THESIS

DEVELOPING A KILN TREATMENT SCHEDULE FOR SANITIZING BLACK WALNUT WOOD OF THE WALNUT TWIG BEETLE

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2012

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ABSTRACT

DEVELOPING A KILN TREATMENT SCHEDULE FOR SANITIZING BLACK WALNUT WOOD OF THE WALNUT TWIG BEETLE

Geosmithia morbida is a fungus that causes numerous cankers on branches and trunks of walnut tree species (*Juglans* spp.), hence the common name "Thousand Cankers Disease" (TCD), which results in widespread morbidity and ultimately, tree mortality. This fungus is vectored by the walnut twig beetle (*Pityophthorus juglandis*) that feeds aggressively in the bark. Subsequently, cankers develop around the beetle galleries in the phloem.

TCD is currently a major concern in Colorado. The beetle and fungus have been identified and confirmed in three states within the native distribution of black walnut trees; if the fungus expands beyond the quarantined counties and throughout the native range of black walnut (*J. nigra*), it could have devastating impacts on the nut and timber production industries. Black walnut wood products are valuable for their strength properties and rich dark color. Developing a protocol for heat-treating black walnut lumber and logs with bark intact is important so that they can be sanitized and then safely used.

The purpose of this research was to determine whether the International Plant Protection Convention (IPPC) International Standards for Phytosanitary Measures (ISPM-15) standards and United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ) Treatment T314-a/c regulations are sufficient to kill live beetles in the bark. The thermotolerance of the walnut twig beetles was evaluated by subjecting walnut twig beetle populations at all stages (including eggs, larvae, pupae and adults) to a series of time and temperature regimens. This experiment was conducted from October 2011 to February 2012 by heating walnut twig beetle-infested black walnut wood in a laboratory oven. The heat-treatments were developed based on the ISPM-15 standards and USDA APHIS PPQ Treatment T314-a/c regulation standards centered on internal wood temperature. The treatments ranged from 42°C to 71.1°C (108°F to 160°F) and lasted between 30 and 120 minutes. The ability of adult beetles to emerge was used to evaluate if the treatment was successful.

Results from the emergence trials showed that adults were able to survive up to 48°C (118°F) but no survival of any stage of beetle development was detected at 50.1°C (122°F) when wood samples were heated for 30 minutes. Results suggest that walnut twig beetle survival is variable depending on heating conditions, and an internal wood temperature of 56°C (133°F) for 30 minutes should be considered the minimum for safe treatment of walnut lumber and wood with intact bark.

ACKNOWLEDGEMENTS

Thank you to my committee members Kurt Mackes, Ned Tisserat and Rocky Coleman. Thank you to Bill Jacobi, Whitney Cranshaw, Emily Peachey and Rachael Fithian in the Bioagricultural Science and Pest Management Department at Colorado State University (CSU) for your love of crawly critters and guidance. I am grateful for the hard work and am indebted to Jon Hubert of Singing Saw Woodworks, Kathleen Alexander and Kendra Nash of the City of Boulder, Craig Jones and Tim Reader of the Colorado Wood Utilization and Marketing (CoWood) within the Colorado State Forest Service (CSFS), and John Linz of American Property Services, Inc. For log acquisition, thank you to Ted Thompson, Rob Davis, Steven Traylor, and Mike Swanson of the City of Denver. For laboratory space, Jim Self from the CSU Soils Lab and Chad Hoffman for the storage space in the Fire Science lab in the department of Forest and Rangeland Stewardship. Thank you to the United States Department of Agriculture Forest Service for the American Reinvestment and Recovery Act (ARRA) funding provided through a grant from the CSFS. Thank you to Mike Eckhoff for being a huge pillar of support, a grand source of enthusiasm and passion toward education, and ultimately for pushing me to finish and be an “A” student. Finally, thank you to my friends and family for all of your love and support. A special thank you to my grandpa, Mike Mullins, who always told me to go to college, well here it is. I love you and miss you. R.I.P.

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APHIS: Animal and Plant Health Inspection Service

ARRA: American Recovery and Reinvestment Act

CoWood: Colorado Wood Utilization and Marketing

CSFS: Colorado State Forest Service

CSU: Colorado State University

EAB: Emerald Ash Borer

IPPC: International Plant Protection Convention

ISPM-15: International Standards for Phytosanitary Measures

PPQ: Plant Protection and Quarantine

SG: Specific Gravity

TCD: Thousand Cankers Disease

USDA: United States Department of Agriculture

WTB: Walnut Twig Beetle

CHAPTER 1: INTRODUCTION

1.1 Introduction

An article from the Boulder, Colorado online newspaper, *The Daily Camera*, reported that "'Last Man Standing' gets it wrong on black walnut trees." The story refers to the "Tree of Strife" episode of the popular sitcom starring Tim Allen, where a Siberian elm was cast in the role of a black walnut. The article states that the character cast as the city forester and council chair diagnoses the "black walnut" as having thousand cankers disease (TCD) by merely glancing at the bark of a branch that fell from the tree. The act of just glancing at the branch is a laughable offense if you are familiar with the tree and disease. Foresters and pathologists have to pry the bark off to even see that there are cankers affecting the health of the tree. However, the article gets it right when it mentions that "the problem with leaving the diseased trees standing is the mobility of the walnut twig beetle…which carries the fungus… from tree to tree" (O'Meara, 2012). The TV episode took a light approach to TCD and the black walnut value, in this case a series of memories and sentimental values, but in reality, the value loss and the disease continue to be major issues.

Black walnut wood is highly prized for wood products. A large, veneer grade black walnut log can be worth from $3 to over $15 per board foot. According to the Greenwood Nursery (2012) website, the most that has ever been paid for a black walnut log is $90,000 in the 1980's. However, because of Colorado's climate and dry soils, black walnut trees are slow-growing and are typically found in residential landscapes that promote an open growth pattern that is more appropriate for nut production. The ideal growth structure for veneer logs is a straight trunk with minimal small branches and a tight canopy. Unfortunately, a black walnut tree in Colorado can take more than 20 years to grow to a size that is worth much more than fifty dollars, as Denver residents found during the summer of 2011. Black walnut trees that were located on private properties and were condemned by the City of Denver's Department of Forestry had to be removed at the property owner's expense as per city ordinances. The trees were infected with TCD, and infested with hundreds and more likely, thousands of WTB.

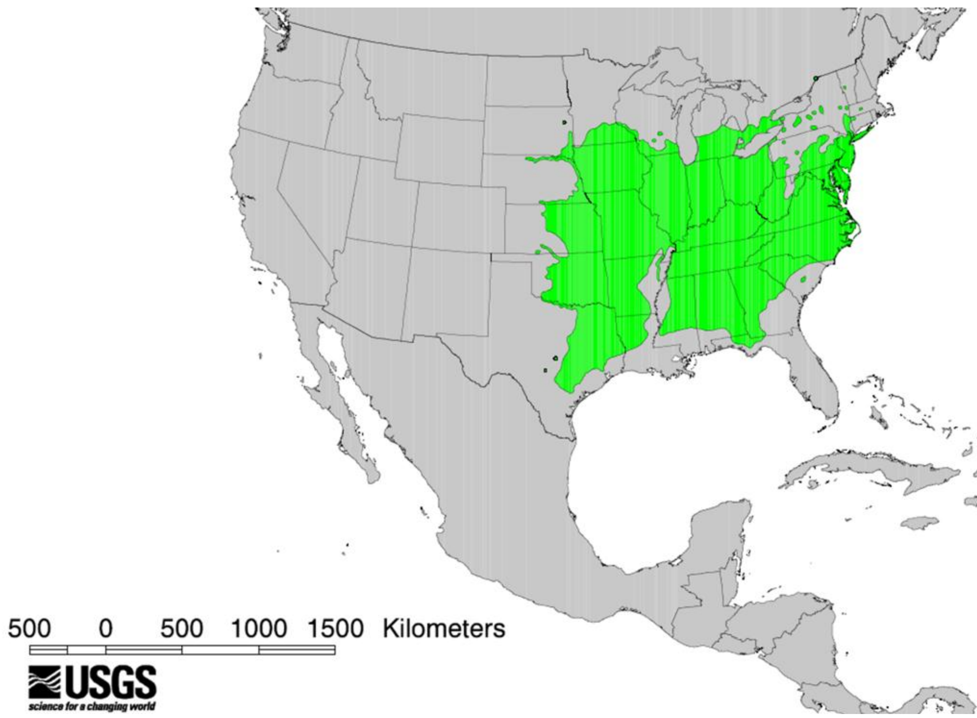
1.2 Introduction to the Host Tree: Black Walnut and Symptoms

Black walnut (*Juglans nigra*) is a monoecious, deciduous tree that has been widely planted throughout the western United States as an ornamental landscape tree. In Colorado, these trees grow slowly under the drier soils and semi-arid climate. In the native range where they are typically a large tree that reaches an average height of 15-23 meters (m) and up to 38-46 m maximum (50-75 ft. and up to 125-150 ft. maximum). According to the 'Trees Recommended for the Front Range' an online publication from the CSFS, Colorado Tree Coalition and the United States Department of Agriculture (USDA) Forest Service, black walnuts are considered to be large shade trees reaching heights around 23 m (50 ft.) in Colorado climates. In Colorado, these trees are typically found in urban and residential areas. The leaves are pinnately compound and can reach up to 61 cm (24 in) in length with 15-23 leaflets. The bark is dark brown to grayish black and divided by deep, narrow furrows forming a roughly diamond-shaped pattern (Dirr, 1997).

The genus *Juglans* contains 15 different species that grow on four different continents including South America, Europe, Asia and North America. There are six native species found in North America, two of which are utilized for commercial products

(*J. cinerea* and *J. nigra*) (Alden, 1995). The native distribution of black walnut trees is found throughout the eastern U.S. (Figure 1.1).

“Digital Representations of Tree Species Range Maps from "Atlas of United States Trees" by Elbert L. Little, Jr. (and other publications)”



Green indicates black walnut native range.

Figure 1.1. Map of black walnut native distribution

Source: http://esp.cr.usgs.gov/data/atlas/little/

Small natural groves of black walnut are frequently found in mixed forests with moist, alluvial soils that have been heavily logged. On the western fringe of its range in Kansas, walnut is fairly abundant and frequently makes up 50 percent or more of the basal area in stands of several hectares (Burns, 1990). Pure stands of black walnuts are rare and these trees are usually found on the forest edge. Black walnuts exhibit allelopathy and other plants growing within the root system extent of black walnut trees are subjected to a toxin called juglone, which is produced in the leaves, bark, nut husks and roots of the trees. This toxin can be lethal to several coniferous species at high concentrations (Burns, 1990).

