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Managing Threats to the Urban Forest: From Dutch Elm Disease to Emerald Ash Borer - Learning from Experience

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MANAGING THREATS TO THE URBAN FOREST:

FROM DUTCH ELM DISEASE TO EMERALD ASH BORER – LEARNING FROM EXPERIENCE

by

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MANAGING THREATS TO THE URBAN FOREST: FROM DUTCH ELM DISEASE TO EMERALD ASH BORER – LEARNING FROM EXPERIENCE

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The urban forest provides important essential services to all municipalities; however, its value is often overlooked. The urban forest contributes to energy savings, environmental benefits, psychological well-being, and social benefits. Managing the urban forest in a sustainable manner is important if we wish to benefit from these services well into the future. Reliable management techniques have been created through previous experiences with pests, and these should be utilized and improved for use on urban forests.

American elm (*Ulmus americana* L.) was once a major component of the urban forests of North America. In 1927, Dutch elm disease (DED) was introduced to the U.S. state of Ohio, and within 60 years the disease had decimated most of the American elm population of North America. This had a dramatic effect on communities largely planted with elms. Management techniques need to disrupt the disease cycle. Control can be achieved through persistent integrated practice. Some of the tools and techniques used for DED management can also be used in fighting a relatively new introduced invasive species, emerald ash borer (EAB) (*Agrilus planipennis*). Ash trees are currently a major component of the urban forest, and EAB poses a very similar threat that DED had in the past. By learning

from our experiences, we may be able to slow the mortality rate of ash trees and utilize our resources in a sustainable manner.

Large-scale management of urban forest pests is important, and one technique that aids in managing diseases is tool sanitation. Contaminated tools have been documented transferring fungal and bacterial diseases to healthy trees. A preliminary study is presented that tests the efficacy of 70% isopropyl alcohol, 10% bleach, Lysol®, and ShockWave Green24® when used for tool sanitation. Results suggested that all chemicals are suitable for eliminating the fungi *Ophiostoma* sp., but some provided poor control of other unidentified fungi. The experiment showed the value of sanitation in the field in the prevention of spreading disease.

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CHAPTER 1

THE IMPORTANCE OF URBAN FORESTS AND THE ROLE OF ARBORETA

Importance of the Urban Forest

Urban forests play an essential role in any sustainable city. There are numerous benefits the forest contributes to an urban area, including increased well-being of urbanites, overall energy savings, and improved environmental quality (Bolund, 1999; Chiesura, 2004; Dwyer, 1992). Before the appearance of agrarian culture and sprawling urban areas, humans interacted and depended on their natural surroundings daily. It is important that basic need is provided to people that live in urban locations today. Research has shown that people living in urban areas near greenspaces lead happier healthier lives compared to urbanites who live with no natural areas nearby (Chiesura, 2004; Ulrich, 1981; Kaplan, 1983; Schroeder, 1991). The urban forest is the backbone of greenspace, and should be considered a critical element in urban planning.

Programs aimed at preserving natural environments exist both on national (U.S.) and international levels. However, many of these efforts are more concerned with large, bio-diverse, untouched ecosystems (Chiesura, 2004). These ecosystems are important in their own right, and deserve the attention they receive. However, these ecosystems are generally uninhabited by man, and do not have a direct influence on urbanites. By 2050, it is estimated that 70% of the world's population, including developing countries, will be located in urban areas (Ahern, 2011). Many developed countries already have a much higher percentage of their population in urban spaces. The United States already has over

75% of its population in urban areas (Nowak, 2001). Urban land in the United States is projected to grow from 3.1% in 2000 to 8.1% in 2050 (Nowak, 2005). Even though our population is increasingly urban, we still depend on nature in a number of ways in order to live a satisfying life. For this reason, the importance of urban-natural systems should not be discounted. Legislation on this matter will ultimately determine how a city incorporates greenspaces into planning. Unfortunately, during periods of economic stress and decreased spending, parks and greenspaces usually see budget cuts (Tyrväinen, 1998). Under appreciation of the value of urban nature is likely the basis of these kinds of decisions. If more trees can be planted in cities, properties closer to forested areas will have increased property value (Tyrväinen, 2000). Governments could theoretically see more income from property taxes with higher property values, and at the same time provide all these indirect benefits.

Urban societies depend on natural systems located outside of urban locations for food and other natural products. The urban forest does not provide these direct consumables to communities, but still fulfills very important non-consumptive human needs. Increased well-being and quality of life is associated with natural areas (Chiesura, 2004). A popular study by Ulrich (1984) demonstrated that hospital patients recovering from surgery had faster recovery times when their rooms had window views of trees and green space compared to those patients who could only see buildings through their windows. The well-being and happiness of urbanites is important to a sustainable city as happier people tend to be more productive (Oswald, 2009). Consequently, urban nature is providing not only individual emotional and psychological benefits, but also large-scale societal benefits.

The urban forest also provides substantial energy savings for cities. Residential, commercial, and industrial areas all benefit from trees. Trees help reduce energy costs of heating in the winter by blocking winter winds, and cooling in the summer by shading buildings (Dwyer, 1992). These energy savings reduce demand for more electricity and new power plants, indirectly lowering pollution emissions (Nowak, 2007). In order for this to work, trees need to be strategically positioned to avoid detrimental effects on energy use. To save on cooling costs, deciduous trees should be placed on the east and west side of buildings. Annual leaf drop allows winter sun to penetrate through the canopy and radiate into the building. To save on heating costs, evergreen trees should be placed on the side of the building to protect from prevailing winter winds (Nowak, 2007). Evergreens have better ability to block wind during winter months than their deciduous counterparts. A house with properly placed mature trees is estimated to save 20% to 25% on energy costs compared to the same house in an open area (Heisler, 1986).

Urban heat islands are another problem facing cities. These are areas in a city where air temperatures are generally higher than the surrounding rural values (Taha, 1997). The urban forest significantly decreases the effects of urban heat islands (Taha, 1997). Albedo (reflection coefficient, or ratio of reflected radiation to incident radiation) and evapotranspiration from trees effectively cool an urban environment through radiant heat interception and evaporation of water. Simply increasing vegetation in urban areas can result in a 2°C decrease in air temperature (Taha, 1997).

The urban forest also provides environmental benefits, such as air filtering, noise reduction, and reducing rainwater runoff. (Bolund, 1999). Trees remove harmful pollutants from the air such as ozone, carbon monoxide, and sulfur dioxide. Pine trees in

Los Angeles were projected to remove about 8% of the ozone in the atmosphere under 400 meters (Rich, 1971). Properly planned and planted trees and shrubs can significantly reduce noise in urban areas (Bolund, 1999). Wide belts of plantings will have a greater effect on noise than single rows of street trees, but both can be beneficial to the urban environment. The urban forest can also have a great effect on urban hydrology. During precipitation events, trees intercept, retain and slow the flow of water into the sewer system. A study conducted in Dayton, Ohio showed that the existing canopy cover of 22% was able to reduce potential runoff from a major rain event by 7%. With a modest increase to 29% cover, the canopy was estimated to reduce runoff by 12% (Sanders, 1986).

The urban forest provides countless benefits to cities and their inhabitants. Many of these benefits go unnoticed and are underappreciated, but they are not to go unheeded. With much of the world's population moving into urban areas, incorporation of trees and greenspaces into planning should be of very high importance. We live in a world that is increasingly aware of the significance of sustainable systems. Early integration of greenspace into urban planning has the potential to save cities money through avoiding the costs of incorporating them later through a change in infrastructure, plus all the added benefits described above over multiple years.

The Role of Arboreta

Arboreta play a vital role in the conservation of tree species by performing research on the urban forest, and general education to the public. The term arboretum literally denotes a collection of trees. However, they are usually more than just a simple collection. Many arboreta today are more like botanical gardens, which display their

plant collections in large aesthetically pleasing landscapes. An arboretum is more specialized by having a heavy focus on trees and forests. A large collection of woody plants provides great opportunities for research and public education. Arboreta have added a great amount to the primary literature of peer-reviewed publications. The research done at arboreta is important in providing guidelines for managing all kinds of tree pests, understanding tree biology, and maintaining successful breeding programs. Public education is another objective role that arboreta assume. Attracting the public with attractive gardens and striking landscapes gives arboreta a chance to educate through hands-on experiences and educational seminars. Public education is important in spreading the word about invasive species, quarantines, and general tree care as well. The more the public knows about these issues the better chance they take responsibility for their own trees and help preserve the health of urban forests.

Internship at The Morton Arboretum

As part of the requirements for graduation from the Doctor of Plant Health Program, I spent the summer of 2014 as an intern at The Morton Arboretum in Lisle, IL. I was positioned in the plant pathology lab where I was exposed to a variety of activities the arboretum performs. These activities included and were not limited to diagnostics, research, and teaching.

The Morton Arboretum's mission statement outlines its overall goals and values and reflects similar goals of many other arboreta around the world. "The mission of The Morton Arboretum is to collect and study trees, shrubs, and other plants from around the world. The Arboretum maintains living collections on display across naturally beautiful

landscapes for people to study and enjoy, and to learn how to grow them in ways that enhance the environment" (Morton, 2014).

As part of the staff at the arboretum, I helped to realize this mission statement through various tasks. One of my main duties was to perform the in-house diagnostics for the arboretum. Public volunteer scouts came to the arboretum weekly and searched for insects, disease, or any other plant disorders on the grounds. The volunteers' samples were then submitted to us in the lab for diagnostic work. Results from the diagnostics were then combined with public samples submitted to the arboretum's plant health clinic to produce a weekly plant health care report for publication. This publication is available online from April through August every year at www.mortonarb.org.

The weekly plant health care report made use of degree-days and indicator plants in the landscape. This enabled readers to become prepared for forthcoming pests in their own landscapes. Plant pests such as insects and plant pathogenic fungi must be synchronized to their plant hosts (Orton, 1989). If phenological cycles are out of sync, the pest may miss the window of opportunity to begin feeding on its susceptible plant host. The use of degree-days is a great way to track phenological cycles of many organisms. Degree-days are a measure of the accumulation of thermal units. They are calculated over a 24-hour period by averaging the high and low temperatures, and subtracting a threshold temperature. Threshold temperatures vary according to species, but commonly, bases of 30°F, 50°F, or 10°C are used for general analyses. Key stages in pest and plant lifecycles (i.e. hatching, adult emergence, sporulation, bud break, or bloom time) can be predicted through the tracking of accumulated degree-days. The concept of correlating plant life stages to pest life stages is known as synchronous phenological

indicator (SPI) (Orton, 1989). This concept dates back well before the solar calendar, and was a useful tool in developing agricultural techniques. "It's time to plant corn when the oak leaves are the size of a mouse's ear." "Look for morels when the lilacs begin to bloom." "Plant potatoes when the forsythia are in full bloom." These are all examples of SPI. A more modern example is "Apply crabgrass pre-emergent herbicide when the forsythia bloom." (Orton, 1989). Indicator plants are easily recognizable and well-known plants that can give you a general idea of how the weather has progressed over the season. Correlating bloom time of certain plants with pest control timing is a useful way for homeowners and green industry personnel to achieve control of pests. Nature evolved to follow its own phenological calendar associated with the local weather, not manmade solar calendars (Orton, 1989).

At Morton Arboretum, I was involved in multiple research projects as well. A larger, long-term project I assisted with was locating and propagating Dutch elm disease resistant American elms (*Ulmus americana* L.). This involved searching for survivor trees, propagating them, growing them out, and eventually testing for resistance. Survivor trees are those trees that have experienced high disease pressure in past epidemics, yet are still alive today. This gives us a clue that something about that tree allowed it to survive the epidemic. Genetics contributing to resistance may be the case in some trees, but others may have simply escaped from the disease. This is one reason the collected samples need to be replicated and tested. Chapter two of this document covers the history of the American elm and Dutch elm disease.

