrences. However, several tree species that were found to host the fungus are significant street trees that are commonplace in many municipalities in Ontario, including silver maple, white birch, Manitoba maple, and balsam poplar. Despite *C. purpureum*`s known association with the Family Rosaceae, infected host species were unrelated. As a wound parasite, the host range of *C. purpureum* is likely wider than previously perceived. There has been a significant lack of research on the potential impact *C. purpureum* can cause on forest trees. A survey identified 561 occurrences of the fungus in herbaria within Canada and the United States (Setliff 2002), of which 45% were found on members of the Betulaceae, with the majority of infections on *Betula* species while only 4% on the Aceraceae members (Setliff 2002). The survey concluded that *Chondrostereum purpureum* is a severe pathogen with epidemic potential on forest trees and that its indicative silvering symptom is highly inconspicuous on non-rosaceous trees. Furthermore, susceptible trees with the highest vulnerability are those growing in adverse environmental conditions conducive of infection and frequent stem injuries (Setliff 2002). These findings support that *C. purpureum* can become a significant pathogen on urban street trees. Forest trees including white birch and maple species are commonplace as urban street trees and may possess a heightened vulnerability to *C. purpureum* infection growing in ecologically inappropriate areas. As such, the fungus may be frequently overlooked on street trees with an absence of silvering and few inconspicuous fruiting bodies.

Tree species that are susceptible and within the host range of *C. purpureum* are highly vulnerable to wood degradation if colonized. The fungus causes aggressive decay of the living sapwood of its host. Once fruiting bodies establish, the bark and cambium around the site of infection is likely dead with large portions of the stem rapidly decaying. The sap rot can continue to spread throughout the stem hollow in the absence of fruiting bodies, making early identification of infection and determining the extent of decay difficult (Luley and Kane 2009). The disease has proven to be significantly lethal within a short period of infection. Tree saplings of *Betula, Sorbus* and *Salix* were inoculated with the fungus in a study by Hamberg *et al*. (2017). After a 3-month duration, lethality was significantly high in *Betula*, where 47% of the saplings were dead. The fungus was present in the stumps of all saplings of all species tested, but that the fungus could utilize the woody material of birch better than other susceptible species (Hamberg *et al.* 2017). With regards to hazard severity, urban street trees colonized by this fungus are likely to undergo progressive sapwood decay overtime, subject to structural hazards followed by a deterioration in tree health. Interestingly, *C. purpureum* is commercially available as a biocontrol agent and commonly used to reduce weedy trees, particularly species of alder and aspen (Harper *et al.* 1999). According to the Canadian Pest Management Agency, the use of *C. purpureum* does not pose a threat among non-target trees as healthy trees are not at risk while unhealthy trees are normally susceptible to naturally occurring populations (PMRA 2002). However, the effect of an increase in spore load on the incidence of infection on non-target species is not yet fully understood. Conflicting studies question the influence between tree wounding and the fungus` spore load (PMRA 2002). Regardless, *Chondrostereum purpureum* will continue to be a threat to susceptible street trees, with infected hosts becoming structurally hazardous over time.

CONCLUSION

Tree hazard assessment is an interdisciplinary, complex and difficult process that is highly beneficial to a municipal urban forest. Hazard trees are frequently subject to structural instability and breakage from wood decaying fungi. For the City of Thunder Bay, *Cerrena unicolor* is the most successful opportunistic pathogen, frequently colonizing wounds of weakened, mature street trees, particularly silver maple. Once established, the fungus can quickly spread past the compartmentalization reaction in the host, casing heart and sap rot. An excess of wounded and mature silver maple in Thunder Bay has predisposed the urban forest to a significant decline in canopy cover into the near future. It is recommended that the City plant smaller stature trees, less susceptible to stem breakage and weak wood formation, such as mountain ash or little leaf linden. As a tradeoff, smaller street trees do not provide the same degree of shading or aesthetics as large canopy trees like silver maple, however smaller street trees will reduce hazards posed by wood decay and will reduce the cost of maintenance. When assessing tree hazard severity, it is important to delineate infected trees based on their potential to become hazardous in the future, similar to a triage system. This can be applied to street trees infected with *Pholiota squarrosa*, which are not likely to become hazardous over a long period of time due to very slow wood degradation of the tree buttress. However, trees colonized by *Pholiota squarrosa* with additional species of decay fungi have a greater probability of developing wood decay and becoming structurally unstable. Similarly, trees with fruiting bodies of *Chondrostereum purpureum* should be paid special attention to. As an aggressive wood decaying fungus, *C. purpureum* can cause extensive portions of sap rot in the stem prior to the growth of inconspicuous, small fruiting bodies. The fungus can commonly grow unnoticed in busy urban landscapes, until a host stem is significantly decayed and requiring removal. Further research is required to fully understand host – fungus relationships and the pathogenicity of wood decaying fungi in the urban forest. As urban landscapes expand in the future, the practice of arboriculture will become increasingly more valuable and in demand. The study of forest pathology will be at the forefront for making good urban forest management decisions in our cities.