In a mixed forest, black walnut must be dominant or co-dominant to survive and is classified as shade intolerant. The growing season in the native range is about 140 days in the north and 280 days in western Florida. On the best sites these trees may grow up to 122 cm (48 in) per year. Mature trees with proper care, ideal environment and climate, can be ready to harvest for saw logs in 30-35 years with 41 cm (16 in) diameters. It may also be possible to produce veneer logs in 40-50 years (Burns, 1990).

Black walnuts have an almost white sapwood layer, while the heartwood is light brown to very dark and often has a purple cast and dark streaks. The wood is hard and has high shock resistance which makes it a great wood for products like furniture, fixtures, cabinets, gunstocks, novelties, interior paneling, and veneers. The wood is very resistant to heartwood decay and as mentioned in the USFS Products Laboratory publication Hardwoods of North America, black walnut is "one of the most durable woods, even under conditions favorable to decay" (Alden, 1995).

The weight properties of this species are typically as follows: specific gravity (SG) of green wood is 0.51 (range is <0.39 to about 0.88) and weighs about 929 kg/m^3 (58 lbs./ft^3) and at 12% moisture content the SG is 0.55 and weighs around 609 kg/m^3 (38 lbs./ft^3). SG is the ratio of wood density (oven dried weight divided by the volume of dried wood) to the density of water at 4°C (39.2°F) (density of water is constant). The change in SG is always based on the weight of the oven-dried wood, divided by the volume at the moisture content specified. This is why SG of green wood is less than SG at 12 percent. Wood shrinkage occurs below the fiber saturation point and has less volume as it dries (Mackes, 2012). This straight grained wood is easy to work with hand-tools and by machine (Alden, 1995).

The first black walnut decline was described in Utah and Oregon in the early 1990s. The original host tree is believed to be Arizona walnut (*J. major*), whose primary range is found in New Mexico, Arizona and Chihuahua, Mexico. Arizona walnut is most resistant and able to tolerate the beetle and fungus. The susceptible walnut species include: black walnut, Hinds walnut (*J. hindsii*), California walnut (*J. californica*), little walnut (*J. microcarpa*), Manshurian walnut (*J. mandshurica*) and to a lesser degree English walnut (*J. regia*). Other common species found in the family Juglandaceae, pecan (*Carya illinoiensis*, native) and butternut (*J. cinerea*, native), do not develop the cankers and appear to be resistant to the pathogen when tested (Newton*,* 2009) (Table 1.1).

Table 1.1. Table of Juglandaceae Trees Distribution, Uses, and Susceptibility

Species/Common Name	**Status/Distribution**	**Uses**	**Susceptibility**
Juglans californica California walnut	Native/Natural range restricted to southern California	Native tree	Susceptible (Utley *et al*., 2009)
J. cinerea butternut	Native/Natural range throughout NE U.S. and into southern Appalachian region	Nuts, ornamental, timber	Nil (preliminary) (Utley *et al*., 2009)
J. hindsii Hinds walnut or northern California walnut	Native/Natural range from CA to OR	Timber, rootstock for English walnut	Susceptible (Utley *et al*., 2009)
J. major Arizona walnut	Native/Natural range AZ, NM, Mexico (Chihuahua)	Native tree	Resistant (tolerant)
J. mandshurica Manshurian walnut	Exotic	Ornamental	Susceptible (Utley *et al*.,

			2009)
J. microcarpa little walnut	Native/Natural range restricted to scattered populations in NM, TX, OK, and KS	Ornamental, nuts (not commercial), rootstock in TX for non-native *Juglans* spp.	Susceptible (Utley *et al*., 2009)
J. nigra black walnut	Native/Natural range extends throughout eastern U.S. and into KS and Nebraska; planted throughout U.S.	Timber, nuts and ornamental tree; used as rootstock for English walnut grafts	Highly susceptible (Tisserat *et al*., 2009; Utley *et al*., 2009)
J. regia English walnut	Exotic/Planted in commercial groves particularly in CA (264.517 acres) and OR (1,460 acres)	Nut production – 99% of U.S. production of walnuts from CA English walnuts	Susceptible (Lauterback, 2007; Seybold and Leslie, 2009; Ford, 2009)
Carya illinoiensis pecan	Native/Natural range through Central U.S.; widely planted throughout U.S.	Nut production; ornamental	Nil (preliminary) (Utley *et al*., 2009)

Source: Newton, 2009. USDA Pathways Assessment (Refer to Appendix D: Diseases and other Damaging Agents: for Black Walnut)

During 2008 and 2009, Kolarik *et al.* (2011) found "*G. morbida* was isolated from necrotic phloem surrounding *P. juglandis* galleries in *J. major* in native stands in AZ and NM, but the fungus was not causing branch dieback or mortality in this species," suggesting that these walnut species are more tolerant to the beetle/fungus complex. However, trees susceptible to thousand cankers exhibit the following identifying symptoms:

- Sparse foliage or thinning of the canopy,
- Leaf yellowing or wilting or branch dieback toward the crown (i.e. top),
- Excessive staining of the bark surface,
- Presence of beetle holes in bark or galleries in branches or the trunk and
- Presence of brown to black tissue surrounding beetle galleries inside the bark. (Colorado State Forest Service, 2011) (Figure 1.2).

Infested and infected trees typically die three-to-four years after symptoms start to show. The celerity is a direct result of the aggressive feeding in the phloem layers where the WTB reside and galleries and cankers develop (Kolarik *et al.,* 2011).

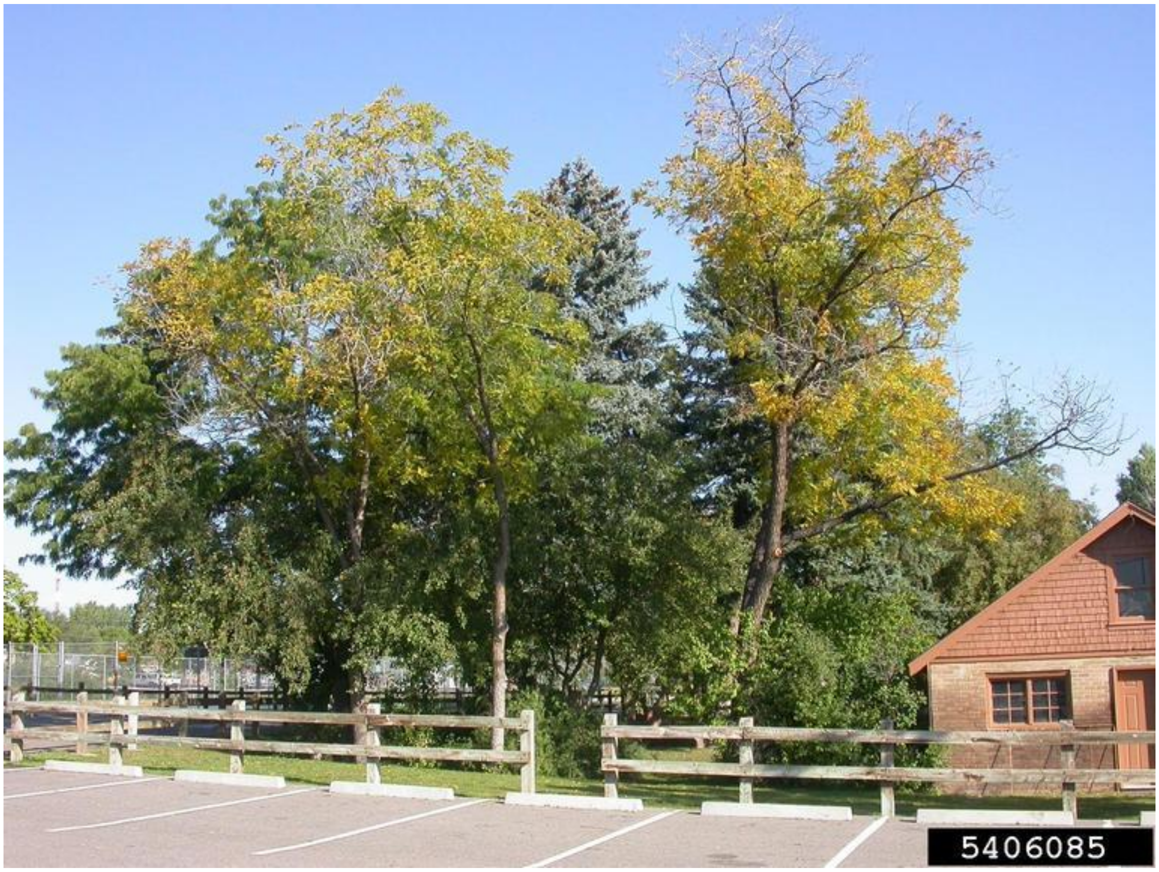


Figure 1.2. Black walnut trees showing symptoms of TCD

Source: Ned Tisserat, Colorado State University, Bugwood.org

1.3 Introduction to the Vector: Walnut Twig Beetle

The walnut twig beetle (WTB) (*Pityophthorus juglandis* Blackman, 1928) (Coleoptera, Curculionidae, Scolytinae) is a yellowish-brown bark beetle, about the same size as a pencil tip (1.5-1.9mm) (Figure 1.3). WTB is native to North America and was first described by M. W. Blackman in 1928 from specimens collected in New Mexico. *P.*

juglandis was first found on Arizona walnut (*Juglans major*) but may be native to other walnut species (Cranshaw and Tisserat, 2010).

Figure 1.3. *Pityophthorus juglandis* beetles (male)

Source: Steven Valley, Oregon Department of Agriculture, Bugwood.org

The WTB carries the fungal conidia spores on its elytra, the modified, hardened wing cover (Newton, 2009). However, "the walnut twig beetle apparently does not possess mycangia [the morphological structure to carry symbiotic fungi] for transport of the fungus but beetles are heavily contaminated externally by *Geosmithia* spores when they emerge from trees" (Cranshaw and Tisserat, 2010). Male beetles colonize newly cut branches then are joined by females and brood galleries are created; both sexes contribute to the aggregation pheromone to attract both sexes to the infested trees. Brood galleries that occur on the native host (*J. major*) are found on branches that are 1.5 cm in diameter or greater (Newton, 2009). Two, possibly three, overlapping generations and flight times from April to October have been recorded in Colorado (Cranshaw and Tisserat, 2010). It is also noted that for black walnut, tunneling and larval development only occurs in branches 2 cm and larger (Cranshaw *et al*., 2009).

According to the Cooperative Agricultural Pest Survey (CAPS) results from the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Plant Protection and Quarantine (PPQ) Center for Environmental and

Regulatory Information Systems (CERIS), twelve counties in Colorado have confirmed cases of the WTB and TCD (Figure 1.4).