Although I was not directly involved in projects concerning the introduced emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), it is

an important new pest in North America and warrants attention. Areas in danger of infestation should be prepared for its imminent arrival and can learn from what other communities have done about it. Chapter three covers this new invasive pest and some management solutions.

I also conducted an experiment testing the efficacy of common chemicals for sanitizing pruning tools. The practice of sanitizing pruning tools in the field is not strictly followed by workers, and is sometimes looked at as time consuming and burdensome. However, it is important in various situations to be cautious and sanitize pruning tools between cuts. This experiment is outlined in chapter four of this document.

I was also given the opportunity to lead a disease workshop under my supervisor's guidance at the 2014 Illinois Arborist Association's (IAA) summer conference in Monticello, IL. The workshop introduced common canker diseases of landscape trees, and why it is important to identify them correctly. Cankers are localized dead areas on twigs and branches that have been infected with a pathogenic fungus, or sometimes bacteria. They are usually darkened and slightly sunken compared to the surrounding healthy tissue. Depending on the species, the causal organism may infect various species, or might be limited to only one tree species. Some of the more common canker fungi that can infect multiple species of trees are *Botryosphaeria* spp., *Fusarium* spp., *Phomopsis* spp., and *Nectria* spp. Canker causing fungi that are more species specific are *Thyronectria austro-americana,* and *Cryptodiaporthe corni.* It is important to know how to identify these cankers so that proper treatment can be implemented. Plant pathogens, especially those that invade the vascular system or cause oozing cankers, can be transferred from one tree to the next by using infested pruning tools

(Chalker-Scott, 1999). Proper identification and knowledge that a canker fungus has potential to infect other trees in the area will help decisions in the field. The worker should take extra precautions to sanitize pruning tools before moving to other susceptible trees. However, if a tree has a canker specific to only one species, it may not be as crucial to sanitize pruning tools when moving to a new species of tree. If the canker is unknown or unidentified, sanitation of pruning tools is still a good idea in order to avoid potentially serious mistakes.

The management of trees involves knowledge of a broad range of disciplines including plant physiology, horticulture, entomology, plant pathology, soil science, and sometimes urban planning, to name a few. The objective of this document is to discuss classic management problems from the past and present, and provide sustainable management plans and techniques to address these issues.

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CHAPTER 2

DUTCH ELM DISEASE

American Elm and History of Dutch Elm Disease

American elms (*Ulmus americana* L.) are native and well adapted to the temperate forests of eastern North America. They became, and remain, prized trees in the North American landscape. They are especially known for their rapid growth rate, open and upright habit, vase-shaped canopy, and hardiness. On average, American elms grow about 10 to 12 feet in five years (Dirr, 2009), and once established some cultivars have been known to put on up to five and a half feet of growth per year (McPherson, 2009). American elms have a very high tolerance to all types of urban conditions including compacted soils, pollution, and disturbance from construction. They can also tolerate temperatures down to around -40° C (Dirr, 2009). These factors made the American elm an ideal tree for planting throughout urban areas in temperate zones across North America.

Before 1940, American elms could be seen in almost every Eastern and Midwestern city across the U.S and much of Canada. American elms were often planted as monocultures, lining either side of the streets in both residential and public areas. At maturity, trees would have grown and arched over those streets to create allées that provided shade for the entire neighborhood (Fig. 2.1).

Unfortunately, these monocultures would contribute to the demise of the American elm. In the early 1900s, an exotic disease called Dutch elm disease (DED) was

unintentionally imported into the U.S. The disease took advantage of this monoculture planting style, and transformed the appearance of the North American landscape. DED is very well known in the horticulture and arboriculture communities. It only took around 60 years for the disease to destroy over 80% of the original estimated 77 million trees in the U.S. (Hubbes, 1999). The state of Illinois first reported the disease around 1950, and by 1959 it is estimated that 95% of the state's trees had perished due to the disease (George, 1979). DED has proven to be one of the most devastating shade tree diseases in the United States (Karnosky, 1979). It can be compared to the destruction caused by chestnut blight in the late 1800s, which nearly wiped out all American chestnut [*Castanea dentata* (Marsh.) Borkh.] trees resulting in a loss of over 25% of the original Appalachian forest canopy.

DED was first reported in Europe in the early 1900s (Brasier, 2000), but it wasn't until 1922 when a Dutch scientist, Bea Schwarz, isolated and characterized the fungus associated with the disease. Schwarz had in fact described the fungus that had caused the first of two epiphytotics to sweep across the U.S. and Europe (Brasier, 1991). Schwarz had named the fungus *Graphium ulmi* based on its synnematal (asexual) state. Another Dutch scientist, Christine Buisman would later find and describe the sexual state and name it *Ceratostomella ulmi* (Brasier, 1991). The DED fungus has gone through numerous name changes, from *Ceratostomella* (Buisman, 1932) to *Ophiostoma* (Melin, 1934), to *Ceratocystis* (Moreau, 1952), and back to *Ophiostoma* (Hoog, 1984) where it is classified today. It should be noted that Dutch elm disease gets its name from the extensive amount of research done by the Dutch scientists who worked on the disease, not because of its place of origin. Because resistance was found in Asiatic species, such

as Siberian elm (*U. pumila* L.), Wilson's elm (*U. wilsoniana* Schneid.), and Chinese elm (*U. parvifolia* Jacq.), the disease is thought to have originated from Asia (Karnosky, 1979), not the Netherlands.

There is often confusion when referring to the disease, as the name of a tree *Ulmus* x *hollandica* 'Major' is commonly referred to as the Dutch elm. Although the Dutch elm is susceptible to DED, it is not the only species to be affected. DED affects a wide host range of elms native to both Europe and North America. Some of the more common hosts other than *U. americana* include *U. minor, U. procera, U. glabra, U.* X *hollandica, U. thomasii, U. rubra,* and *U. laevis* (Gibbs, 1978, Braisier, 1996). *U. americana* is one of the most highly susceptible species to the disease (Gibbs, 1978).

Causal Agents of Dutch Elm Disease

DED is a vascular wilt disease caused by two rather different species of ascomycetus fungi, *Ophiostoma ulmi* (Buisman) Nannf. and *O. novo-ulmi* (Brasier). *O. ulmi* was the casual agent of the initial epiphytotic of DED. *O. novo-ulmi* is a much more virulent species that also causes DED, and has mostly replaced *O. ulmi* in nature as a more fit species (Brasier, 2000). *O. novo-ulmi* is the main causal agent of DED in most of the affected areas of the world today.

DED was first reported in the U.S. in Ohio in 1927 (Brasier, 2000). It is thought that it arrived via timber importations from Europe containing *O. ulmi* infested European bark beetles (*Scolytus multistriatus* Marsh.), which are vectors of the disease (Brasier, 2000). From Ohio, the disease spread via this beetle, and the native elm bark beetle (*Hylurgopinus rufipes* Eichh.). This first epiphytotic, although very destructive, was not as bad as the second epiphytotic caused by the much more virulent *O. novo-ulmi*. In the

1940s, *O. novo-ulmi* appeared almost simultaneously in two places; eastern Europe and the southern Great Lakes in North America (Brasier, 2000). From these two locations, the disease spread rapidly across both continents, killing millions of trees.

Dutch Elm Disease Symptoms – Impact on Tree Health

Typical symptoms of the disease are fairly easy to recognize. Vascular wilt is quite self-descriptive in that the main symptoms seen in an affected tree are wilting of entire branches and death of cambium (vascular) tissue. Single branches can be seen in the canopy with wilted leaves that eventually yellow (flagging), and abscise much earlier than healthy leaves (Fig. 2.2) (Haugen, 1998). Vascular staining can be observed in infected twigs and branches by peeling back the bark to expose the xylem. Dark brown to black streaks can then be seen following the grain of the wood (Fig. 2.3) (Haugen, 1998). It is important to cut deep enough to expose the infected tissue. This can be seen most readily on small branches that are between 1 – 2 inches in diameter. Later in the season, it may be difficult to see this symptom if the infection has been sealed over by new growth (latewood). A cross-section of the twig may reveal a continuous or discontinuous ring of dark infected tissue from earlier in the season (Fig. 2.4).

Depending on when the tree is initially infected, the tree could die suddenly within a couple months, or slowly over a few years. During the spring, most trees produce “springwood” or “earlywood”. This is xylem tissue composed of relatively large vessels. Later in the season, “summerwood” or “latewood” is also produced by the vascular cambium. Latewood is xylem tissue with either thicker cell walls, smaller diameter cells, or both, with elms producing both types (Pallardy, 2008). The difference between these two types of tissue can be seen with the naked eye as the annual rings in a

cross-section of a woody stem. New infections generally occur in the newly developed tissues. Infections that occur in the spring infect the current season's earlywood. With the larger diameter of the xylem cells, it is much easier for the fungus to move through these tissues. Infection can then move through the entire tree rather quickly, and even kill a highly susceptible tree in just one season (D'Arcy, 2000). Trees that are infected later in the season are less likely to die as quickly as early infections. Late season infections occur in the latewood. Thus, fungus is not able to move throughout the tree as quickly in the much smaller diameter latewood tissue. One or two branches may succumb to the disease, but the entire tree is unlikely to die that same year. In some cases, the tree may be able to seal off the infection via compartmentalization (described in more detail later).

Dutch Elm Disease Cycle

The disease cycle of DED is representative of many other tree-fungus-insect disease complexes. In North America, there are two species of bark beetles that vector DED fungi, the European elm bark beetle (*S. multistriatus*) (Fig. 2.5) and the native elm bark beetle (*H. rufipes*). Similar to many other tree insect pests, these two species prefer to lay eggs in trees that have been weakened by drought or disease (Kalisch, 2010). Thus, DED infected elm trees are preferentially selected for oviposition by the beetles. Adult females bore through the bark and create a gallery in the vascular cambium, between the bark and old wood. *S. multistriatus* females generally open the gallery parallel with the grain of the wood (vertical), and *H. rufipes* will open it either at a slight angle or perpendicular with the wood grain (Agrios, 2005). The female lays her eggs all along the sides of the gallery, and depending on temperature, the eggs hatch a few days

later. The newly emerged larvae begin boring galleries of their own at a 90° angle to the original gallery (Fig. 2.6) (Agrios, 2005). These galleries remain very humid, and provide perfect growing conditions for both species of the DED fungi (Brasier, 1991). The beetles are known to have two to three generations per year (Cuthbert, 1979). Emerging overwintering adults and the progeny of the first generation are more likely to spread the disease because of the timing of their emergence and the growth of susceptible earlywood. Second generations may still cause new infections, but they may not be as severe.

DED fungi produce four types of spores in nature, the teleomorph (sexual) *O. ulmi* or *O. novo-ulmi,* and three anamorphic (asexual) spore types, *Graphium, Sporothrix,* and yeast. The sexually reproducing teleomorphs, *O. ulmi* and *O. novo-ulmi*, are rarely observed in North America because only one mating type of the species is usually found in areas of DED contamination (Agrios, 2005). However, when two mating types encounter one another, sexual reproductive structures called perithecia are produced in the beetle galleries. The perithecia are black, spherical, and depending on species, have relatively long necks (*O. ulmi* 280-420µm, *O. novo-ulmi* 230-640µm) (Brasier, 1991). Within the base of the perithecium, numerous asci (sacs) develop that each contain eight sexually recombinant spores called ascospores. Once mature, the asci degenerate and the ascospores are released into the perithecium. As the number of ascospores increases within the base of the perithecium, they are forced up through the perithecial neck, and accumulate at the tip of the neck in a sticky globule.