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APPENDIX I

COLLECTION DATA

Location	Tree Species	Tree Size	1st Disease	2nd Disease	3rd Disease
79 Algonquin	Ms	57.3	*Hypsizygus tessulatus*		
91 Algonquin	Mn	54	*Hypsizygus tessulatus*		
113 Algonquin	Ms	80.4	*Ganoderma applanatum*		
125 Algonquin	Ms	88.4	*Hypsizygus tessulatus*	*Ganoderma applanatum*	
542 Luci	Sw	44.2	*Phaeolus schweinitzii*		
317 Norah	Ag	81	*Pholiota squarrosa*		
428 Norah	Bw	72.5	*Pholiota aurivella*		
535 Norah	Bw	60.3	*Inonotus obliquus*		
535 Norah	Bw	44	*Pholiota squarrosa*		
538 Norah	Bw	52.5	*Fomes fomentarius*		
609 Norah	Bw	62.7	*Pholiota squarrosa*	*Fomes fomentarius*	
609 Norah	Bw	45.1	*Fomes fomintarius*		
634 Norah	Bw	58.5	*Pholiota squarrosa*		
514 Riverview	Bp	19.6	*Chondrostereum purpureum*		
516 Riverview	Ms	110	*Chondrostereum purpureum*		
605 Riverview	Ms	49.1	*Pholiota squarrosa*		
123 Blanchard	Bw	44	*Irpex lacteus*	*Piptoporus betulinus*	
17 Emmerson	Bw	49.3	*Cerrena unicolor*		
17 Emmerson	Bw	58.7	*Piptoporus betulinus*	*Cerrena unicolor*	
17 Emmerson	Ms	71	*Piptoporus betulinus*		
29 Emmerson	Bw	49.9	*Bjerkandera adusta*	*Cerrena unicolor*	*Piptoporus betulinus*
336 Archibald	Bw	47.5	*Cerrena unicolor*		
338 Archibald	Bw	58	*Pholiota squarrosa*		
40 Peter	Bw	60.5	*Piptoporus betulinus*		
58 Ontario	Ms	54	*Trametes versicolor*		
531 Catherine	Bw	58.9	*Pholiota squarrosa*		
633 Catherine	Bw	54	*Pholiota squarrosa*		
512 Vickers	Bw	36.6	*Chondrostereum purpureum*		
501 Marks	Bw	57.6	*Chondrostereum purpureum*		
18 Hodge	Ms	66	*Volvariella bombycina*	*Ganoderma applanatum*	
19 Hodge	Ms	65.7	*Pholiota aurivella*		
209 Hodge	Ms	114.6	*Hypsizygus tessulatus*		
110 Windsor	Linden	69.3	*Pholiota squarrosa*		
218 Secord	Syringa	20	*Irpex lacteus*	*Ganoderma applanatum*	
402 Simon Fraser	Linden	26	*Irpex lacteus*		
218 Rockwood	Malus	31	*Pholiota squarrosa*		
244 Rockwood	Ms	87.5	*Pholiota aurivella*		
28 Hills	Mn	49.3	*Cerrena unicolor*		
844 Brodie	Mn	48.2	*Hypsizygus tessulatus*		
1303 Ridgeway	Mn	89.8	*Cerrena unicolor*		
1303 Ridgeway	Mn	88	*Cerrena unicolor*		
64 Shuniah	Mn	83.9	*Chondrostereum purpureum*		
64 Shuniah	Mn	79	*Stereum*		
101 Keystone	Ms	82.6	*Cerrena unicolor*		
131 Marlbourough	Ms	80.8	*Ganoderma applanatum*		
105 Kenogami	Ms	100.3	*Cerrena unicolor*		
159 Kenogami	Ms	108	*Cerrena unicolor*	*Pholiota aurivella*	
160 Kenogami	Ms	104	*Pholiota aurivella*		
182 Kenogami	Ms	69.5	*Cerrena unicolor*		
204 Kenogami	Ms	97.1	*Cerrena unicolor*		
223 Kenogami	Ms	84.9	*Cerrena unicolor*		
227 Kenogami	Ms	71.5	*Hypsizygus tessulatus*		
229 Kenogami	Ms	95	*Cerrena unicolor*		
199 Clarkson	Ms	68.5	*Pholiota squarrosa*		
226 Cedar	Linden	80	*Pholiota squarrosa*		
2020 Hamilton	Ms	103.7	*Chondrostereum purpureum*		
2021 Hamilton	Ms	48.9	*Hypsizygus tessulatus*		
2015 Sills	Ms	85	*Cerrena unicolor*		
2021 Sills	Ms	113.8	*Hypsizygus tessulatus*	*Panus serotinus*	
2033 Sills	Ms	88.6	*Hypsizygus tessulatus*	*Panus serotinus*	
2246 Sills	Ms	96.1	*Hypsizygus tessulatus*	*Pholiota aurivella*	
212 Walsh	Ms	90	*Pholiota aurivella*		