"Infestation Survey Status of Thousand Cankers Disease – *Geosmithia morbida* 2009 to present"

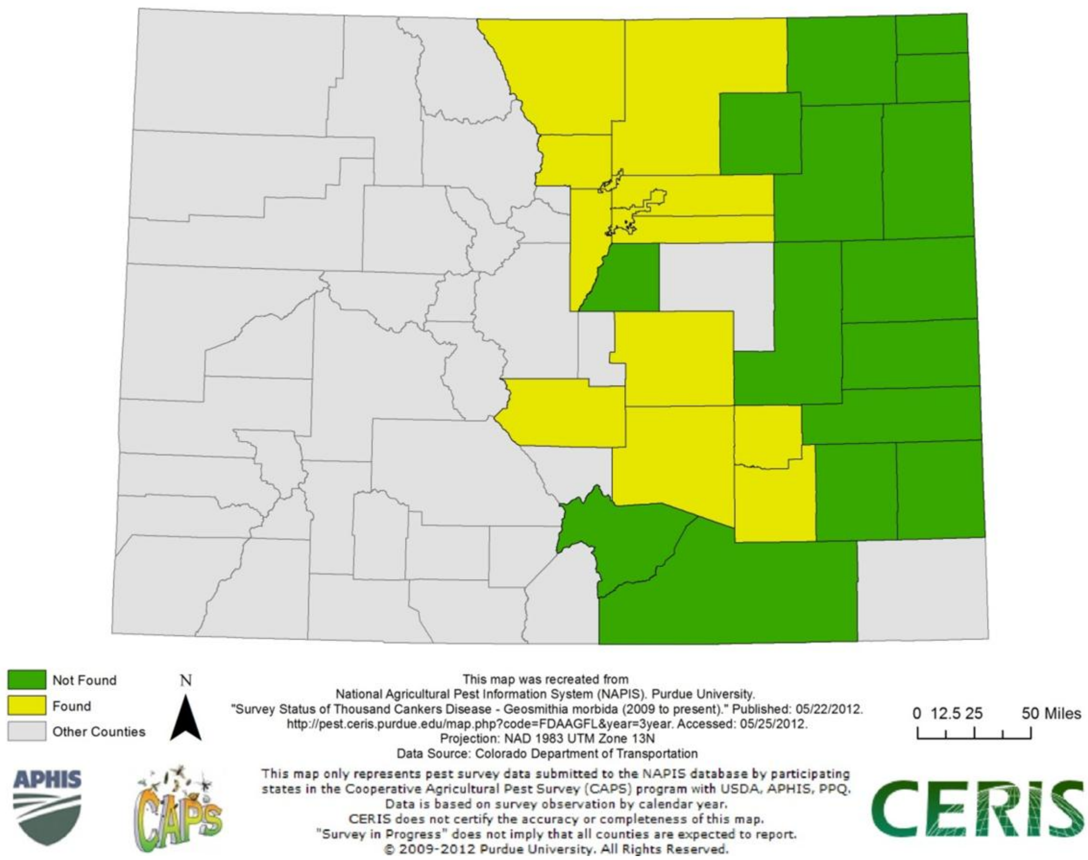


Figure 1.4. Map of Colorado counties with confirmed cases of thousand cankers disease. Source: http://pest.ceris.purdue.edu/map.php?code=FDAAGFL

Geosmithia morbida is not systemic. Systemic is defined as a pathogen capable of spreading throughout its host and other host trees (Helms, 1998), and therefore the fungus requires a vector to be moved (Cranshaw and Tisserat, 2010). A vector is any agent capable of transplanting a microorganism to a host (Helms, 1998). *Geosmithia* species can also be dispersed by wind or water (Kolarik *et al.*, 2008), but the WTB is the main vector for *G. morbida*. Concerns exist that other beetles could also vector this fungus (Table 1.2).

Table 1.2. Additional Beetles Capable of Vectoring *Geosmithia* sp.

Species	Information on potential vector
Pityophthorus lautus	**Distribution:** Northeastern and Midwestern US: MN and Quebec to KS and MS, including at extremes of range ME, MO, and NC (Wood, 1982) **Hosts:** *Juglans nigra* (Wood, 1982) **Comment:** Not a major pest, but known to attack *J. nigra* in native range (Wood, 1982)
Xylosandrus germanus	**Distribution:** In CA and throughout the native range of black walnut in the eastern U.S.; Asia (native); Europe (introduced) (CABI, 2007) **Hosts:** Polyphagous, including *J. nigra, Carya illinoiensis,* and many other hardwoods **Comment/Associated Fungi:** A significant pest of black walnut in the Midwestern U.S. and often associated with *Fusarium* spp. cankers; can attack vigorous trees, especially young trees in plantations (Katovich, 2004); two known *Geosmithia* species (*G. lavendula* and *G. obscura)* have been isolated from the mycangia of a congener. *X. matuliatus*, in Mississippi (Six *et al.*, 2009)
Xyleborinus saxesenii	**Distribution:** British Columbia, Ontario; Western U.S. and throughout the native range of black walnut (CABI, 2007); North America, Asia, Australia, Europe, and South America (Wood, 1982) **Hosts:** *J. regia* (Bright and Skidmore, 1997); polyphagous- multiple hardwood species (CABI, 2007) **Comment/Associated Fungi:** Not considered a major walnut species; beetles favor lower stumps and lower portions of dead and dying trees (Kolarik *et al*., 2008); found on black walnuts with thousand cankers disease in Colorado (Tisserat *et al*., 2009)
Xyleborinus ferrugineus	**Distribution:** MA south to FL and west to MI and southern CA; Hawaii; Mexico; Central and South America; tropical Africa; Asia; Australia (Soloman, 1995) **Hosts:** *Juglans* spp. *Carya illinoiensis*; has a host range of 180+ species worldwide (Katovich, 2004) **Comment/Associated Fungi:** Not considered a major walnut pest; most common attacking stumps and logs on the ground (Katovich, 2004); has a well-known symbiotic relationship with *F. solani* (Norris and Baker, 1967)
Hypothenemus eruditus	**Distribution:** From WV to MS (Baker, 1972) **Hosts:** *J. nigra* (wood and Bright, 1992); *J. regia* (Bright and Skidmore, 1997) **Comment/Associated Fungi:** Not known to be a significant pest of walnut; it is capable of carrying *Fusarium* spp. (Romon *et al*., 2007)

Source: Newton, 2009. USDA Pathways Assessment

1.4 Introduction to the Disease Causal Agent: *Geosmtihia morbida*

In 2011, the fungus was named *G. morbida*, based on "morphological and molecular methods (ITS rDNA sequences)" (Kolarik *et al.,* 2011). *G. morbida* is the first species documented as a plant pathogen within the genus and also within the Bionetriaceae fungal family. Kolarik *et al.,* (2011) found that "*Geosmithia* spp. are found typically in association with phloeophagous [phloem feeding] bark beetles (Kolarik *et al.* 2006, 2007, 2008) but also with woodboring ambrosia beetles where they can act as primary or auxiliary [secondary] ambrosia fungi (Kolarik and Kirkendall 2010)".

G. morbida is a dry-spored anamorphic fungus that colonizes the galleries (i.e. tunnels) built by the WTB as they feed on the phloem tissue of walnut trees (Tisserat *et al.*, 2009) (Figure 1.5). The fungal cankers that surround the galleries are usually restricted to the cork cambium. *G. morbida* expands in the phloem and outer bark causing a darkening of the tissues (Newton, 2009). However, the cankers eventually extend to the vascular cambium and are not usually seen unless a thin layer of bark is removed. A canker, defined by Helms (1998), is a disease of the bark and cambium that causes a usually well-defined sunken or swollen necrotic lesion.

When the bark is removed from a twig, branch or trunk, numerous small, roughly circular-to-oblong diffuse-type cankers can be detected (Figure 1.6). These cankers eventually coalesce and girdle the twigs and branches, resulting in progressive dieback and ultimately tree mortality when high vector population numbers are present. The numerous cankers found in the twigs, branches and trunks of infected trees have led to the common name "Thousand Cankers Disease" (TCD) (Cranshaw and Tisserat, 2010).

Figure 1.5. Walnut twig beetle galleries

Source: Whitney Cranshaw, Colorado State University, Bugwood.org

Figure 1.6. Walnut twig beetle in a necrotic lesion

Source: Whitney Cranshaw, Colorado State University, Bugwood.org

Before July 2010, the beetle/fungus complex had not been found on black walnut trees in the eastern U.S. However, after July 2010, there have been confirmed cases of infested and infected black walnuts found in Tennessee (2010) and in 2011 Pennsylvania and Virginia (Spaulding, 2012) (Table 1.3). TCD is a serious issue for eastern nut and timber producers and could have a devastating impact on the billion-dollar black walnut timber and nut industries (O'Meara, 2012). The discovery of the infested and infected walnut trees led to regulations restricting the movement of infested material (Appendices A, B, and C).

Table 1.3. Black walnut and *Geosmithia morbida* timeline

Black Walnut Timeline	
Year	**Happening**
1929	Walnut twig beetle described by W. M. Blackman *Pityophthorus juglandis*
1959	Found in Los Angeles on Southern California walnut
1988	WTB collected in Utah
1992	Cankers noted on trees in UT
1998	Oregon and UT observe walnut decline
2001	WTB first attributed to black walnut mortality in New Mexico and Colorado
2003	First report WTB found in Colorado Springs, CO and Idaho
2004	WTB Found in Boulder, CO
2005	WTB Found in Westminster, CO
2006	Pathogenic connection to fungus and beetle
2007	Pathogen is isolated from galleries in twigs and branches
2008	*Geosmithia* pathogen is isolated from declining black walnut trees
2009	Pathogen is isolated from declining black walnut trees
2010	*Geosmithia morbida* described and found in Tennessee
2011	*G. morbida* found in Pennsylvania and Virginia

The fungal canker of black walnut has been found and confirmed in several western states including California, Washington, Oregon, Nevada, Idaho, Arizona, Utah, New Mexico and Colorado (Tisserat *et al.,*2011) (Figure 1.7).