DED fungi primarily reproduce asexually. In beetle galleries, the fungi produce anamorphic (asexual) *Graphium*-type spores. These spores are produced on structures

called synnema (coremia). Synnema are loosely bound conidiophores grouped together to form a dark stalk with a sticky broadening head on which spores collect. A synnema is similar to a perithecium only in macroscopic structure in that spores produced amass in a sticky droplet on the end of a stalk.

When adult beetles emerge from their galleries, they pass over these sticky drops produced by both perithecia and synnemata and become infested with thousands of spores. Before finding a mate, newly emerged adults feed on elm trees. *S. multistriatus* will feed in the crotches of green twigs, and *H. rufipes* feeds on stems that are 5 to 30 centimeters in diameter (Agrios, 2005). As the beetles feed, they open up wounds and expose the earlywood xylem tissue. Spores carried by the beetle are deposited in these fresh wounds, germinate, and grow into the xylem vessels. At this stage, the fungus grows as *Sporothrix*-type mycelia and produces asexual spores. These spores can either be yeast-like and reproduce by budding, or create new mycelial colonies of *Sporothrix*. Spores also flow with xylem sap but generally are too big to pass through the perforation plate between xylem cells. Once a spore reaches a pore in the perforation plate, it will germinate through the pore and infect the adjacent cell. Although the perforation plate helps to slow the spread of the fungi within the tree, it cannot stop it completely.

Beetle vectors are the main source of new infections, but transmission can also occur through natural root grafts (Agrios, 2005). A heavily diseased tree with DED fungi growing in its root system is at risk of transferring the disease to nearby elm trees if they have formed natural root grafts. Consequently, monocultures that were planted along streets became a major problem during management efforts. When two trees are growing close enough to one another, they are likely to form root grafts. If one of these trees

becomes infected and is to be removed, these grafts should be severed before removing the diseased tree. If root grafts are left intact when the diseased tree is cut down, the highly negative water potential caused by transpiration of the living tree canopy will literally suck the sap out of the diseased root system, carrying spores and hyphae with it to infect the healthy tree. These root infections are serious and likely fatal. Fig. 2.7 illustrates the entire disease cycle of DED.

Figure 2.1 – Residential neighborhood with both sides of the street planted with American elm.
Photo credit: Joseph O'Brien, USDA Forest Service, Bugwood.org

Figure 2.2 – Dutch elm disease infected branch exhibiting wilt, yellowing, and necrosis of leaves.
Photo credit: Joseph O'Brien, USDA Forest Service, Bugwood.org

Figure 2.3 – Vascular streaking.
Photo credit: George Hudler, Cornell University, Bugwood.org

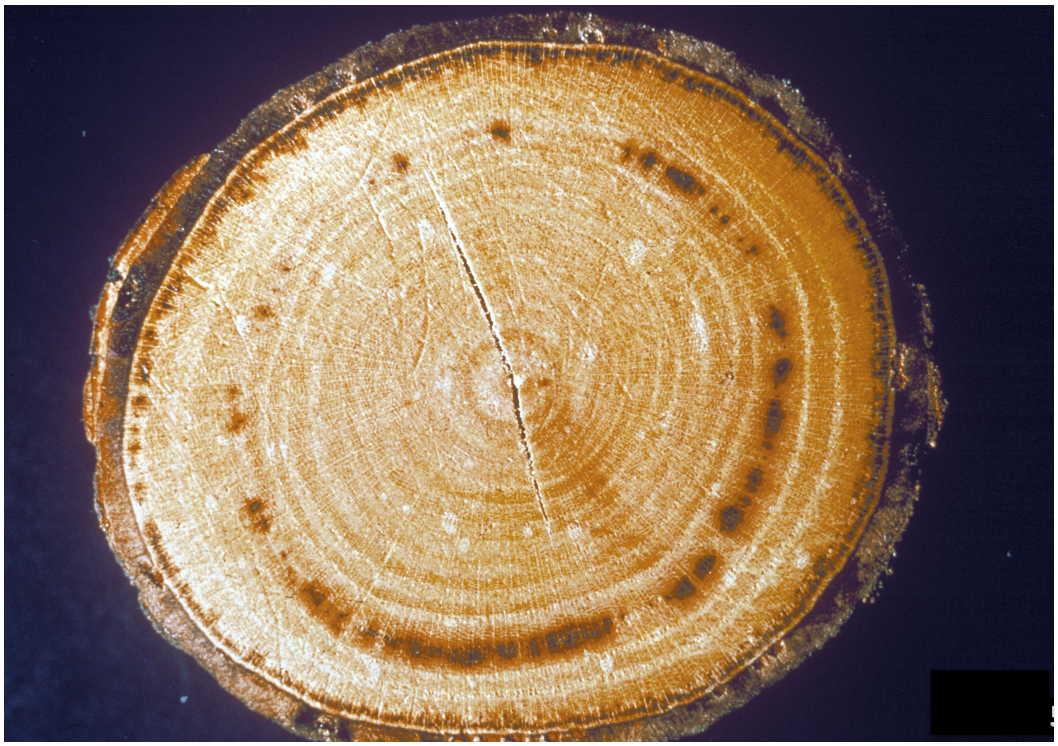


Figure 2.4 – Discontinuous ring of vascular staining. Infection has been sealed by two years of new wood.
Photo credit: UK Forestry Commission Archive, Bugwood.org

Figure 2.5 – European elm bark beetle adult (*Scolytus multistriatus)*
Photo credit: Maja Jurc, University of Ljubljana, Bugwood.org

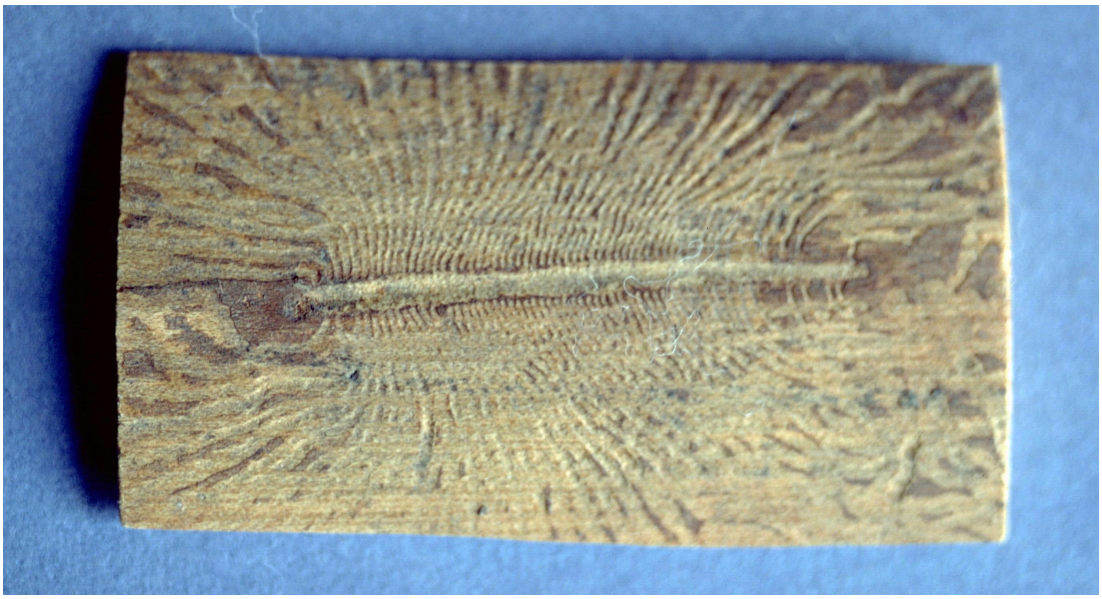
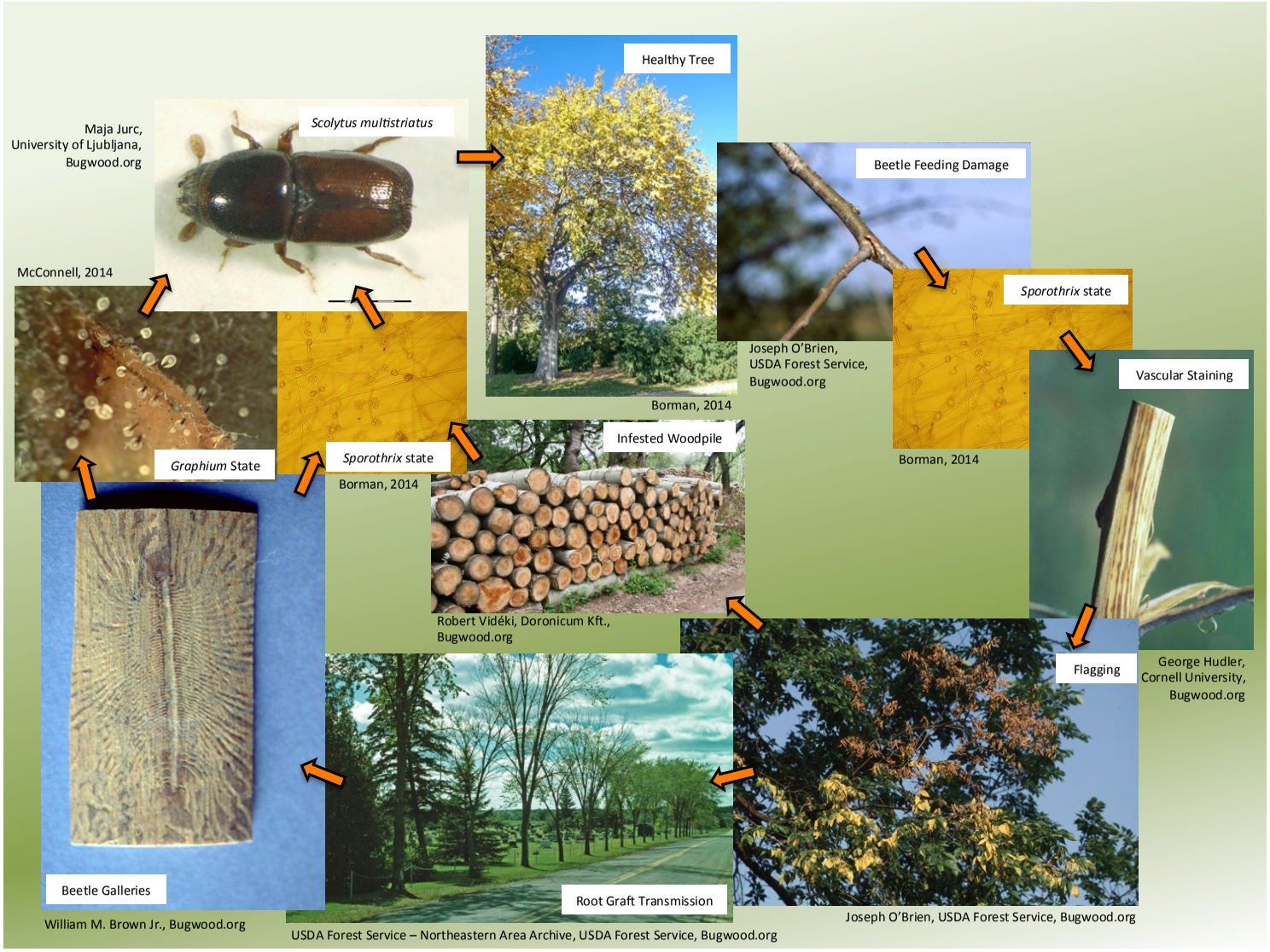


Figure 2.6 – Beetle galleries made by the European elm bark beetle (*Scolytus multistriatus*). Maternal gallery with the grain of the wood.
Photo credit: William M. Brown Jr., Bugwood.org

Figure 2.7 – Disease cycle of Dutch elm disease



Tree Defenses Against Dutch Elm Disease

Elm trees may seem defenseless against fungal invaders, but they do have a method that helps fend off decay fungi. This method is shared by all woody plants, and is called compartmentalization of decay in trees (CODIT). Dr. Alex Shigo devoted 16 years of his career researching and dissecting over 10,000 trees in order to develop this model for a better understanding of wound sealing in trees (Shigo, 1977). In some biological systems such as animals, healing a wound involves restoring damaged tissue to its original functional state. Trees cannot repair damaged xylem, in part because portions of it is made of non-living, non-meristematic cells. Trees are highly compartmentalized, and they seal off wound areas through this compartmentalization to prevent pathogenic organisms from entering (Shigo, 1977) or moving into new and healthy wood.