Location	Tree Species	Tree Size	1st Disease	2nd Disease	3rd Disease
210 Powley	Ms	69	*Cerrena unicolor*		
210 Powley	Ms	74.3	*Pholiota aurivella*	*Cerrena unicolor*	
225 Clavet	Ms	45.7	*Panus serotinus*		
227 Clavet	Ms	97.2	*Hypsizygus tessulatus*		
229 Clavet	Ms	81	*Pholiota aurivella*		
175 Prospect	Mr	45.5	*Irpex lacteus*		
202 Prospect	Mr	49	*Irpex lacteus*		
319 Albany	Ms	74	*Cerrena unicolor*		
329 Albany	Ms	84.1	*Pholiota aurivella*		
343 Albany	Ag	69	*Ganoderma applanatum*		
2613 Walnut	Ms	78.7	*Panus serotinus*		
2629 Parkrow	Ms	69	*Hypsizygus tessulatus*		
347 Queen	Ms	94.9	*Pholiota aurivella*		
388 Queen	Ms	77.7	*Coprinus micaceus*		
397 Queen	Ms	54	*Cerrena unicolor*	*Pholiota squarrosa*	
414 Queen	Ms	59.6	*Cerrena unicolor*		
415 Queen	Ms	55.4	*Cerrena unicolor*		
419 Queen	Ms	63	*Cerrena unicolor*		
423 Queen	Ms	82	*Ganoderma applanatum*		
364 Second	Ms	76.9	*Pholiota aurivella*		
372 Second	Mr	23.3	*Cerrena unicolor*		
448 Brown	Ms	45	*Daldinia concentrica*		
637 Brown	Ms	57.9	*Fomes fomentarius*		
503 Wiltshire	Ms	86	*Pholiota squarrosa*		
507 Wiltshire	Ms	57.8	*Daldinia concentrica*		
509 Wiltshire	Ms	89.6	*Ganoderma applanatum*	*Cerrena unicolor*	
279 Pearl	Ag	47.2	*Pholiota squarrosa*		
238 Red River	Linden	13.2	*Schizophyllum commune*		
188 Madeline	Ms	59	*Pholiota aurivella*		
188 Madeline	Ms	48.2	*Pholiota aurivella*		
312 Dufferin	Ms	55.4	*Cerrena unicolor*		
60 Oak	Or	51.5	*Ganoderma applanatum*		
67 Oak	Or	44	*Ganoderma applanatum*		
93 Oak	Or	36.8	*Trametes versicolor*		
112 Ray	Ag	37	*Hypsizygus tessulatus*		
98 Phyllis	Mn	68.7	*Cerrena unicolor*		
76 Cherry	Malus	24	*Cerrena unicolor*		
342 Ambrose	Ms	55.1	*Cerrena unicolor*		
365 Lark	Am	22.1	*Cerrena unicolor*		
2612 Chestnut	Ms	67	*Hypsizygus tessulatus*		

APPENDIX II

ACRONYMS USED FOR TREE SPECIES LISTED IN APPENDIX I

Acronym	Species name
Ms	Silver maple
Bw	White birch
Ag	Green ash
Bp	Balsam poplar
Linden	Little leaf linden
Syringa	Flowering lilac
Malus	Flowering crab apple
Mn	Manitoba maple
Mr	Red maple
Or	Red oak
Am	Mountain ash
Sw	White spruce