"States known to have Thousand Cankers Disease as of August 23, 2011"

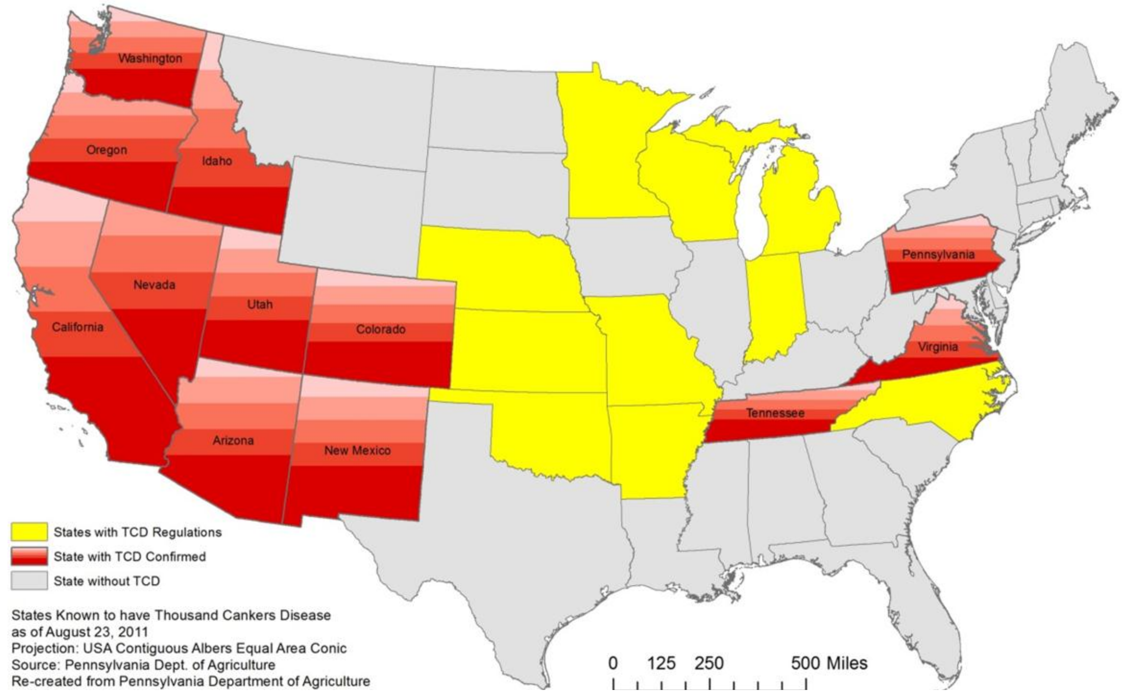


Figure 1.7. Map of known walnut twig beetle and thousand cankers disease infestation in the United States

Source: http://www.portal.state.pa.us/portal/server.pt/gateway

WTB is found throughout the western United States (Tisserat *et al.,* 2011) and until 2010 the Front Range of the Rocky Mountains in Colorado served as the eastern most extent of spread when it was found in Tennessee (Appendix D). It was also found in Virginia and Pennsylvania in 2011 (Appendices E and F). These states have implemented quarantine zones that restrict the movement of any black walnut wood from these sites.

1.5 Research Questions

The purpose of this project was to evaluate the efficacy of several heat-treatment schedules for sanitizing black walnut sawn lumber and slabs infested with WTB's and infected with TCD. This research was specific to heat-treating black walnut logs that had bark intact and were diagnosed with TCD. This methodology was not designed for treating standing live trees.

The goal was to develop an efficient and effective heat-treatment kiln schedule for private and commercial lumber, firewood and other wood product operation producers and consumers that will allow for infested and infected black walnut wood to be transported and utilized freely without the risk of spreading the vector and pathogen, while preserving the value and quality of the wood for products.

The objectives of this study included: 1) investigating the potential for a kiln to kill fungus-carrying beetles and 2) conducting an extended (2-5 months) demonstration of heat-treatments during the fall/winter 2011 and early 2012. The primary stages of this demonstration were:

1. Develop a plan for the safe removal and transport of black walnut to a safe storage site,
2. Demonstrate that the kiln was capable of killing the beetles that spread *G. morbida*,
3. Develop a treatment protocol (kiln schedules) for sanitizing black walnut, and
4. Establish a safe use/disposal of infested slabs, small logs, and branchwood not suitable for processing into lumber.

This study provided a basis for heat-treating black walnut logs as an informative and scientific paper for educating black walnut enthusiasts and wood workers to avoid the transmission of TCD to the native range east of the Colorado Front Range, where there is potential for major nut, lumber, and other black walnut product industry losses.

1.6 Plan of the Thesis

Specifically, this paper addresses the question: What should be done to sanitize infested black walnut wood? Chapter Two provides literature that discusses control methods utilized for international trade and domestic quarantine regulations. Chapter Three outlines materials, methods and processes used for acquiring black walnut logs and experiment descriptions that were followed and adapted from research that was conducted for the emerald ash borer (EAB) epidemic. Chapter Four examines the results of this experiment and defines issues that occurred throughout the experiment processes. Chapter Five provides conclusions and recommendations for future research and methods for transporting black walnut wood safely.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

There are many fact sheets available from local, state and federal agencies, most of which explain what the causal agent and TCD are, what the vector is, and what the industry impacts will be if TCD spreads throughout the black walnut's native range. TCD is a recently discovered disease and limited research exists that demonstrates control methods. There are few articles that specifically describe sanitation and heat-treatment methods utilizing black walnut wood; therefore, studies for emerald ash borer-infested ash trees will be substituted. Although EAB and Asian longhorned beetle (ALB) are exotic pests, federal regulations and quarantines have been implemented in order to reduce the spread of the woodboring beetles. The articles reviewed provide an overall description of what control methods can be utilized for other bark beetles and wood borers, like emerald ash borer (*Agrilus planipennis* Fairmare) or Asian longhorned beetle (*Anoplophora glabripennis*) that can be adapted for the black walnut study. The methods applied toward EAB are applicable because EAB, much like WTB, thrive under the bark and in the wood. EAB methods were used in this research as a proactive approach to treating black walnut infested with WTB.

2.2 Control Methods: Heat-Treatments

The International Plant Protection Convention (IPPC) developed the International Standards for Phytosanitary Measures (ISPM-15) Guidelines for Regulating Wood Packaging Material in International Trade (2002) that directly addresses the need to treat wood materials of a thickness greater than 6 mm that are used to ship products between countries. The main purpose is to prevent the international transport and spread of pathogens and insects that could negatively affect native plants or ecosystems. ISPM-15 affects all wood packaging material (pallets, crates, dunnages, etc.) requiring that they be debarked and then heat-treated or fumigated with methyl bromide and stamped or branded with a mark of compliance. Revision of ISPM No. 15 (2009) under Annex 1, requires that wood used to manufacture ISPM-15 compliant wood packaging must be made from debarked wood (not to be confused with bark free, i.e., free and clear of any bark), indicating that it is possible for some small (less than 3 mm in width or total surface area less than 50 cm^2) sections of bark to still be intact. ISPM-15 standards require that wood packaging materials must be heated in accordance with time-temperature schedule of 56°C (133°F) throughout the entire profile of the wood including its core for 30 minutes.

The USDA APHIS PPQ treatment schedules for miscellaneous plant products lists a heat-treatment schedule for logs, and firewood schedules may employ steam, hot water, kilns or any other methods that raise the temperature for a specified time. The USDA regulations for imports and exports, specifically Treatment Schedules T300 – Schedules for Miscellaneous Plant Products T314-Logs and Firewood (T 314-a) schedule, are listed for EAB infested wood from quarantine areas to heat to a temperature of 60°C (140°F) for 60 minutes before it was revised and added to the T314-c schedule that mandates a minimum temperature of 71.1°C (160°F) for 75 minutes in 2011 (USDA, 2011). These standards and regulations set a base foundation for temperature trials.

The USDA Forest Service, Forest Products Laboratory outlines kiln drying processes for hardwood species in the drying hardwood lumber general technical report (Denig *et al.*, 2000). This report focuses on methods for drying lumber of different thicknesses, for high quality applications, which ties directly to the purpose for this research. Determining which schedule to use for a kiln should be determined by the proportion of sapwood to heartwood in a kiln charge, typically, sapwood dries relatively faster than the heartwood. Other considerations are that black walnut wood is susceptible to several drying defects such as end checks, iron stains, honeycomb, collapse and ring failure due to severe drying, extractives and wetwood. This study focused mostly on drying bark, where the beetles reside, and sapwood. During the drying and heating process certain temperatures can affect strength properties and for black walnut heartwood the range is listed at 52°C - 68°C (125°F - 155°F) (Denig *et al.,* 2000).

These federally enforced regulations offer a baseline for heat-treatment temperatures and, while keeping the Forest Products Laboratory heating considerations in mind, there are two specific studies that offer competent control methods to determine heat-treatments based on lab experiments: (1) a study conducted at Michigan State University's Tree Research Center in East Lansing provides a model for kiln treatment schedules for EAB infested ash trees (Nzokou *et al.*, 2008) and (2) an experiment conducted by Myers *et al.* (2009) outlines an experiment where heat-treatment schedules were evaluated for the EAB based on the ISPM-15 standards.

In the Michigan State University study (Nzokou *et al.*, 2008), a conventional laboratory kiln from Standard Dry Kiln Co., Indianapolis, Indiana was utilized. The dry and wet bulb settings were calibrated to obtain an ambient kiln temperature of 82°C (180°F). The logs were then inserted and monitored to the desired temperature and kept in for an additional 30 minutes before they were removed. Two k-type thermocouples wired to a datalogger were inserted to the center of the logs and one centimeter into the phloem; the logs were removed 30 minutes after the core temperature reached levels of 50, 55, 60 or 65°C (122, 131, 140, or 149°F, respectively). These treatments were applied to green logs with initial moisture contents between 40 and 70 percent. The study indicated that the kiln heat-treatments at a level of 65°C (149°F) or greater were an effective sanitation process for EAB-infested logs and wood materials. However, further studies using larger sample sizes are needed to determine the actual viability of the cutoffs temperature range (Nzokou *et al.*, 2008).

In the Myers *et al.* (2009), study, researchers conducted four separate experiments on EAB larvae and prepupae at the USDA-APHIS Emerald Ash Borer Laboratory in Brighton, Michigan, from December 2006 to January 2008. They studied the thermotolerance of the immature stages of the wood-boring beetles by exposing the larvae and prepupae to a range of temperatures and times using infested ash (*Fraxinus* spp.) logs and samples. The time and temperature combinations were based on current USDA APHIS quarantine regulations and IPPC ISPM-15 standards for transporting woody materials internationally. Conversely, Myers *et al.,* (2009) determined that 60°C for 60 minutes should be considered the minimum temperature and time combination the safe heat-treatment combination for firewood infested with EAB. These two studies determined that temperatures above the ISPM-15 standard are necessary to sanitize EAB infested ash logs. However, the difference between the two experiments for EAB should be more thoroughly examined due to the five-degree Celsius difference in the temperatures (Myers *et al.,* 2009).

2.3 Discussion and Considerations

Material evidence is available that describes the occurrence of the WTB and the *G. morbida* fungus, as well as the possible impacts on the industry; however, these articles lack control options for both infested and infected standing trees and cut logs. The Nzokou *et al.*, (2008) and the Myers *et al.*, (2009) studies utilize both kiln and microwave heat-treatments and provide excellent models for the black walnut wood study. Similar processes were implemented to those found in the EAB kiln treatment methods.

Sanitation methods used for EAB infested ash logs may also be sufficient for killing the WTB, potentially restricting the *G. morbida* vector to areas that are already infested. Because black walnut is an important woodworking/timber product, some pre-heating treatments could be used to ensure the wood is still in workable condition, such as pre-steaming (Smith, 2002) or pressure treatment with wood preservatives (Schauwecker, 2008). Other studies conducted for EAB produced multiple end products during trials, including boards and chips; these studies offer treatment options for before and after milling and grinding treatments (Haack, 2009 and McCullough, 2007). These pre/post-treatments could be employed subsequently if the heat-treatments alone do not work.