Wounding of a tree can come in a variety of sources, such as insect feeding, rodents, humans, lightning, strong winds, etc. Regardless of the method of wounding, the tree will initiate a defensive response by creating four separate barriers (Wall 1-4) to invading organisms (Shigo 1977) (Fig. 2.8 & 2.9). Wall 1 is the first response to wounding and results in blocking or plugging the vertical vascular system above and below the wound. Depending on the species, this blockage is formed with gum deposits, xylem pit aspirations (physically sealing of xylem pits with a membrane or torus), the formation of tyloses (outgrowths of parenchyma cells into xylem vessels), or a combination of these. This wall is considered to be the weakest wall.

Wall 2 is a preexisting wall that consists of the last ring of xylem cells put on the previous season. It is continuous around the tree, except where there are sheets of ray cells (wall 3). Wall 2 is the second weakest wall.

Wall 3 is also a preexisting wall and consists of sheets of parenchyma ray cells that extend from the center of the tree. Ray cell sheets are discontinuous and vary greatly in length, width, and thickness. Wall 3 is the strongest wall at the time of wounding.

Wall 4 is similar to wall 2. It is produced by the vascular cambium and is a physical and chemical barrier to pathogens. It is a barrier zone that separates wood formed before wounding and wood formed after wounding. Wall 4 is the tissue that grows over a wound, and is often a donut shape when growing over properly made pruning cuts. This wall is the strongest of the four walls.

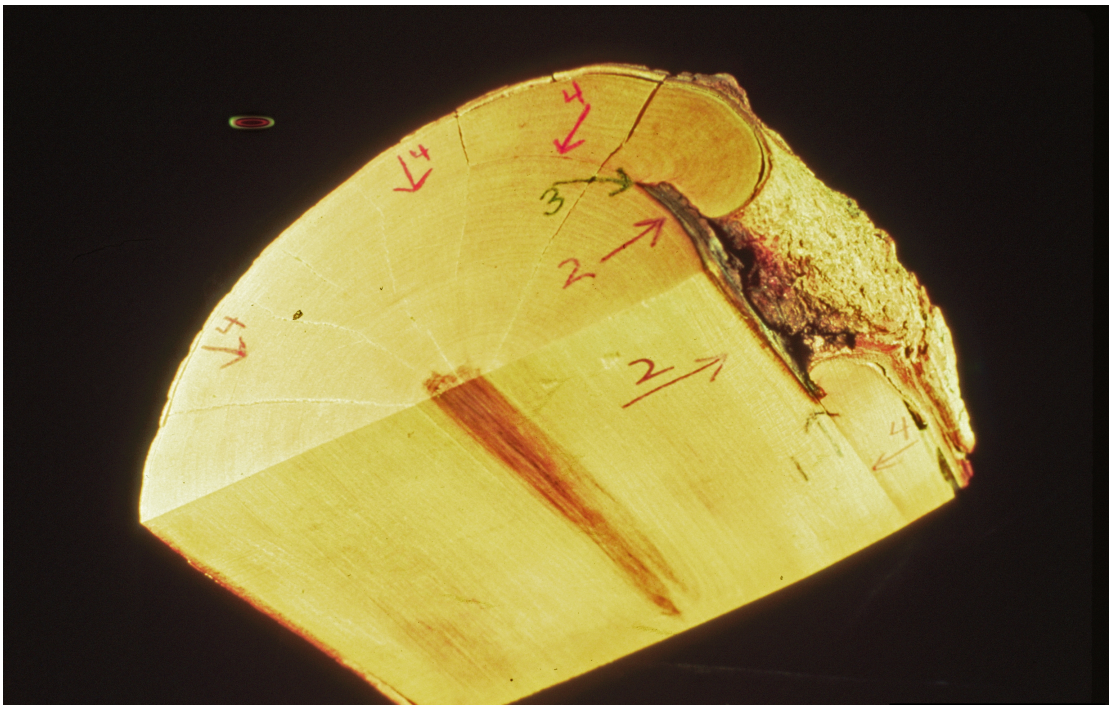


Figure 2.8 – Compartmentalization of decay in trees (CODIT) labeled on wood.
Photo credit: USDA Forest Service – Northeastern Area Archive, USDA Forest Service, Bugwood.org

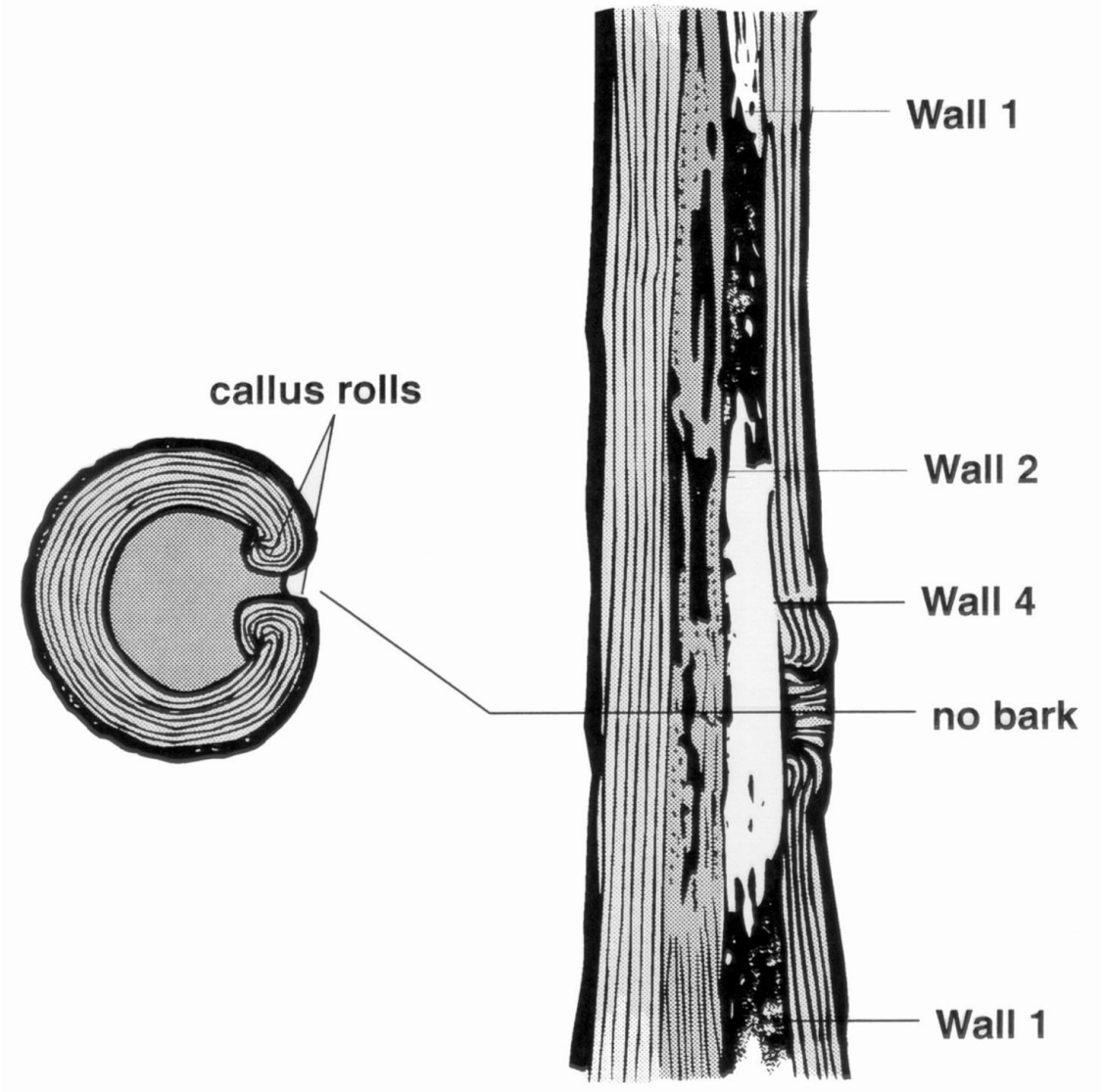


Figure 2.9 – Compartmentalization of decay in trees (CODIT)
Photo credit: International Society of Arboriculture, ISA, Bugwood.org

Management of Dutch Elm Disease

As with many other tree diseases, management of DED is best accomplished through prevention (prophylaxis) rather than a cure (therapy) (Stipes, 2000). DED prevention should reduce the spread of the disease from tree to tree. Curative measures should eliminate disease from a single tree and include removal of infected wood and fungicide treatments. DED prevention has a much higher success rate in maintaining

plant health (Stipes, 2000). Methods of prevention include sanitation, insecticides that kill vectors, severing of root grafts, regular fungicide injections, and planting of disease resistant trees. The key to successfully managing this disease is to disrupt the disease cycle in one or more places.

Curative practices can be successful if done correctly. Trees selected for curative practices should be high value trees. DED-infected trees that can easily be replaced or are of limited value should be removed entirely to reduce potential inoculum levels in the area. Infected branches should be removed from the canopy to rid the tree of the disease. In addition, it is recommended that at least 5 to 10 feet of clear healthy wood be removed below any discolored wood (Haugen, 1998). This practice can disfigure the tree canopy, but may successfully cure the tree of DED. After removal of diseased tissue, a regular fungicide program will help to allow the tree to seal off the wounds successfully and prevent future infections. It is important to destroy the infected wood by burning or chipping as soon as possible after removing.

Methods for prevention fall into three categories, cultural (sanitation and root graft severance), chemical (insecticides and fungicides), and use of resistant varieties. Sanitation is very important when managing DED. Sanitation involves removal of an entire tree from an area. By removing diseased wood, both fungal inoculum and beetle breeding grounds will be destroyed. Removal should be completed within two to three weeks of detection for the best control (Haugen, 1998). Wood must be burned, buried, or chipped to destroy the vector habitat and fungi. This should be done immediately after removal because beetles can still emerge from woodpiles carrying the fungi and spread disease. Wood can be stored for burning if it is debarked or covered with four to six mil

plastic from April 15th through October 15th (Haugen, 1998). Debarking desiccates the xylem tissue where the fungi live, and prevents spore production. The plastic cover should be sealed to the ground to prevent beetle spread. (Haugen, 1998).

Severing root grafts of neighboring trees can prevent root transmission. When working with relatively older trees (e.g. trees planted before the DED pandemic), root graft severance should be considered. Trees that are located 20 ft or less from a DED-infected tree have nearly a 100% risk of infection through root grafts (D'Arcy, 2000). Trees that are 40 ft or more apart are at a much lower risk. (D'arcy, 2000). Severing root grafts often is not practical as many street trees are planted close to buried utility lines that would also be severed. To overcome this obstacle, an airspade could be used to expose roots and utilities and then selectively prune the roots (Ames, 2003). Roots should be pruned to a depth of three feet in heavier clay soils and at least five feet in sandy soils (BioForest Technologies, 2014).

