TITLE: **MORRIS ARBORETUM EMERALD ASH BORER PLAN: Planning for the Imminent Arrival of Emerald Ash Borer (EAB) (*Agrilus planipennis* Fairmaire) and its effect on *Fraxinus* spp;**

To be Adapted and Modified for Future Impact of *Geosmithia morbida*, Causal Agent of 'Thousand Cankers Disease' (TCD) on *Juglans* spp., Vectored by *Pityophthorus juglandis* (walnut twig beetle)

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ABSTRACT:

Are the splendid botanical edifices in arboreta collections archaic? Millennia of poor land management, increased global trade, and climate change, have combined to create radical changes in plant communities and forest ecosystems. As a result, not just individual plants but whole genera are being eradicated. As global trade mounts and more goods are plied overseas, both intentional and accidental cargos have been altering ecosystems around the world. According to a study by Maher in Agricultural and Resource Economics Review (2006), the yearly economic impact of invasive species in the U.S. is estimated at $133.6 billion. One such migrant, the emerald ash borer (EAB) *(Agrilus planipennis* Fairemaire*)*, was identified in 2002 and thought to have arrived via shipping material from China to the U.S.'s upper Midwest. The consequence has been 100% mortality of all native North American ash exposed to EAB. Since its discovery, the insect has made its way relentlessly east and now approaches eastern Pennsylvania and Morris Arboretum, in particular.

Planning for the future of *Fraxinus* spp. was a luxury not found in the upper Midwest ten years ago, when clouds of unidentified green beetles were noticed feeding on ash trees. As the arrival of this destructive insect becomes imminent at the Morris Arboretum, a general and specific readiness plan must be put into place to reduce risk, minimize impact, and respond effectively to this invasion. This policy provides guidelines and methods for tree and pest survey, as well as education, control, and eradication strategies to support management efforts. Best management practices, limited as they are, and still evolving. As more and better information becomes available these practices must be put into place and updated regularly. Restoration of ecosystems, diversification, seed storage, and hybridization for resistant species are critical as the effects of globalization and climate change become more entrenched.

Morris Arboretum Emerald Ash Borer Plan

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INTRODUCTION

In the early years of human civilization, the inscrutability and mystery of the cosmos was likened to the tree, becoming its symbol. Perhaps those high cirrus clouds were actually branches (Appendix A, Fig.1). The ancient Norse civilization had stories about this Cosmic or World Tree, with its top in the heavens, its roots deep in the earth and underworld, calling it *Yggdrasil* (Internet Sacred Texts Archive). A tree canopy, living high, as in the realm of the gods must also, therefore, be divine. The tree "with its seed, its roots, its trunk, its resting perches, its knitting knots, its pith, its main branch, its leaves, its flowers and their sweet smell, it's refreshing shade, its immortal sap, and the spot where it grows, all brought into close and exquisite analogy with man and his universe" (http://www.sacred-texts.com/earth/boe/boe16.htm).

Seen as a mediating link between earth and the heavens, the ash (*Fraxinus excelsior*), which grows throughout Europe, became sacred in myth, folklore, and religion. The *Edda*, a collection of Nordic poetry relates how Odin (or Wodan) the High God of the Vikings, made the first man from a block of ash wood. The first woman was created from alder (Boom and Kleijn). Interpreted in many ways by many civilizations, trees were not considered themselves divine but dwelling places of the gods.

The world we live in in the 21st century is very different. Oceans have been crossed and land barriers scaled. Nor did humans travel alone. They have always brought with them their "crop plants, domesticated animals, pets, pathogens, and parasites" (Nentwig 2007). In addition, millennia of poor land management, whether from ignorance or outright disregard for ecosystem needs, has led to degradation of natural environments and contributed to climate change. These factors, combined with increased global trade, mean that the thirty new invasive insects discovered annually in the U.S. find a viable and proliferative new home with untold quantities of vulnerable vegetation and few, if any, natural predators (Nentwig 2007).

As global trade has mounted, more goods come from overseas, sometimes bringing with them accidental cargo of destructive bugs and plants, some even to public gardens. An estimated 500 million plants are imported to the U.S. each year. Shipments through one plant inspection station doubled to 52,540 between 2004 and 2006, according to the U.S. Department of Agriculture. In a study found in Agricultural and Resource Economics Review in 2006, the entire yearly economic impact of invasive species in the U.S. is estimated at $133.6 billion. That number includes the cost of control and prevention such as pesticides, inspection programs at ports, and damage to crops" (Maher 2008). There have been no significant revisions to import laws since 1918. New regulations were proposed in 2009 to ban imports of certain plants but USDA says inspection is approaching or may have reached the limits of efficiency. According to Richard Schulhof of the Arnold Arboretum,

> "A 2002 National Academy of Sciences study determined that the U.S. Department of Agriculture (USDA) inspects roughly 2 per cent of cargo shipments yet intercepts over 53,000 arthropods, pathogens and plants annually. Although few

> introduced organisms successfully establish, it is conservatively predicted the one hundred fifteen non-native insect species and five plant pathogens will become naturalized in the United States between 2000 and 2020." (Public Garden 2007)

Loss of biodiversity is recognized as the greatest long-term consequence of invasive species, second only to habitat loss as a primary cause of the decline of native species in the United States (Schulhof 2007). However, even native insects can cause devastation when plants are taken out of their natural range. The walnut twig beetle (*Pityophthorus* juglandis) has been identified as the vector of *Geosmithia morbida,* the fungus that causes 'Thousand Cankers Disease' (TCD) and mortality of eastern black walnuts (*Juglans*) (Appendix G).