Burns (1990) mentions that "species that can cross within a genus usually have distinct (often adjacent) ranges, while species that occupy the same sites in the same regions develop barriers to hybridization." Black walnut trees have been crossed with other *Juglans* species in order to increase nut production, produce a thin-shelled nut, or produce a faster growing tree. One of the hybrids (Royal, *J. nigra* and *J. hindsii*) has been successful, vigorous and has been recommended for timber areas (Burns, 1990). Planting resistant species or varieties would be a viable alternative control method.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The primary focus of this research was to determine a heat-treatment protocol to eliminate the WTB in black walnut logs and prevent the spread of the vector and causal agent in the native range of the host trees. This project used a containerized, wood-drying kiln to develop a heat-treatment protocol. A heat-treatment schedule was developed to sanitize WTB infested logs before transporting out of a known infested location to prevent the spread of the disease.

Utilizing adapted versions of both the Myers *et al.*, (2009) and the Nzokou *et al.,* (2008) methods, the thermotolerance of WTB was evaluated by subjecting WTB populations at all stages, including eggs, larvae, pupae and adults, to a series of time and temperature combination regimes. In this study, heat-treatment of the WTB was compared to heat-treatment studies of EAB to determine if similar quarantine methods are adequate for sanitizing infested logs with bark intact.

Studies were based on the IPPC ISPM-15 and USDA APHIS PPQ Treatment T314-a/c regulations. These standards and regulations were utilized as a basis for this study to determine if the aforementioned systems are sufficient to kill live WTB's in black walnut mill residues that have bark intact.

Trials were conducted at Colorado State University (CSU) in Fort Collins, Colorado from October 2011 to February 2012. Experiments followed procedures and methods similar to EAB studies used by Nzokou *et al.*, (2008) and Myers *et al.*, (2009). The overall approach was to expose WTB infested black walnut wood to a range of temperature and time combinations that were in accordance with ISPM–15 and the

Treatment T314-a/c regulations; these standards were based on internal wood temperatures. The treatments ranged from 42°C - 71.1°C (108°F - 160°F) for 30 to 120 minutes and the ability of adult beetles to emerge from the heat-treated samples was used to evaluate if the treatment was successful.

3.2 Black Walnut Log Acquisition

Collected sample logs were donated for research from public properties through the City of Denver Forestry department and private citizens whose trees were condemned and removed. Acceptable black walnut logs needed to have a minimum small end diameter of 25 cm (10 in) to be processed into sawn products, although smaller logs were accepted for safe disposal. Longer log lengths of 2.6, 3.2, 3.8, 4.4 and 5 m (8.5, 10.5, 12.5, 14.5 and 16.5 ft., respectively) were preferred, but lengths as short as 1.4 m (4.5 ft.) were also accepted.

City ordinances dictated that the trees needed to be removed due to WTB infestation and positive confirmation that the trees had TCD. The trees were cut and removed from those properties in September 2011 and transported to the Singing Saw Woodworks (SSW) mill located at 11218 Highway 93, Boulder, CO 80303. The SSW milling operation was run by Jon Hubert and was a safe storage, milling, and yarding site. The mill was considered a safe location because it was located where the disease and beetle had been confirmed and there were no endangered black walnut trees in the near vicinity. Black walnut logs were milled into cants and then further processed into dimensional lumber yielding over 3,500 board feet. A cant is a piece of lumber made from a log by removing two or more sides in sawing (Helms, 1998). Any small logs, branchwood, and other woody residues (i.e. slabs) with bark intact were transported to

Gilpin County Public Works by CoWood and Peak-to-Peak Wood. These slabs were chipped and burned in a wood-fired boiler used to heat the Gilpin County Road and Bridge Facility site, which was located at a higher elevation. Gilpin County, Colorado, was situated at an elevation between 2,121 and 4,052 m (6,960 - 13,294 ft., respectively) and was secluded from other potential host trees, preventing further infestation along the Colorado Front Range.

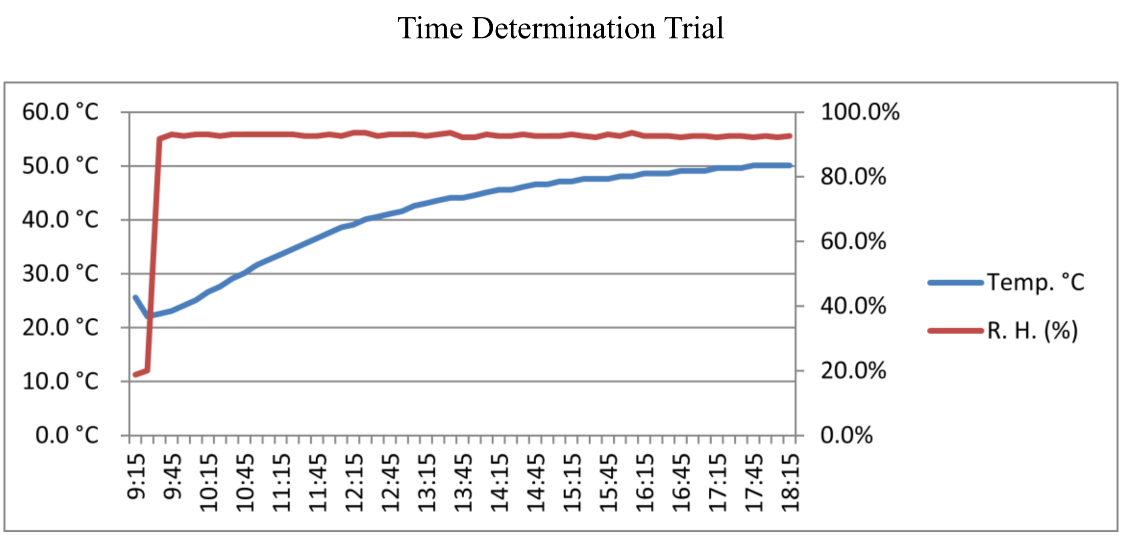
3.3 Experiment Preparation

Walnut wood used for this study came from trees showing symptoms of TCD in Denver, Colorado. Infected walnut trees were cut at the end of September 2011 and milled within about 14 days. Logs with 25.4 cm (10 in) + inner diameters were cut to a minimum of 2.6 m (8.5 ft.) lengths and, if available, cut at 61cm (2 ft.) intervals past the minimum length 3.2, 3.8 m etc. (10.5, 12.5 ft. etc.). Logs were then transported to the Singing Saw Woodworks Inc. mill south of Boulder, Colorado, where they were milled into cants, retaining as much of the heartwood as possible. The slabs with sapwood and bark intact were cut into 146 sample blocks, where 19 were used in the oven temperature trials to determine the time it took to reach the goal core temperatures, 34 were heat treated and put in the emergence chambers, 34 were used for destructive sampling and 59 remained unused due to irregularities in block thickness, missing bark, knots, etc. (34 of the remaining 59 samples were meant to be used for the re-infestation trials). The mean width and thickness of the blocks was 152 mm ± 6 mm (6 in ± 0.5 in) and 76 mm ± 3 mm (3 in ± 0.25 in), the length of the blocks ranged from 216-292 mm (8.5-11.5 in) on the cut side, all measurements include bark thickness. The blocks were stored in opaque plastic storage bins between 22-23°C (71-73°F) in the Forest Ecology laboratory in the Natural and Environmental Sciences Building on the CSU main campus in Fort Collins, Colorado.

Wood temperature was measured in each piece of wood using one Watchdog B-series Datalogger (Spectrum Technologies, Plainfield, IL) per sample block. A battery powered hand drill and 19 mm (0.75 in) drill bit were used to drill holes in the sapwood surface of the sample blocks to a depth of 3.8 cm (1.5 in) into the center of each block perpendicular to the wood grain direction. Temperature was measured at a constant depth to ensure that the temperature was recorded below (approximately within 13 mm (0.5 in) of the phloem layer in the sapwood) where the adult WTB, larvae, and pupae were found. According to Myers *et al.* (2009): "because the [sample] pieces heat from the outside in, choosing this depth also helped ensure larvae in the wood would experience a maximum temperature that was equal to or greater than the treatment target temperature." Black walnut sapwood core plugs were used to seal the data loggers in place and prevent heat penetration into the drilled hole where the data logger was located. The wood blocks were placed on a single steel rack vertically along the latitudinal transverse surface roughly six inches from the floor of the drying oven (Figure 3.1).

The time required to reach core temperature was determined by placing sample blocks with dataloggers inserted in the oven for approximately one week. Then, the dataloggers were removed and the time and temperatures were downloaded to the computer (Figures 3.2 and 3.3).

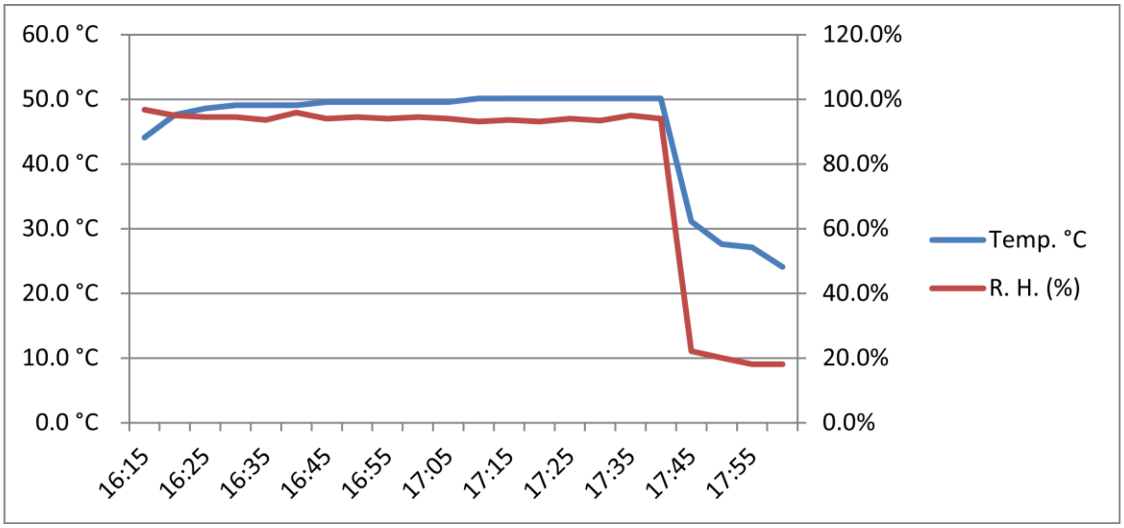
Figure 3.1. Black walnut wood sample blocks and tools (left) and Thelco Scientific oven with plugged core wood sample blocks (right)



The horizontal axis indicates time. The right axis represents the Relative Humidity (R.H.) in percent. This graph shows the time for the core of the sample block to reach the desired temperature, in this case nine hours to reach 50.1°C.