Insecticide control can be somewhat effective in managing DED, but is rarely used today due to better fungicide options. Methoxychlor and DDT have been used in the past to control beetle vectors (Karnosky, 1979); however, these chemicals have since been banned due to their acute toxicity to mammals, bioaccumulation, and endocrine disruption activity (US-EPA, 2003). These sprays were effective in many city programs. For instance, in 1979 at the peak of the epidemic, New York City was able to save about 33,000 mature American elms with a thorough sanitation and methoxychlor spray program (Karnosky, 1979). However, human and environmental exposure concerns today have reduced insecticidal treatments to near zero.

More commonly, fungicides are used to control the growth of the fungi. Fungicide treatments include thiabendazole hypophosphite (Arbortect 20-S®) and microencapsulated propiconazole (Alamo®). Both fungicides are macro-injected into the root flare of the tree and systemically move to the canopy of the tree. The chemicals are able to move through functioning infected wood and temporarily stop the pathogenic action of the fungi. This enables the tree to seal off the infection sites through a wall-4 formation (Stennes, 2000). These fungicide treatments last between two and three years, and need to be re-administered routinely to ensure proper control. In order to avoid buildup of resistant strains of the fungi, the two fungicides should be rotated regularly.

The planting of disease resistant elm trees is another way to slow the spread of DED. There are cultivars of American elm that have been selected for higher tolerance to DED. Some of these include 'New Harmony', 'Valley Forge', and 'Princeton' (Smith, 2007). These varieties have gone through rigorous selection trials to ensure the future health of the population. Asian elm hybrids are another option, as Asian elms are naturally resistant to the disease. The USDA has released several Asian elm cultivars that have been shown to be both resistant to DED, and also have high horticultural desirability. Some of the more popular releases include 'Homestead', 'Pioneer', and 'Frontier' (Townsend, 1993). Replacing an American elm with another disease resistant species is always another option.

Because of the limited selection of resistant American elm varieties on the market today, researchers are still selecting new varieties. The selection process begins by finding mature trees that survived through the DED epidemic. To ensure that disease resistance is coming from natural tolerance, the tree should not have been treated with

fungicides in the past. Trees that experienced high disease pressure during the height of the epidemic are good candidates for selection. These types of trees are typically over 50 years old, and may have been planted in monoculture along roadsides, or in parks.

To test for resistance, genetic clones of the selected trees must be produced. Semi-lignified green (semi-hardwood) cuttings of elm have been successfully rooted, even without mist and rooting hormones (Saul, 1978). The timing of taking these types of cuttings is crucial and should be done in late spring to early summer. Cuttings should be a length of about 5-8 inches with the bottom few leaves removed. Cuttings with larger leaves should have the leaves cut in half to reduce transpiration. A fungicide dip will prevent decay fungi while rooting. A thiophanate methyl dip is commonly used for this purpose. Although the use of rooting hormone has been shown to not be necessary (Saul, 1978), using one will not harm the cuttings and may increase the success rate of rooting. The cut ends are dipped into the rooting hormone, and inserted into a coarse moist rooting media. Flats of cuttings should be placed in a shaded area for rooting. Placing the cuttings in a mist room will slow transpiration and water loss, but it is not necessary (Saul, 1978). Roots should start to grow from the cuttings within 3-4 weeks, and should be ready for transplanting in 3-4 months.

Once cuttings are rooted and ready for transplanting, they should be potted into larger containers to increase their size. After one season, saplings should be ready to be planted in the field, or into large pots for greenhouse experiments. Trees that are approximately four years old or older are the preferred age to perform inoculations (Tchernoff, 1965). There are two methods for inoculating elm saplings, a European and an American method. The European method was developed in the Holland and is called

the Dutch slit inoculation. This method guarantees almost 100% infection of treated trees (Mittempergher, 2004). A slit is cut into the large xylem vessels of the lower trunk, and with the knife still in contact with the cut tissue, two drops of a conidium suspension are placed onto the knife. The liquid will then be sucked up with the rising sap (Mittempergher, 2004). This method is quite artificial, and does not mimic the type of wounding that the beetles produce in North America. For this reason, a second method was developed in Wisconsin by the Townsend group. This technique more closely mimicked the way the beetles would transmit the fungus. A 2.4 mm slanted hole was drilled into the bottom one-third of the trunk, and inoculum was introduced to the hole (Mittempergher, 2004).

Once infection is confirmed, the selection process can begin. Susceptible trees will likely die within a month or two. Resistant varieties may show symptoms of the disease, but will be able to recover and seal off the infection. These trees should be selected for further testing and possible release to the market.

Elm Yellows

Once a selection is determined to be tolerant and/or resistant to DED, it would be beneficial to screen it for another terminal disease of elms, elm yellows (EY). EY is not as widespread in the U.S. as DED, but it is just as lethal. Infected *U. americana* can die within one year of showing first symptoms (Braun, 1976). Currently, it is present in the Midwest from eastern Nebraska to parts of Pennsylvania and New York, south to Louisiana and Mississippi. Disease occurrences tend to be sporadic and intense (Sinclair, 2000). EY is caused by the Elm phloem necrosis phytoplasma, or *Candidatus Phytoplasma ulmi* (Lee, 2004). Phytoplasmas are mollicutes, a class of bacteria

characterized by their small size (0.2-0.3 μm) and a lack of a cell wall. They express pleomorphism (ability to change shape) and have very small genomes. Phytoplasmas are mostly obligate parasites found within plant phloem, but also live in the insects that act as vectors, and other insects that feed on infected plant phloem (Sinclair, 2000). The phytoplasma must be transferred from plant to insect, back to plant in order for the insect to be considered a vector. If an insect acquires the phytoplasma via phloem feeding but does not transmit it to another plant while feeding, it is not considered a vector. EY is only known to be vectored by the white-banded elm leafhopper (*Scaphoideus luteolus* van Duzee). However, it is likely vectored by other phloem feeding insets as well.

The first symptom of EY is rootlet necrosis, and it will usually go unnoticed. Degradation of phloem tissue will follow and result in canopy symptoms, including foliar epinasty (Fig. 2.10), yellowing of leaves (Fig. 2.11), and eventually leaf death. Leaves will turn from green to olive-green to yellow (Fig. 2.12) or sometimes reddish-gold, depending on species. Then the leaves will suddenly wilt and become necrotic, and sometimes remain attached to twigs. Discoloration of phloem tissues on peeled bark can be observed as a butterscotch color, compared to a healthy creamy white (Fig 2.13). In some species (*U. alata, U. americana, U. crassifolia,* and *U. serotina*) infected living phloem will produce methyl salicylate (oil of wintergreen) and is produced in high enough quantities to be detected by sniffing the freshly exposed surface (Sinclair, 2000). This wintergreen smell is diagnostic to the disease, and is considered adequate for field diagnostics as well.

There is currently no cost effective treatment for elm yellows, but there is evidence that the phytoplasma associated with elm yellows does respond to antibiotics,

especially those in the tetracycline group (Sinclair, 2000). However, treatment would often only reduce symptoms for a period of time before the tree would redevelop symptoms. Removal is the best option if a tree is infected with EY.

Although DED and elm yellows are not specifically related to one another, it is important to consider both diseases when selecting for resistance. By broadening resistance to more than just one disease, we can avoid future epidemics and prevent huge losses in our elm inventories. Elm was once a very significant tree in the landscape, and is worth the efforts we have put into understanding DED. By learning from our experiences managing DED, we may be able to effectively manage newly emerging diseases such as thousand cankers disease of black walnut and sudden oak death. Both of these diseases pose a great threat to some important landscape and forest trees. With the application of our knowledge and integrated management practices, we may be able to delay and or halt the forthcoming threat to our forests.

Figure 2.10 – Foliar epinasty and necrosis resulting from elm yellows.
Photo credit: Pennsylvania Department of Conservation and Natural Resources – Forestry Archive, Bugwood.org

Figure 2.11 – Yellowing of leaves resulting from elm yellows.
Photo credit: Pennsylvania Department of Conservation and Natural Resources – Forestry Archive, Bugwood.org

Figure 2.12 – Healthy leaves (left), elm yellows infected branch (right).
Photo credit: Wayne A. Sinclair, Cornell University, Bugwood.org

Figure 2.13 – Healthy tissue is creamy white (left), elm yellows infected tissue is butterscotch yellow (right).
Photo credit: Wayne A. Sinclair, Cornell University, Bugwood.org

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CHAPTER 3

EMERALD ASH BORER

The emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is a recently introduced invasive species of wood boring beetle that has already killed millions of ash (*Fraxinus* spp.) trees since its discovery in North America in 2002 (Knight, 2013). The Midwest and eastern United States face a projected $10.7 billion price tag over 10 years for the treatment, removal, and/or replacement of an estimated 37.9 million ash trees on developed land that will be affected by EAB (Kovacs, 2010). This cost doubles to around $25 billion if all of the work were to be done at once, and hence justifies the need for investments into slowing the spread of EAB (Kovacs, 2010). Ash is also an important timber tree in North America. The undiscounted compensatory value of forest ash in the U.S. was estimated at $282.3 billion in 2003, with national stumpage value of trees at risk of $25 billion (Federal Register, 2003). Without investment in research and widespread application of management technologies, the end result of this exotic pest invasion will be comparable to the devastating epidemics of chestnut blight and Dutch elm disease.

EAB is native to northeastern Asia, where it is not considered a major pest. It is thought to have come to North America in solid wood packing material such as pallets and crates used for international trade (Cappaert, 2005). EAB was first discovered in southeast Michigan and nearby Windsor, Ontario, and as of April 2014 it was known to be in 22 states and 2 Canadian provinces (Herms, 2014).

Ash trees, particularly green ash (*Fraxinus pennsylvanica* Marsh.) and white ash (*Fraxinus americana* L.), have long been very popular and important landscape trees in the Midwest and eastern United States. Both species are fast growing, adaptable, tolerant of urban environments, and important shade trees (Dirr, 2009). For these reasons, ash trees have been planted extensively across North America. Green ash, as one of the most tolerant and hardy species, has been overplanted according to some sources (Dirr, 2009, Gilman, 2011). Santamour (1990) suggested in order to increase diversity, no more than 10% of a single species, 20% of a single genus, and 30% of a single family be planted in a community. This concept is one of the more well-known and accepted rules of thumb in urban forestry. In many localities, ash trees make up more than 20% of the local tree canopy (Raupp, 2006, Kovacs, 2010). This percentage is right at the suggested threshold, and EAB alone now threatens that 20% of those urban canopies. Researchers have concluded that EAB puts 16 species of ash native to North America at risk (Bauer, 2010) including all cultivars of green and white ash (Stepanek, 2014).

The spread of EAB populations within North America has been attributed mainly to human movement of infested ash wood used for firewood, movement of live ash nursery stock infested with EAB, and natural dispersal of the beetle (Marshall, 2013). Currently, EAB has not yet been reported in Nebraska, but it is anticipated to arrive in the next few years. EAB has been confirmed as close as Kansas City, MO and Union and Boone Counties in central Iowa (USDA, 2014). Bauer et al (2003b.) has shown that EAB adults are capable of flying 5,233 m over a period of 40 hours. Extrapolating from these data, it is only a matter of time before EAB reaches Nebraska. Often, infestations may go

unnoticed for a few years, and the first positive identification may not be confirmed until 3-6 years after the initial invasion (NFS/CTAP, 2013).