Figure 3.2. Watchdog datalogger recorded data for core temperature time duration

50.1°C - 30 Minute Sample Data Downloaded January 15, 2012



The horizontal axis indicates time. The right axis shows the R.H. This graph shows the 30 minute time duration as the core temperature reaches 50.1°C. The steep decline in temperature indicates when the sample block was removed from the oven.

Figure 3.3. Watchdog datalogger 50.1°C for 30 minutes data download

To capture any remaining live beetles, emergence chambers were utilized. Cardboard boxes measuring 7.6 cm width x 46 cm length x 32 cm depth (3 in x 18 in x 12.75 in) were used as emergence chambers. Also, 45-degree polypropylene fixtures were fitted to a 2.54 cm (1 in) hole in the end of each box with a glue-gun and duck-tape. A screw-top was attached to the fixture and a 50 milliliter clear Falcon plastic tube was screwed into the cap and fixture. The inside surface of the tube was abraded with a Dremel tool to allow WTB to walk across it. All box seams were sealed with standard gray duck-tape and re-enforced with hot glue so no light could penetrate except at the tube opening where adult beetles would be captured because they are attracted to light.

3.4 Heat-Treatment

This experiment was conducted using a THELCO GCA Precision Scientific Model 17 (Chicago, IL) with a 2.77 cubic foot-capacity drying oven to heat WTB-infested wood, to determine the temperature required to kill WTB at any stage of development including eggs, larvae, pupae and adults using black walnut. The initial treatment was based in the internal sapwood temperature as measured by the Watchdog data logger at a depth of 3.8 cm (1.5 in) from the outer sapwood surface of each piece of wood used. The dataloggers were set to record temperature and times from a base computer but had a 15 minutes delay before it started to record the data to allow for transporting between laboratories. The oven temperature was set to 42°C (108°F) and when the ambient temperature was reached the sample blocks were placed inside the oven standing on the transverse cut to leave as much surface area untouched by the oven walls. Both wood and air temperatures were monitored at five-minute intervals during the heating process by placing a button (1) inside the cored sample where it was then plugged with a sapwood plug so the temperature was read as a core temperature and another button (2) was placed inside the oven to measure the ambient temperature. The temperatures were monitored by removing the button and downloading the data to a computer while another button (3) was placed inside the sample block and placed back inside the oven. This was to prevent the wood from cooling during the data downloading time. Individual wood blocks were removed from the oven as they reached the desired time and temperature combinations and sealed in an emergence chamber. In the initial experiment, treatments were 42, 46, 48, 50, 56, 64, 71.1 and 76.1°C (108, 115, 118, 122, 132, 147, 160 and 169°F, respectively) for 30 minutes and each treatment consisted of three sample wood blocks each. The three sample blocks were used to monitor for (1) voluntary emergence in the emergence chambers, (2) destructive sampling if no adult beetles emerged after the 48 hour waiting period) and (3) the last block was initially to be used for a re-infestation trial. If beetles did not emerge from any heat-treated sample blocks, the trial was repeated.

3.5 Post Treatment

The efficacy of each treatment was determined by the ability of adult beetles to emerge from the infested wood blocks in emergence chambers. The boxes were oriented horizontally and stacked. Laboratory temperature was maintained at between 22-23°C (71-73°F). Moisture content of the sample blocks was not recorded. Natural light from large windows was the primary light source. Boxes were monitored daily for adult beetle emergence for 21+ days. The number of beetles that emerged from the sample blocks was not recorded. The expected results of an efficient sanitation are 100% mortality of the beetles. Therefore, if adult beetles emerged from heated samples the trial was deemed ineffective.

3.6 Additional Sampling

To evaluate the effect of heat-treatments two methods of extracting adult beetles were utilized. The sample block that was monitored for voluntary beetle emergence was described previously in the initial experiment methods; the second sample was used for beetle extraction and a destructive method was implemented where bark was peeled from the sapwood to expose the inner bark layers, after a 48-hour heat-treatment recovery period. A scalpel was used to shave off layers of inner bark to find galleries with eggs, larvae, pupae and adult beetles. This destructive sampling method determined if live beetles were found inside the bark after being heated but had not yet emerged, as well as to determine if larvae and pupae survived the heat-treatments. A treatment was considered successful if no live adults, pupae, larvae or eggs were found.

CHAPTER 4: DATA AND RESULTS

4.1 Results

Adult emergence was observed from wood samples that were heated at 42°C, 46°C and 48°C (107.6°F, 115°F and 118°F, respectively) temperatures over 30, 60 and 120 minutes, whereas zero beetles emerged from wood samples that were heated to 50.1°C (122°F) in two iterations of that trial. Further, through destructive sampling, no live eggs, larvae, pupae or adults were found to be alive in tests where specimens were heated to 50.1°C or above. Although the number of adult beetles that emerged was not counted, in the experimental conditions where WTB survived the heat-treatments, there was considerable variation in emergence frequency among replications in the experiment trials.

Table 4.1: Observations Post Heat-Treatment for Beetle Emergence (live beetles)

Time (minutes)	30		60		120	
	Emergence Chamber	Destructive Sample	Emergence Chamber	Destructive Sample	Emergence Chamber	Destructive Sample
Temp (°C)						
22-24 (Control)	Y	Y	(N/A)	(N/A)	(N/A)	(N/A)
42.1	Y	Y	Y	Y	Y	Y
46.1	Y	Y	Y	Y	Y	Y
48.1	Y	Y	Y	Y	Y	Y
50.1	N	N	N	N	N	N
50.1 (2)	N	N	N	N	N	N
50.1 (3)	N	N	N	N	N	N
56.1	N	N	N	N	N	N
56.1 (2)	N	N	N	N	N	N
64.1	N	N	N	N	N	N
71.1	N	N	N	N	N	N
76.1	N	N	N	N	N	N

Y indicates beetles emerged or N indicates that no beetles emerged

Upon visual inspection of the emergence chambers it appeared that fewer numbers of WTB adults emerged from the control groups, which indicated that the wood may not have been as heavily infested with WTB as the wood used in the trials. It is not uncommon for emergence numbers to vary considerably given the variation in WTB populations throughout black walnut trees in the Denver area, and the difficulty of assessing the infestation level in a tree without removing the bark (Myers *et al.,* 2009).

Overall results indicate that a minimum temperature of 50.1°C (122°F) for 30 minutes internal core temperature was sufficient to allow wood products with intact bark to be disinfested of the WTB. Assuming that re-infestation does not occur, the IPPC ISPM-15 and USDA APHIS PPQ T314-a and T314-c standards are adequate for heating measures.

4.2 Discussion

There were several factors that could have contributed to these results. In this study, the internal wood temperature was monitored at a single point in each piece of wood. Given the lack of uniformity in size and density of the wood blocks, there was likely to be considerable variation in the temperature individual insects experienced. Therefore, the exact time duration and temperature experienced by the insects contained inside the wood would be extremely difficult to determine. Attempts were made to compensate for this by measuring temperature at a consistent depth of 3.8 cm (1.5 in) from the sapwood surface, approximately 13 mm (0.5 in) below the interface of the inner bark and vascular cambium tissue where WTB's were located. Recent studies that were conducted at CSU to determine the effects of temperatures on the survival of WTB provided comparable results of heating exposed beetles to at least 49°C and claimed that logs must reach a temperature of at least 51°C to provide effective control of the WTB (Peachey *et al.,* 2012). These findings corroborate the results of the trials conducted for this experiment.

While the small sample size in this experiment provided conservative estimates of the ISPM-15 treatment, the temperature and time estimates did offer a baseline to evaluate the treatment schedule of 56°C (133°F) for 30 minutes described in this study. A study much larger in scale than the one reported here would be required to establish improved probit-9 level estimates. Probit-9 standards require 93,613 test subjects as the minimum sample size for accurate results of 99.9968 percent mortality and a 95 percent confidence level (Shortemeyer, 2011). This is a difficult task for wood inhabiting insects as large numbers are difficult to obtain due to the short life cycle of WTB's.

As stated by Myers *et al.*, (2009): "if heating rates play a major role in determining the efficacy of the heat-treatment it would be pertinent to reexamine these treatment schedules at rates closer to those experienced in a commercial facility." This study focused on the high temperature-short duration treatments that can be beneficial to local wood product producers. This may however increase energy consumption and retail costs.

High temperature treatments may be less compatible with kilns used to dry dimensional lumber as the higher temperatures can cause checking and splitting that lowers wood quality. However, according to the USDA Forest Service, Forest Products Lab black walnut wood can be heated between 52°C (125°F) and 68°C (155°F) before strength properties are compromised. Therefore, the resulting temperature determined in this study was acceptable in that range of temperatures including the ISPM-15 and T314-

a heating schedules but not the T314-c schedule which exceeds the high temperature in this range at 71.1°C (160°F). During trials in this experiment samples that were treated at this temperature did show signs of checking and other drying defect. However, a lower temperature-longer duration experiment that focused more on lowering the moisture content could provide a viable alternative to the treatments reported in this study.

Initially there was a plan to determine if wood that was heat-treated could be re-infested by the WTB. Re-infestation was not addressed in the study due to unforeseen challenges. The sample blocks that were treated came from logs that were previously infested with beetles. Examining the sample blocks for re-infestation proved challenging, especially, identifying fresh beetle entrance and exit holes from pre-heat-treatment holes. Additionally, determining if any found WTB carcasses were those from the heat-treatment would have proved difficult during extraction. Using beetle-free and clear wood samples would have been the optimal choice for this particular experiment because entrance and exit holes would be fresh and other evidence such as frass and live beetles, eggs, larvae and pupae would have been easily identified upon inspection. Unfortunately, uninfested wood was not available and the experiment was not completed.

4.3 Implications: Black Walnut Production and Uses

The spread of TCD throughout the native range of black walnut trees would be catastrophic. The value of the black walnut industry is substantial; the introduction of this disease would cause annual losses of $36 million in wood products production, $35 million in nut production, and $65 million in ornamental/urban street trees for Missouri alone, and has projected a total of $851 million in industry losses by 2030 (Treiman *et al.* 2009). Missouri produces about 65% of annual wild black walnut nut harvests. The largest processing plant is operated by Hammons Products located in Stockton, Missouri (Burns, 1990). If Missouri produces 65% of black walnut products this suggests that potentially $1.4 billion will be lost if the disease claims all black walnut trees by 2030 (Treiman, 2009). These losses include the products that come from black walnut trees. In fact, Dirr (1998) reported that "the wood is so valuable that 'Walnut Rustlers' have developed sophisticated techniques to remove trees, such as midnight operations and the use of helicopters."