EAB has been confirmed as far west as Boulder, CO. However, the relatively ash tree-free region of the western Great Plains (i.e. Kansas, Nebraska, and eastern Colorado) create a major ecological barrier to the natural movement of the insect (Cranshaw, 2014). Because of this natural barrier, it is likely that the introduction of EAB into Colorado resulted from either movement of infested nursery stock, or illegal movement of firewood that contained developmental stages of the insect (Cranshaw, 2014). Colorado's ash tree populations are mostly hand planted, and occur in concentrated pockets, mainly municipalities; therefore, it may be possible for the Colorado infestation to be contained and/or slowed, but probably not eradicated (Cranshaw, 2014). Also of concern is that the nearby Denver metropolitan area has an estimated 1.45 million ash trees (CDA, 2014) that would be at risk to EAB infestation. It may be possible to save the Denver ash trees if containment practices are enforced.

Symptoms of Emerald Ash Borer Infestation

Both adults and larvae of EAB feed on ash trees. Adults feed on foliage, but this feeding results in negligible damage to the trees. The area of concern is the larval feeding of phloem and vascular cambium tissue. When larvae are numerous in the tree, the serpentine galleries they create eventually limit the normal upward flow of water and nutrients in the tree (McCullough, 2014). Ultimately, all water and nutrient flow is blocked, and branches above the infestation site will die. Initial symptoms in ash trees are longitudinal cracks in the bark (Fig. 3.1) where EAB larvae have been actively feeding (McCullough, 2008). Increased woodpecker feeding may also be observed

feeding on late instars or prepupal larvae. As larval densities increase in the tree, wilting leaves, thinning canopies and death of large branches are the next symptoms observable (McCullough, 2008). Epicormic shoots begin to form lower in the canopy on the main branches and the trunk (Fig 3.2). These shoots normally arise from dormant buds when a tree is under stress, has been through fire, or in response to heavy pruning or crown dieback. Emerging EAB adults leave distinctive D-shaped exit holes in the bark of the tree (Fig. 3.3). These exit holes are easier to see on younger, smoother barked trees. The exit holes generally appear on the upper portion of the trunk the first couple of years of infestation and may go unnoticed. A tree in its third or fourth year of infestation will likely have exit holes lower on the trunk and therefore they would be more visible (Haack, 2002). By this time, the infestation may have done excessive damage, and the tree may not be salvageable. Debarking the trunk will reveal the serpentine galleries made by the larvae (Fig. 3.4). These galleries are typically packed with frass (larval excrement).

Emerald Ash Borer Identification

Adult EAB is generally larger than the native North American species of *Agrilus* ranging from 7.5 to 13.5 mm long (McCullough, 2008). It is very characteristic of the family Buprestidae in that it has a bullet-shaped body and a metallic coloration. The main body is usually a bronze, golden to reddish green, with the elytra (wing covers) a darker iridescent emerald green (Fig. 3.5 & 3.6) (McCullough, 2008). When the wings are fully spread, the dorsal side of the reddish purple abdomen can be seen (Fig. 3.7).

Larvae are dorso-ventrally flattened, creamy white with a 10-segmented abdomen (Fig. 3.8). Abdominal segments 2-7 are increasingly trapezoidal, becoming bell-shaped

in segments 5-7 (Chamorro, 2012). This bell shape is a diagnostic characteristic of the species when comparing EAB to other native *Agrilus* sp. (Zablotny, 2014).

Eggs are somewhat difficult to find because of their size, and often they are deposited in cracks and crevices of the bark. Newly deposited eggs are white and about 1 mm in diameter (Fig. 3.9), and change to an amber color before hatching (Fig. 3.10).

Emerald Ash Borer Lifecycle

EAB has one generation per year. Eggs are deposited from mid-June through July in most locations in North America (Bauer, 2010). Depending on temperature, larvae will emerge in about 7–14 days (McCullough, 2008, Bauer, 2010). The larvae hatch on the underside of the egg and immediately start boring through the bark until they reach the vascular cambium layer. There they feed on phloem and outer sapwood (McCullough, 2008). While feeding, they create serpentine galleries that eventually cut the flow of water and nutrients within the tree. Larvae go through four distinct instars (Cappaert, 2005). The fourth instar bores into the outer sapwood or bark of the tree and excavates a pupation chamber in late summer. There they overwinter as prepupae. The following year, pupation

Figure 3.1 – Longitudinal crack over EAB gallery.
Photo credit: Michigan Department of Agriculture, Bugwood.org

Figure 3.2 – Epicormic shoots.
Photo credit: Edward Czerwinski, Ontario Ministry of Natural Resources, Bugwood.org

Figure 3.3 – D-shaped exit hole.
Photo credit: Pennsylvania Department of Conservation and Natural Resources - Forestry Archive, Bugwood.org

Figure 3.4 – Serpentine galleries.
Photo credit: Art Wagner, USDA - APHIS, Bugwood.org

Figure 3.5 – Emerald ash borer adult, *Agrilus planipennis.*
Photo credit: David Cappaert, Michigan State University, Bugwood.org

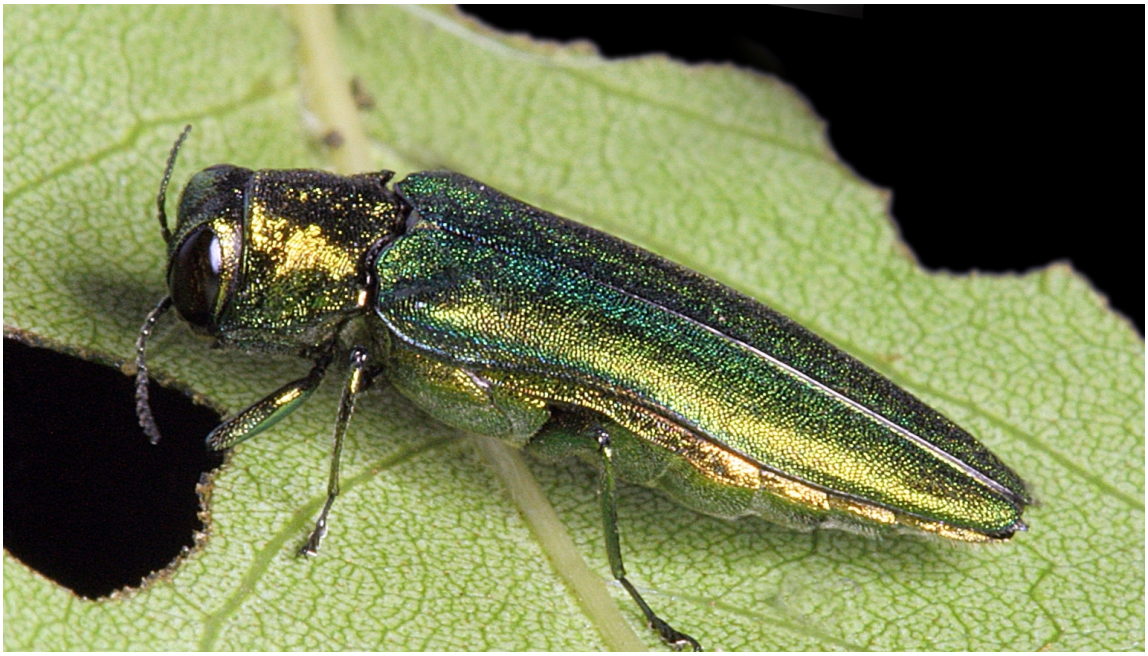

Figure 3.6 – Emerald ash borer adult, *Agrilus planipennis*.
Photo credit: David Cappaert, Michigan State University, Bugwood.org

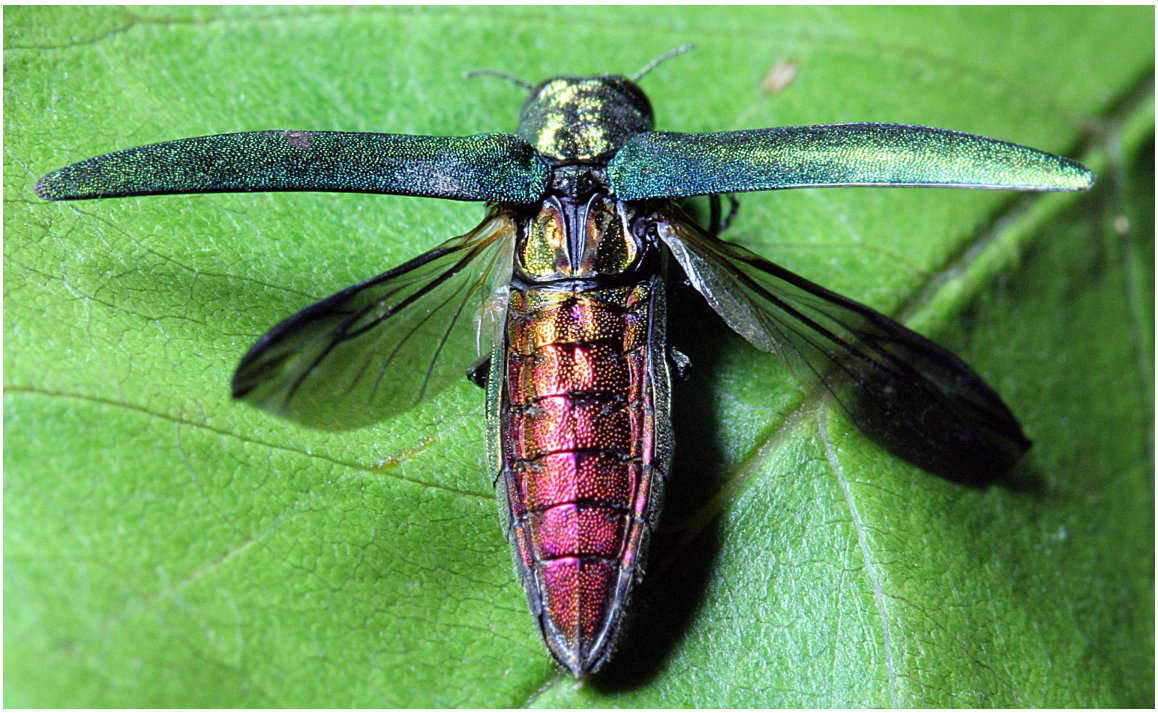

Figure 3.7 – Reddish purple dorsal side of abdomen.
Photo credit: David Cappaert, Michigan State University, Bugwood.org

Figure 3.8 – Emerald ash borer larvae with diagnostic bell shaped abdominal segments 5 – 7.
Photo credit: David Cappaert, Michigan State University, Bugwood.org

Figure 3.9 – Newly deposited egg with creamy white coloration.
Photo credit: Houping Liu, Michigan State University, Bugwood.org

Figure 3.10 – Mature egg with amber coloration.
Photo credit: Houping Liu, Michigan State University, Bugwood.org

occurs in late spring, and adults begin to emerge at around 230-260 degree days, using base 10° C (Brown-Rytlewski, 2005). Adults leave the pupation chambers via a distinct D-shaped exit hole in the bark. Adults fly to feed on ash tree leaves before they can mate, and prefer to feed on ash leaves the remainder of their lives. Adults can be found on warm sunny days flying around ash tree trunks and branches. They land on the bark to mate or to lay eggs (Bauer et al, 2003a.). An adult female can lay between 50-90 eggs in her lifetime (Poland, 2006).

Emerald Ash Borer Management

Cultural practices aid in reducing the EAB population and slow spread to new uninfested areas. Rapid removal of infested, dead and dying trees will help lower population numbers and reduce the pressure on healthy trees. It is important that removal is coupled with prompt chipping or burning of infested material. Although EAB prefers stressed trees for oviposition, they are known to readily attack even healthy mature trees (McCullough, 2008). Maintaining tree health via supplemental irrigation, mulching, and fertilization may help the tree to recover from minor infestations, but even good tree health will not prevent EAB attack.

It is also important that new plantings include EAB non-host species. Current research states that in North America, EAB only completes its lifecycle on ash species (McCullough, 2008). EAB females will sometimes make ovipositional "mistakes" and deposit on non-host species such as black walnut (*Juglans nigra*), American elm (*Ulmus americana*), privet (*Ligustrum* sp.), and shagbark hickory (*Carya ovata*) in the field (McCullough, 2003). Development on these non-host species is impaired and larvae are not likely to mature. However, there is some evidence that white fringetree

(*Chionanthus virginicus*) (in the same family as ash – Oleaceae) may be a suitable host to EAB and needs further research to assess how damaging EAB could be to this native shrub (Hannah, 2014).

There are a number of chemical options currently recommended that directly control EAB in ash trees. Application methods include soil injection or drenches, trunk macro-injections, systemic bark sprays, and trunk/branch/foliar cover sprays. Insecticides with systemic action are likely to be more efficient at maintaining tree health, plus they can last for a longer period of time. Two insecticides used for soil drenches and injections are imidacloprid and dinotefuran (Herms, 2014). A soil drench is possibly the easiest form of application and is often used by homeowners. Soil drenches merely require a bucket or watering can to pour the diluted insecticide over the soil at the base of the trunk. Some insecticides, such as imidacloprid, readily bond to organic material, so it is important not to apply the mixture over mulch or leaves. Any organic material should be raked out to a distance of 18 inches or more (Herms, 2014) and the mixture should be directly applied to the mineral soil. The area within 18 inches of the trunk is where there is the highest density of fine roots that will take up the chemical applied. The same products used as soil drenches are applied as soil injections. This type of application requires special equipment and is limited to use by only professionals. Soil injections have the advantage of bypassing any organic mulches and placing the insecticide in direct contact with fine roots. Both soil drenches and injections should only be done when the soil is moist, and not excessively wet or dry. Wet soils or soils with high water tables increase the risk of runoff, and dry soils reduce the amount of chemical uptake by the roots.

Macro-injection is becoming more and more popular due to limited environmental exposure, especially for non-target organisms. When done correctly, macro-injections are useful for sites where soil-drenches should not be done, such as excessively wet soils, sandy soils, or compacted soils (Herms, 2014). Two of the most common and effective macro-injection treatments are imidacloprid (Imicide®) and emamectin benzoate (TREE-äge™)(Herms, 2014). Macro-injections involve drilling holes into the base of trees and thus, can be damaging if done yearly. Treatments that are effective for longer than one year will allow for previous holes to seal before the next treatment is needed. Some treatments, including some formulations of imidacloprid and emamectin benzoate, have been shown to be effective for at least two years (Herms, 2014). In a study done by Smitley (2010), applications of emamectin benzoate made in mid-May of 2005 have been shown to be close to 100% effective for three years. In 2008, untreated trees had an average of 28.7 ± 21.5 EAB larvae per m^2 of bark surface, compared to treated trees that had 0 ± 0 larvae per m^2 (Smitley, 2010). It is thought that the timing of the application in mid-May allows the insecticide to be distributed throughout the tree and be present when EAB eggs hatch and the young larvae begin feeding on treated tissue in July. It is more effective to target the earlier instars rather than late instars and adults because enzymes that detoxify insecticides vary greatly between instar stages, with younger larvae usually being more susceptible (Yu, 1983).

Systemic trunk sprays have the advantage of being non-invasive and having rather fast application times. When done properly, there is little drift and the insecticide does not enter the soil. Dinotefuran is the only product labeled for this technique. This product is more water-soluble than imidacloprid, and easily moves through the bark and

is translocated through the tree (Herms, 2014). Efficacy of this technique is similar to an imidacloprid soil drench, and lasts for about a year (Herms, 2014).

Cover sprays of permethrin, bifenthrin, cyfluthrin, and carbaryl are also effective at controlling EAB adults and newly emerged larvae that haven't bored into the tree. Timing of these sprays is crucial. The first application should be made at beetle emergence at about 500 growing degree days (base 50° F), or when black locust (*Robinia pseudoacacia*) is in full bloom. A second application should be made about four weeks later. Cover sprays also run a high risk of affecting non-target organisms, as these chemicals are broad-spectrum and not contained within the tree.

Most of these recommended treatments are restricted use products that require application by certified applicators. Thus, homeowners are often not able to apply the insecticides themselves. Injection treatments also require the use of specialized equipment not available to homeowners. Thus, it is recommended that they contact a certified arborist in their area to discuss treatment options.

The selection of trees to be treated must be carefully evaluated. There is no value in treating a tree that will need to be removed in the near future due to other impending reasons. Examples of trees that should not be treated include trees under overhead power lines, trees next to structures, trees in poor health, or trees with no added value. Ash trees under overhead power lines will grow too close to the wires and will need to be either routinely trimmed or removed. When a tree is repeatedly trimmed to accommodate the overhead wires, the tree will likely become disfigured and will require regular maintenance to prevent branches from becoming entangled in the wires. These trees should be removed and replaced with a species that will not encroach into the lines.

Trees next to structures are also not good candidates for treatment because their roots increase in number and in size and have the potential to damage building foundations, sidewalks, and other structures. Canopies of these trees may also create hazards because they often become unbalanced and heavy on one side due to shading or physical restriction of the opposite side of the tree.

Careful inspection and assessment of tree health is important before deciding to treat. When trees have visible openings in the trunk or in larger branches, it is possible they have been exposed to a fungal infection. Heart rots caused by fungi (white rot and brown rot) weaken a tree's structural integrity, and trees may fail in strong winds or ice storms. Conks (fungal fruiting bodies) and mushrooms growing from the trunks of trees are good signs of fungal rot in a tree.

Ash trees that have been previously attacked by other native borers may not make good candidates either. Ash/lilac borer (*Podosesia syringae*), flatheaded appletree borer (*Chrysobothris femorata*), and roundheaded borers like redheaded ash borer (*Neoclytus* acuminatus) and banded ash borer (*Neoclytus caprea*) can all do substantial damage to young trees especially. If damage is extensive enough, it may not be a good idea to treat these trees.

Trees that do not provide any specific benefit to the owner would not be worth the time and money to treat. These trees can be left standing until EAB has been confirmed in the area. Once treatment is recommended for the area, the tree should be taken down. This kind of action will help reduce the number of host trees and in turn reduce EAB populations. A reduced EAB population may reduce pressure on other trees.

Trees that make good candidates for treatment are trees in good health, have good structure, provide shade or windbreak, or are of historical significance. Established trees that provide shade for homes likely save the homeowner in energy costs for cooling. These savings are more than enough reason to warrant a treatment.

Preparation for Arrival

In places where EAB has not been confirmed, but is anticipated to arrive in years to come, communities should be preparing for its arrival. Figure 3.11 illustrates how quickly EAB can decimate a community's ash tree population if no control action is taken. Distribution of educational materials to the public will help the efforts in controlling EAB. An educated homeowner may be more likely to take action early rather than wait until it is too late to treat. The movement of infested firewood may also decrease if the public has more information on how EAB is spread.

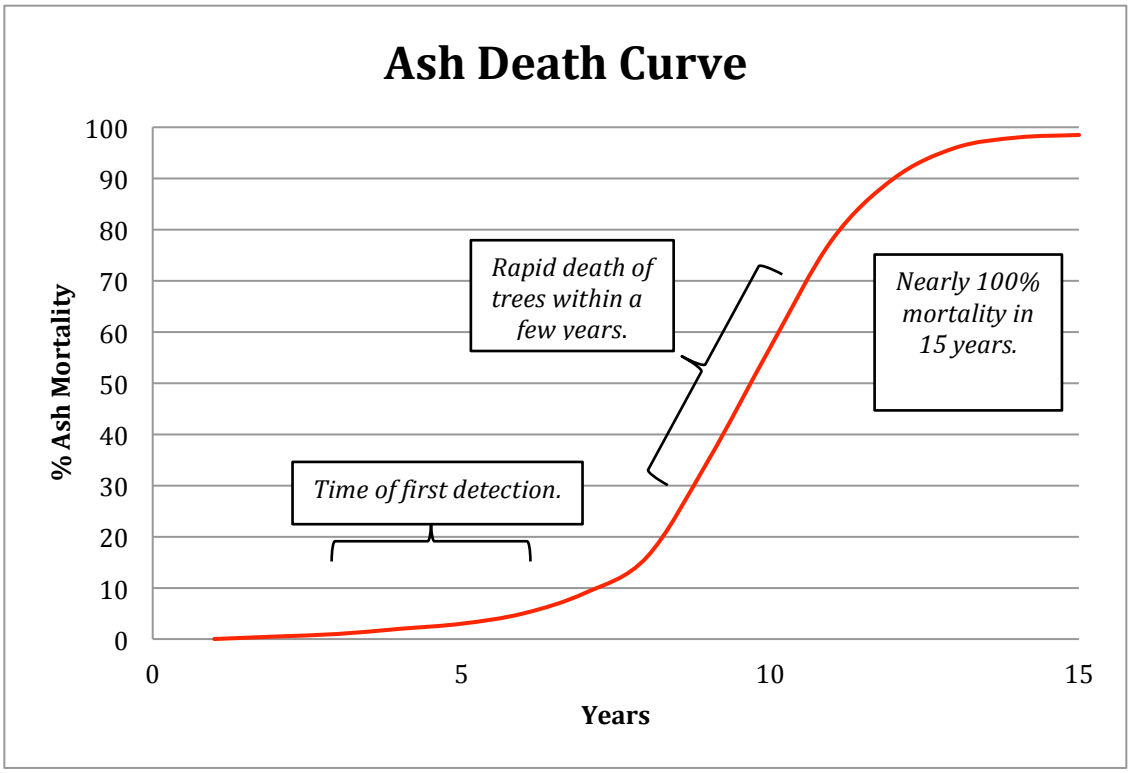

Figure 3.11 – If left unchecked, a community's ash tree population can be decimated in just 15 years. (Adapted from Herms, Ohio State University, 2012.)

Treatment of ash trees should only be considered when EAB has been positively identified within 15 miles of the trees in question (Stepaned, 2012, NFS/CTAP, 2013). EAB is often first confirmed several years after its actual arrival, and the damage it has done in those years is not usually too extensive (NFS/CTAP, 2013). Treatment done before this time is not recommended, and is unnecessarily introducing pesticides into the environment. Once EAB has been confirmed in an area, trees that are already infested can be saved. However, the amount of damage previously done will determine whether or not the tree is worthy of treatment. If a tree is selected for treatment and is known to be infested, a canopy assessment is a simple way to determine eligibility. Trees with 0%-30% canopy loss are good candidates for treatment and are more likely to recover from the infestation (Cranshaw, 2014). The damage in these trees is minimal enough to where vascular cambium tissues are able to recover and reestablish vascular tissue connections into the canopy. Trees with over 50% canopy dieback have had extensive damage done to the cambium and will likely not recover (NFS/CTAP, 2013).

Municipal programs in infested areas range from removal of trees without replacement, treatment of select trees and removal of others, or removal and replacement. While complete removal may directly solve the problem of harboring insects, it severely detracts from the aesthetics and economy of a neighborhood. Large and established trees in any neighborhood add to property values and people's well being (Tyrväinen, 2000; Bolund, 1999; Dwyer, 1992).