The importance of black walnut can be demonstrated through its many uses. Standing and cut trees provide products for two different industries. Products made from standing live trees include oil that is pressed from the seed husks and nuts that are harvested by hand from wild trees. The hard black walnut shell is used commercially in abrasive cleaning, cosmetics, and oil well drilling and water filtration. Not only are the black walnut nut meats eaten by humans, but they are also a food source for wildlife. Products from cut trees include: veneers, furniture, flooring, rifle stocks and numerous other specialty items (Burns, 1990). Consumers prefer the heartwood for its dark rich color. Therefore, the sapwood and bark are the typical residues of milling logs. In this study residual slabs were used. Slabs were comprised of the lighter colored sapwood layer and bark after the main bole was milled into a cant. Other tangible products derived from black walnut trees include:

Wood:

- Furniture
- Paneling
- Fixtures
- Cabinets
- Gunstocks
- Lumber
- Veneer

- Specialty products/novelties

Shells:

- World War II, airplane pistons were cleaned with a "nut shell" blaster
- Deburr precision gears
- Clean jet engines
- Additives to drilling mud for oil drilling operations
- Filler in dynamite
- Nonslip agent in automobile tires
- Air-pressured propellant to strip paints
- Filter agent for scrubbers in smokestacks
- Flourlike carrying agent in various insecticides
- Water filtration

Hulls/Husks:

- Dye
- Tanning cosmetics

Nuts:

- Food source (human and wildlife)
- Oil (edible)

Aside from tangible values and wood properties, landscape trees provide certain intrinsic values that offer ecological, economic, aesthetic, and psychological benefits within urban and residential areas. According to the City of Fort Collins Forestry department these values include:

- Conserve energy by shading our homes and paved surfaces
- Clean and purify our air by absorbing atmospheric pollutants like ozone, carbon monoxide and sulfur dioxide
- Remove atmospheric carbon dioxide (carbon sequestration)
- Reduce stormwater runoff and soil erosion
- Filter and purify groundwater by directly absorbing pollutants
- Provide valuable wildlife habitat and corridors
- Increase real estate values & improve economic sustainability
- Act as very effective wind breaks, screen unsightly urban infrastructure, reduce noise, and provide privacy
- Strengthen our communities and reduce crime & physical violence

Source: fcgov.com Benefits of the Urban Forest

4.4 Implications: Overcoming Barriers to Urban Salvage

The commercial value of black walnut is one of the highest per board foot for native species in the United States. For instance, in Tennessee, walnut forests are valued at $1.47 billion. The loss of urban black walnut trees would change the appearance of most Tennessee communities and the costs associated with the removal and replacement would be very high. The effects on wildlife would be moderate to severe for squirrels, mice and other rodents that feed on the nutritious nut meats (Haun, 2010).

The Ohio State University Extension states that most black walnut trees less than 15 inches in diameter are of little value for quality lumber and veneers and typically trees that are used for products have 18 inch + diameters and are at least eight feet in length with no visual defects or branches. "Most urban walnut trees do not display the characteristics of high-quality marketable trees," Owen (2002) says "[urban] trees usually are avoided by buyers because of the risk that they may contain objects such as nails, wire, insulators, clothes hooks and more, that would damage saw blades or veneer knives" (Owen, 2002).

Most urban trees grow over foreign objects and contain them embedded in the wood. Aside from foreign objects inside the trees, another major issue addressed in the journal is accessibility in urban areas. Loggers must be able to fell and cut the trees into sections of merchantable lengths then deliver them to a mill. Easily accessible trees are found in parks and golf courses. Difficult access was found in areas of homes or other low-intensity urban areas where fences, utility-power lines, sidewalks, etc. can be damaged during tree removal (MacFarlane, 2007).

Many documented success stories exist of urban and community foresters who have invested in portable sawmills and drying kilns. These sawmills and kilns would be an asset to any municipal forestry departments that are experiencing insect or disease epidemics like, TCD, Dutch Elm Disease, EAB, etc. Not only do these trees come from natural disaster events but according to the United States Environmental Protection Agency (1998) the amount of urban wood waste generated was more than 160 million tons, with 29.6 million tons available for recovery. Many marketable products for wood waste exist such as: feedstock for engineered woods, landscape mulch, soil conditioner, animal bedding, composting additive, sewage sludge bulking medium and boiler fuel. Using wood waste prevents filling landfill space, sequestering carbon, reduces carbon dioxide emissions from processing virgin materials, and contributes to sustainable use of natural resources (SWANA, 2002).

According to the Citizen Forester (2008), the NEOS Corporation in Lakewood, Colorado, completed a national inventory of urban tree residues. The residue generators included commercial tree care firms, municipal/county park and recreation departments, municipal tree care divisions, county tree care divisions, electric utility power line maintenance, landscape maintenance/landscaper/nursery firms and excavator/land clearance firms. They concluded that across the U.S. the annual residues equaled over 192 million cubic yards. Seventy percent was given away, disposed of in a landfill or left at the site. About 25 percent was recycled or sold/used for products (Bratkovich, 2008).

Firewood is the most common and highest value of the branchwood and any salvage wood that has dried out and has end checking. Most large, open-grown trees yield at least one cord (128 $ft.^3$) of firewood and black walnut is an excellent medium-density, easily burned wood (Owen, 2002). Other uses more applicable to black walnut salvage would be lumber, engineered wood products, and biomass fuels. However, compost, animal bedding and mulch are not appropriate products for black walnut due to the juglone (5-hydroxy-alphanapthaquinone) substance that is produced in the roots, stems, leaves and bark that prove to be toxic to other plants, humans and horses (Funt, 1993).

One ill-advised use for infested black walnut logs is chipping. Black walnut logs can be chipped using a tub grinder where they are processed into wood chips and buried in a landfill. Beetles can persist in chips for a short period in larger fragments with intact bark (Cranshaw and Tisserat, 2010). If not disposed of properly, chipping can promote the spread of the disease. For instance, when black walnut chips were transported to a local landfill in Erie, Colorado, in 2007 the black walnut trees in the vicinity became infested (Alexander, 2012). The city of Boulder, Colorado, has aggressively removed diseased and beetle-infested trees by condemning black walnut trees on both private and public properties. Between 2004 and 2011, the city of Boulder, Colorado, removed 239 black walnut trees on private properties and enforced city ordinances on tree removals at 1,116 private properties where diseased black walnut trees were located. Compared to the estimated 890 non-symptomatic black walnuts within Boulder city limits, the 1,355 infested black walnuts comprise the majority of black walnut trees in city limits (Alexander, 2012).

However, the news is not all bad. Some of these removed logs have been used in graduate students' research projects, and eventually other logs were chipped and can be found at the City of Boulder wood lot. Much of the wood contained in removals has value and can be used safely if properly sanitized. Also, since 2007, the number of trees removed each year has decreased, when Boulder started enforcing its removal policy, which suggests that good sanitation methods and the trees' natural resistance may increase the likelihood that some black walnut trees may be retained long term (Alexander, 2012).

CHAPTER 5: CONCLUSION

5.1 Conclusion

Domestic and international standards such as ISPM-15 and T314a/c offered the basis for a heat-treatment schedule based on internal wood temperatures. These standards are adequate for sanitizing black walnut lumber and wood products that may be infested with WTB, the known vector of *G. morbida*.

Survival rates of WTB are variable depending on heating conditions, and an internal wood temperature determined by the ISPM-15 standards should be considered the minimum for safe treatment for walnut wood with bark intact. This experiment provides a defined temperature and time combination that will allow for walnut wood to be heated while preserving strength properties for high quality products. Specifically, heating the wood to 50.1°C (122°F) for 30 minutes is suitable for sanitizing any walnut wood with bark intact. These products could then be moved and used freely.

5.2 Recommendations

While 50.1°C (122°F) for 30 minutes will sanitize any black walnut sapwood with bark intact, it is recommended that the ISPM-15 standard of 56°C (133°F) for 30 minutes be used when heat treating walnut wood to meet quarantine standards and international trade regulations. It should be used as the minimum to satisfy ISPM-15 stamp approval, and this schedule provides for a margin of error. The results from this experiment fall within the range of 52°C - 68°C (125°F - 155°F, respectively) where the USDA Forest Service Forest Products Lab determined that strength properties of black walnut may start to be compromised. Therefore, heating black walnut wood to 56°C (133°F) will not reduce or compromise the strength properties of the wood.

Based on this research, a recommended strategy for tree removal, treatment, and disposal using best management practices for removing and using infested black walnut trees, logs, mill residues, lumber, and other products include:

- As soon as TCD is identified and confirmed in a tree, removal must occur within two weeks
- Identify ownership of the tree (private property or public access)
- Call a locally licensed arborist or tree removal professional to remove tree(s) as soon as possible within the allotted time period mandated by city ordinance
- Safely transport tree remains and logs within a known infested area to an identified safe storage site which may include a mill and kiln away from other potential hosts
- Logs and limbs can be milled, stored, and heat-treated at the safe holding site
- Any residues from milled logs and tree remains (leaves, small twigs and branches etc.) should be treated to the determined 50.1°C for 30 minute schedule or the ISPM-15 standard in order to be transported outside of a quarantined area
- Disposing of any remaining residues or unusable materials should be sanitized then chipped and either taken to a local landfill and dumped and buried or used in a wood-fired boiler as a woody biomass fuel source

5.3 Directions for Future Research

Cranshaw and Tisserat (2010) indicated that infested wood can be stored outside for up to three years before the inner bark is dry enough that it can no longer sustain beetle development. However, recent studies provide evidence stating that beetles persist up to 18 months (Peachey *et al.,* 2011) and possibly longer than 20 months (Peachey, 2012). Another sanitation method involves debarking logs, which are then kiln dried and milled into bark-free lumber. Bark-free lumber will no longer support WTB. According to Cranshaw (2010), the WTB will reinvade logs or pieces of wood with any bark intact and therefore the wood remains infectious and can still spread the beetles and fungus: “Movement of a single log with live beetles can be the initial source of an outbreak that could ultimately devastate black walnut in un-infested areas.”

Several states have enacted state quarantines that prohibit the movement of any walnut item that may harbor live WTB’s and that originate from a state/region where TCD is known to be present. While Colorado does not have quarantine regulations for TCD, Nebraska, Kansas, and Oklahoma currently have quarantines in place for wood coming into those states (Kromroy, 2011). Cranshaw (2010) explains that, “there is no evidence that the walnut twig beetle is attracted to or spends any time in association with walnut fruit and does not tunnel into hulls. Furthermore it is very unlikely that the *Geosmithia* fungus would colonize the hull or meat of any walnut species. Even if this were the case, the fungus would be unable to effectively colonize the tree without the presence of the beetle.”