Ash trees are strong and durable trees, and are an important component of urban forests. Municipal governments and homeowners alike should seriously consider the numerous benefits ash trees are providing, and make their decisions carefully. These

added benefits likely outweigh the biennial, or even triennial, costs associated with treatment over a few decades. Delaying serious infestations will allow time for new plantings to become established, and older ash trees to be phased out where needed.

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CHAPTER 4

EFFICACY OF COMMON SANITATION CHEMICALS ON PRUNING TOOLS

Introduction

Sanitation of pruning tools is an important issue that is often overlooked by homeowners and professionals alike. However, they would benefit from paying closer attention because many disease causing organisms are moved successfully from diseased to healthy plants via infested pruning equipment (Agrios, 2005; Broadbent, 1961; Grosclaude, 1973; Murdoch, 1977; Goodman, 1988). There is solid evidence that sanitizing tools between cuts reduces the transmission of certain plant diseases (Chalker-Scott, 1999). Diseases involving the vascular system or those that create oozing stem cankers are especially prone to mechanical transmission via pruning tools (Chalker-Scott, 1999).

A variety of chemicals are available that can be used to sanitize pruning tools, but only a select few are suitable for practical use in the field. The physical action of sanitizing tools also takes a significant amount of time, and workers may not have time necessary for sanitizing tools in the field.

In comparison, products used in the medical field face the same kinds of difficulties. The contact time specified on the labels of the products is often too long to be practically followed (Rutala, W. A., 2008). Depending on the chemical, recommendations require anywhere from a one to ten-minute wait time after spraying tools with a sanitizing agent (Heimann, 1995; Schalau, 2012). In reality, pruning tools

are not regularly sanitized between cuts. This is partially because managers and laborers believe it is impractical to disinfect and wait between each cut. This investment of time may be worth it in the end if it prevents the spread of a lethal disease to a valuable tree or trees. Rather than completely ignoring the sanitation process, perhaps it would be beneficial to sanitize in strategic (i.e. highest risk) situations: 1) between cuts when working with infected plants, 2) between individual trees, and 3) where a transmissible disease has been confirmed in the area.

Dutch elm disease (DED) is caused by the fungi *Ophiostoma ulmi* and *O. novo-ulmi* (Stipes, 1981). The fungi infect the xylem tissue of susceptible elm trees, and persist in dead wood as saprophytes (Agrios, 2005). When removing tissue from a diseased elm tree as a curative measure, it is critical that the final cut, closest to the trunk, be made with a clean tool. Without a clean final cut, the efforts to remove diseased tissue could be ineffective. Both spores and hyphae of the fungi are capable of creating new infections in healthy wood (Agrios, 2005). Murdoch (1977) demonstrated that *O. ulmi* was capable of surviving in chainsaw oil. Whether or not the fungi could survive the elevated temperatures of the oil and bar of the chainsaw while in use has yet to be researched. As a precaution, the use of a second chainsaw with clean oil may be advantageous when making a final cut.

The purpose of this preliminary study was to test the effectiveness of four recommended and commonly available chemicals for use to sanitize tree-cutting tools. These chemicals were tested on three types of tree-cutting tools. The disease causing fungi *O. ulmi O.* and *novo-ulmi* were used as the target organism to test. The chemicals chosen for testing were those that would be practical for field use. Products that are

highly flammable or acutely toxic to humans were omitted from testing for practicality reasons.

Materials and Methods

This preliminary study was carried out at The Morton Arboretum plant pathology lab in Lisle, IL, during the summer of 2014. Tools chosen for this experiment were: chainsaw, hand saw, and hand pruners. These tools are commonly used to prune trees. Each tool was treated as a separate experiment. Chemicals chosen as treatments were rubbing alcohol (70% isopropyl alcohol), 10% bleach solution (0.6% sodium hypochlorite), Lysol® (58% ethanol, 0.1% Alkyl (50% C_{14}, 40% C_{12}, 10% C_{16}) dimethyl benzyl ammonium saccharinate), and ShockWave Green24® (4.85% citric acid, 0.003% silver ion). Ethanol (a common and highly effective recommendation) was not used in this experiment as a treatment because it is not practical to obtain for use in the field.

An American elm (*Ulmus americana* L.), severely infected with DED, was selected for removal at The Morton Arboretum, Lisle, IL. Wood tissue from this tree would serve as inoculum for the experiment. Samples for the chainsaw experiment were collected in the field from large diameter branches. Diseased branches from the same tree were taken to the lab for use as inoculum material for both the hand saw and hand pruners sections of the experiment. All procedures were done aseptically when possible utilizing ethanol, flaming of tools, and a laminar flow hood.

All samples collected for all tools are completed in the following manner. To eliminate contamination, tools were sanitized with 95% EtOH before every chemical treatment. Doing so would ensure any viable fungal parts collected would be from the previous cut only. Twelve pre-test (control) samples were taken to be cultured later as a

check. These controls were taken by cutting into the wood and placing samples onto media without chemical treatment. Samples for the treatments were collected with a sanitized brush and/or forceps into a sterile Petri dish with one sheet of sterile Whatman™ number-2 filter paper. After ethanol sanitation, the tool was used to cut into diseased wood far enough to cut into infected tissue. Cuts were made into five to six locations to increase the probability of contacting fungi. The blade was then sprayed with 70% isopropyl alcohol until dripping. Samples were collected immediately after spraying, and labeled as "spray-and-go" (SG). Enough sample was collected that could produce 40 pieces for culturing. Two minutes after spraying, samples were collected again and labeled "2-minute wait" (2-min). The same procedures were followed for each of the other chemicals, starting with the ethanol sanitation step. To comply with instructions for fungal control with Green24, the 2-minute wait was replaced with a 10-minute wait time for this treatment only (Table 1).

Table 4.1. Treatments applied to each type of pruning tool.

	Spray-and-Go	2-minute wait	10-minute wait
70% isopropyl alcohol	I-SG	I-2	X
Lysol	L-SG	L-2	X
10% bleach	B-SG	B-2	X
Green24	G-SG	X	G-10

In order to comply with its instructions, Green24 was treated with a 10-minute wait rather than a 2-minute wait.
I = 70% isopropyl alcohol, L = Lysol, B = 10% bleach, G = Green24, SG = spray-and-go, 2 = 2-minute wait, 10 = 10-minute wait, X = no treatment.

Chainsaw

Stihl® MS 441 and MS 261 chainsaws were utilized for the experiment. The chainsaws were recently sharpened, and therefore efficient at throwing sawdust away. Very little debris remained on the chains for collection. After spraying chemical treatments, a small amount of residue was collected from the chain and blade areas with a brush. The chainsaws were opened and sprayed with the sanitizing agent, and fresh dust was also collected from the chambers. Samples were taken just after spraying and again after the respective wait period.

Hand Saw

A Silky® IBUKI 390 hand saw was used for the hand saw section. All spraying of chemicals took place under a fume hood. Samples were collected from the saw teeth using forceps. The same procedures for collecting samples from the blade were followed as described above.

Hand Pruners

A pair of Felco® 4 hand pruners was used for the hand pruner section. Spraying of the hand pruners also took place under a fume hood, and procedures for collecting samples was followed as closely as possible. Because the hand pruners yielded very little visible debris, residue left on the surface was collected with sterile cotton swabs. The used cotton swabs were placed in sterile Petri dishes with filter paper and labeled accordingly. The cotton swabs were cut into small pieces (~1mm diameter) with stainless steel dissecting scissors for culturing.

Culturing

All samples were cultured onto acidified PDA (Difco™ & BBL™ Manual, 2nd ed.). Each treatment for all tools received 10 plates, each containing 4 pieces of woody tissue or cotton swab fibers, for a total of 40 samples per treatment. All plates were labeled accordingly, and sealed with Parafilm M®. Cultures were then placed into an incubator set at 20° C. Isolates were examined weekly for three weeks for *Sporothrix* (an anamorphic state of *O. ulmi* and *O. novo-ulmi*) growth and sporulation (Agrios, 2005). All identifications were done morphologically. Samples that were negative for *Sporothrix*, but grew another fungus were marked as other and set aside for future identification. Plates that had no growth at all were labeled as negative, tallied, and destroyed.

Results and Discussion

Results in table 2 show the number of positive *Ophiostoma* spp. and other fungi cultures out of the 40 original samples for each treatment. Samples with no fungal growth are tallied under negative. All control samples were positive for *Ophiostoma* spp., confirming that *Ophiostoma* spp. was consistently present in the wood samples.

Lysol was consistently the best performer in sanitizing pruning equipment, followed by 70% isopropyl alcohol. All treatments seemed to be adequate for destroying *Ophiostoma* spp. except for one outlier. Both Lysol and isopropyl alcohol performed better than bleach and Green24 in destroying other fungi. Although there was no *Ophiostoma* spp. found in the Green24 treatments, many of them had growth of other fungi. The high occurrence of these other fungi lead to speculation as to the effectiveness of Green24 at disinfecting other plant pathogenic fungi or bacteria. Research on other specific pathogens should be carried out to determine the answer to this question.

Tool complexity may have had an effect on the efficacy of treatments as well. The chainsaw, the most complex tool, seems to have less complete control (47.8%) of fungi than the simpler handsaw (75.0%) and pruners (90.0%). Furthermore, the handsaw has less complete control of fungal growth than pruners. This may suggest that simpler tools are easier to effectively sanitize in the field.

There was an interesting outlier in the chainsaw-bleach data. There were many more occurrences of *Sporothrix* in the 2-min bleach treatment compared to the spray-and-go. This suggests there could have been contamination while performing this part of the study. It does not seem logical that pathogens exposed to 10% bleach for two minutes longer than the spray-and-go treatments would have a higher survival rate. This could

have happened because it is difficult to create aseptic conditions in the field resulting in inadvertent contamination from flying sawdust infested with *Ophiostoma* spp.

This experiment demonstrates that not all organisms are eliminated from pruning equipment after proper sanitation recommendations. Some products are more efficient at removing the plant pathogen *Ophiostoma* spp. than others. Other organisms were found in all treatments, but whether or not these organisms are plant pathogens is not known. Future research projects should be carried out to further explore the significance and consistency of these results. It is still recommended that sanitation be a part of protocol in the field because it could reduce the chances of cross-contamination. Even if working with healthy plant material, it is recommended that workers sanitize before work, at noon, and after work. Creating habits like this will greatly reduce the potential for mechanical infection when working with diseased material.

Table 4.2. Numerical results of preliminary screening.

Chainsaw			
Treatment	***Ophiostoma* sp. Y/N**	**Other Y/N**	**Neg Y/N**
I-SG	0	2	38
I-2	0	17	23
L-SG	0	0	40
L-2	0	0	40
B-SG	0	40	0
B-2	31	9	0
G-SG	0	35	5
G-10	0	33	7

Hand Saw			
Treatment	***Ophiostoma* sp. Y/N**	**Other Y/N**	**Neg Y/N**
I-SG	0	0	40
I-2	0	0	40
L-SG	0	0	40
L-2	0	0	40
B-SG	1	20	19
B-2	0	25	15
G-SG	0	16	24
G-10	0	18	22

Hand Pruners			
Treatment	***Ophiostoma* sp. Y/N**	**Other Y/N**	**Neg Y/N**
I-SG	0	7	33
I-2	0	16	24
L-SG	0	0	40
L-2	0	0	40
B-SG	0	1	39
B-2	0	0	40
G-SG	0	0	40
G-10	0	8	32

Table 2. Number of positive samples for *Ophiostoma* spp. or other fungi out of 40 total samples. L = Lysol, I = 70% isopropyl alcohol, B = 10% bleach, G = Green24, SG = spray and Go, 2 = 2-minute wait.

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