Milled wood that produces bark-free lumber will not support WTB’s. Kiln drying will kill beetles and likely accelerate drying so that wood becomes less suitable as a host. However, the potential of re-infestation of kiln dried logs or slabs with bark intact is still unknown. Black walnut wood from TCD affected trees should be milled and used locally to prevent accidental spread of walnut twig beetles that can move the disease into new areas (Cranshaw, 2010).

Studies should be conducted based on these results to determine if re-infestation of WTB is a possible occurrence after the wood has been heat-treated. The heat-treatments should alter the wood properties and components of the phloem and cambium layers that make it an unsuitable environment for the WTB to complete a life cycle. Other research studies that should be considered would be to determine if other beetles associated with walnut trees can act as vectors for the *G. morbida* fungus.

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APPENDIX A: Movement Regulations for Tennessee

MATERIALS REGULATED: (1) The following are regulated articles:

(a) The Walnut Twig Beetle, *Pityophthorus juglandis*, in any living stage of development; (b) The fungal pathogen *Geosmithia morbida*. (c) Firewood of any non-coniferous (hardwood) species. (d) All plants and plant parts of the genus *Juglans* including but not limited to nursery stock, budwood, scionwood, green lumber, and other material living, dead, cut, or fallen, including logs, stumps, roots, branches, mulch and composted and uncomposted chips. (e) Any article, product, or means of conveyance when it is determined by the Commissioner to present the risk of spread of the Walnut Twig Beetle, *Pityophthorus juglandis*, or the fungal pathogen, *Geosmithia morbida sp.* nov. and the commissioner notifies the person in possession of the article, product, or means of conveyance that it is subject to these regulations.

Specific exceptions are nuts, nut meats, hulls, processed lumber (one hundred percent (100%) bark-free, kiln-dried with squared edges), and finished wood products without bark, including walnut furniture, instruments, and gun stocks derived from the genus *Juglans*.

RESTRICTIONS: Regulated articles may be moved from and through a quarantined area only if moved with a certificate or limited permit issued and attached in accordance with this chapter.

If regulated articles originate outside the quarantined area or regulated buffer area they may be moved without a certificate or limited permit under the following conditions:

1. (a) The points of origin and destination are indicated on a document accompanying the regulated article; and

(b) The regulated article is moved directly through the quarantined or regulated buffer area without stopping (except for refueling or for traffic conditions, such as traffic lights or stop signs), or has been stored, packed, or handled at locations approved by the commissioner as not posing a risk of infestation by Thousand Cankers Disease; and

(c)The article has not been combined or commingled with other articles so as to lose its individual identity.

2. The regulated article is moved from a regulated buffer area directly to a quarantined area or directly to another regulated buffer area.

Source: http://nationalplantboard.org/laws/index.html

APPENDIX B: Movement Regulations for Pennsylvania

- Since this pest complex cannot be eradicated in Pennsylvania, and since black walnut is of high value to the forest products industry and to forest and urban ecologies, the Pennsylvania Department of Agriculture is joining with state and federal agencies and Penn State Cooperative Extension to slow the spread of TCD in the state through monitoring and quarantine.
- A quarantine order signed Aug. 10, 2011, restricts the movement of all walnut material including nursery stock, budwood, scionwood, green lumber and firewood. It also covers other walnut material living, dead, cut or fallen including stumps, roots, branches, mulch and composted and uncomposted chips. Due to the difficulty in distinguishing between species of hardwood firewood, all hardwood firewood is considered quarantined.
- The quarantine also restricts the movement of walnut material and hardwood firewood from states known to have Thousand Cankers Disease including Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Tennessee, Utah, Virginia and Washington.
- Non-compliance with the quarantine order could result in criminal penalties of up to 90 days imprisonment and a fine of up to $300 per violation, or a civil penalty of up to $20,000 per violation.

Source:
http://www.agriculture.state.pa.us/portal/server.pt/gateway/PTARGS_0_2_75292_10297_0_43/AgWebsite/ProgramDetail.aspx?name=Thousand-Cankers-Disease&navid=12&parentnavid=0&palid=137&

APPENDIX C: Movement Regulations for Virginia

2VAC5-318-60. Conditions governing the intrastate movement of regulated articles.

A. Movement within a regulated area. Movement of a regulated article solely within a regulated area is allowed without restriction.

B. Movement from a regulated area to an unregulated area. Movement of a regulated article that originates from within a regulated area to an unregulated area is allowed only if the regulated article is accompanied by a certificate or limited permit issued in accordance with 2VAC5-318-70 and attached in accordance with 2VAC5-318-100.

C. Movement from an unregulated area through a regulated area. A regulated article that originates outside of a regulated area may move through a regulated area under the following conditions:

1. With a certificate or limited permit issued in accordance with 2VAC5-318-70 and attached in accordance with 2VAC5-318-100; or

2. Without a certificate or limited permit if:

a. Accompanied by a waybill that indicates the point of origin of the regulated article;

b. The regulated article is moved directly through the regulated area without stopping, except for refueling or due to traffic conditions; or has been stored, packed, or handled at locations approved by an inspector as not posing a risk of infestation; and

c. The regulated article has not been combined or commingled with other articles so as to lose its individual identity.

D. Movement from a regulated area through an unregulated area. A regulated article that originates from within a regulated area may be moved through an unregulated area to a regulated area under the following conditions:

1. With a certificate or limited permit issued in accordance with 2VAC5-318-70 and attached in accordance with 2VAC5-318-100; or

2. Without a certificate or limited permit if:

a. Accompanied by a waybill that indicates the point of origin of the regulated article;

b. The regulated article is moved directly through the unregulated area without stopping, except for refueling or due to traffic conditions; or has been stored, packed, or handled at locations approved by an inspector as not posing a risk of infestation; and

c. The regulated article has not been combined or commingled with other articles so as to lose its individual identity.

Source: http://www.vdacs.virginia.gov/plant&pest/index.html

APPENDIX D: Map of confirmed cases of thousand cankers disease and quarantined areas in Tennessee Counties

"2011 Tennessee Thousand Cankers Disease Regulated Counties"

Blue counties indicate quarantined areas. Orange counties indicate quarantined buffer zones.

Source: http://www.tn.gov/agriculture/publications/regulatory/tcd_map.pdf

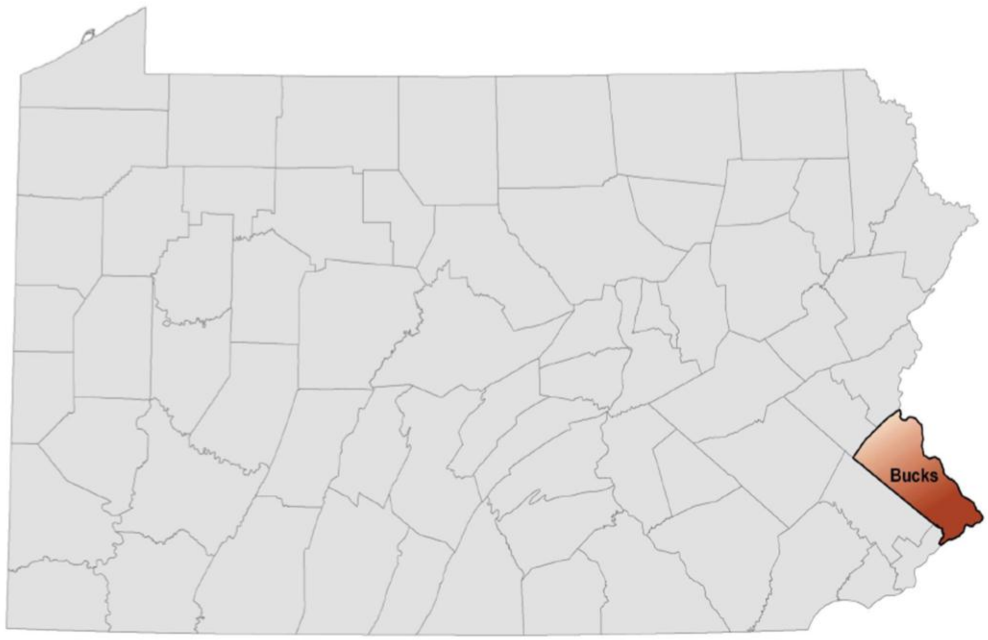
APPENDIX E: Map of confirmed cases of thousand cankers disease and quarantined areas in Virginia Counties

"Thousand Cankers Disease Quarantine in Virginia"

Source: http://www.vdacs.virginia.gov/plant&pest/images/tcdmap.jpg

APPENDIX F: Map of confirmed cases of thousand cankers disease and quarantined areas in Pennsylvania counties

"Counties Quarantined for Thousand Cankers Disease as of August 10, 2011"



Red indicates quarantine locations.

Source:

http://www.thousandcankers.com/media/images/quarantine/PA_County_8_2011.pdf

APPENDIX G: Diseases and other Damaging Agents

There are a number of damaging agents to black walnut. However, only a few are considered to be serious pests.

Type	**Agent**	**Damage**
Insect	Walnut caterpillar (*Datana integerrima)*	Defoliator
	Fall webworm (*Hyphantria cunea*)	Defoliator
	Ambrosia beetle (*Xylosandrus germanus*)	Wood borer
	Flatheaded apple tree borer (*Chrisobothris femorata*)	Wood borer – phloem and sapwood as larvae and foliage as adults
	Walnut curculio (*Conotrachelus retentus*)	Larvae bore into developing nuts
	Walnut shoot moth (*Acrobasis demotella*)	Larvae bore into terminal bud causing forks and crooks in the main stem
	Pecan leaf casebearer (*Acrobasis juglandis*)	Similar to shoot moth but less damaging
	Aphids and plant lice (*Monellia* spp. and *Monelliopsis* spp.)	Sucking insects and deposit honeydew on leaves that turns black and prevents photosynthesis
	Walnut lace bug (*Corythucha juglandis*)	Adults and nymphs suck sap from the lower surface of walnut leaves
Fungi/Disease	*Phytophthora citricola* and *Culindrocladium* spp.	Root rot disease causing fungi
	Walnut anthracnose (*Gnomonia leptostyla*)	Leaf spot disease
	Target leafspot (*Cristulariella pryamidalis*)	Fungus cases premature defoliation
	Leaf spot disease (*Mycosphaerella juglandis*)	Leaf spot disease
	Fusarium spp.	Stem disease causes cankers
	Nectria canker (*Nectria galligena*)	Cankers develop on the main stem where branches break off and an left an open wound
Mold	*Penicillia*	Mold of stored seed and seedlings
Animals	Deer	Browsing
	Mice and rabbits	Gnaw on stems of young trees
	Squirrels	Dig up and eat direct seeded nuts and feed on green and mature nuts still on the tree
	Birds	Perching birds break off terminal buds and new branches. Yellow-bellied sapsuckers drills holes though bark causing girdling

Source: Burns, 1990 Silvics of North America: Vol. 2. Hardwoods.