Introduced destructive insects vary by region in the United States, with the Asian longhorned beetle (*Anoplophora glabripennis*) and the emerald ash borer (*Agrilus planipennis*) threatening in the east and northeast United States. The emerald ash borer (EAB), is a wood boring beetle native to Asia that feeds on and singularly kills both healthy and stressed ash (*Fraxinus* spp.). The emerald ash borer is known to occur in China, Korea, Japan, Mongolia, and the Russian Far East (Appendix A, Fig. 2). "A Chinese report indicates high populations of the borer occur primarily in *Fraxinus chinensis and F. rhynchophylla* forests. Other reported hosts in Asia include *F. mandshurica* var. *japonica, Ulmus davidiana* var. *japonica* (Japanese elm), *Juglans mandshurica* var. *sieboldiana*, and *Pterocarya rhoifolia* (Japanese wingnut)" (Schneeberger and Katovich). In North America, so far, the emerald ash borer has attacked only ash trees. Found near Detroit, Michigan in the summer of 2002 by a Michigan State University entomologist responding to a report of iridescent green beetles near ash trees, EAB has now spread to Ontario and Quebec, Canada as well as fifteen of the United States: Illinois, Indiana, Iowa, Kentucky, Maryland, Minnesota, Missouri, Pennsylvania, Virginia, West Virginia, Wisconsin, and most recently Tennessee (July 2010). In Philadelphia, PA, ash comprises six percent of the 2.1 million park and street trees. Many more outbreaks are likely as movement of infested firewood spreads the insect's range more quickly than the beetle would fly on its own. According to the USDA, removing infested and dead trees and planting replacements could cost local governments and homeowners $10.7 billion over twenty years. The value of ash trees in urban and forested areas is likely in excess of $300 billion (USDA Forest Service).

Beyond the dollar cost to governments and home owners, the cost to ecosystems in a time of accelerated climate change is higher and more difficult to repair. Public gardens, especially those adjoining natural areas, face severe losses in native biodiversity which, in turn, allows increased outbreaks of invasive plant species (Schulhof 2007), further disrupting native systems. Wise management in uncertain times is paramount to safeguard not only public access but also long-term management of collections.

Having never met this pest before, the symptoms were initially thought to be caused by ash yellows or a wilt disease. Initial strategies in Michigan were to contain infestations by eradicating all ash within a half-mile radius of any known borer activity. This plan did not work because it was predicated on a poor understanding of the insects' life cycle habits. Research by Robin Taylor of Ohio State University has shown that ten percent of any EAB populations are "super fliers, capable of covering distances exceeding six miles" (Egan 2007). Unexpected human allies assisted their spread with the movement of firewood and ash nursery stock.

Delaying the introduction of the emerald ash borer (EAB) into southeastern Pennsylvania is beyond the scope of this plan or anyone else's. Preparedness for southeastern Pennsylvania and the Morris Arboretum is now the objective, where preparedness is defined as a comprehensive strategy to assess resources, minimize risk and identify and contain infestations promptly, in a measurable and timely fashion. Holdings must be identified and guidelines prepared for education and response. Developing support to ensure adequate funding and physical resources to protect ash assets is vital. The following preparedness policy covers measures indicated for this purpose.

METHODS

The over arching goal is to protect the, *Fraxinus* species resource by minimizing the impact of emerald ash borer (*Agrilus planipennis* Fairemaire) at the Morris Arboretum of the University of Pennsylvania specific to:

- Collected exotic and native specimens containing valuable germplasm,
- Native ash species growing in natural areas

This plan's methodology may also be used to reduce and manage emerald ash borer infestations at the University of Pennsylvania.

The policy is divided into Pre-arrival and Post-arrival strategies. Pre-arrival strategies include four sections describing *Administrative Readiness*, *Educational Readiness*, *Technical Readiness*, and *Early Detection.* Following that, two sections will describe Post-arrival activities, divided into *Rapid Response*, *Management* and *Restoration* strategies.

I. Pre-Arrival Strategies

A. Administrative Readiness

1. Assemble working group: *The Morris Arboretum EAB Task Force* to be responsible to implement the Emerald Ash Borer management plan.
2. Select a task force chair person: The chair person will coordinate and implement the plan by administering policies and programs.
3. Inventory accessioned and non-accessioned ash on the Morris Arboretum grounds
4. Reference prepared plans; Assure policies are relevant and achievable
5. Identify resources
6. Understand government funding applications and requirements:

B. Educational Readiness

1. Issue media alerts
2. Pest Alert and ID cards available at the Plant Clinic
3. Educational programs for staff and volunteers
4. Educational programs for visitors, including children
5. Web page posted to the plant clinic web site

C. Technical Readiness

1. Draft centralized action plan
2. Classify tree inventory
3. Allow for systematic reporting
4. Follow USDA technical guidelines

5. Take advantage of new research and technology
6. Assure accuracy

D. Early Detection

1. First Detector Training
2. Scouting

II. Post-Arrival Strategies

A. *Rapid Response*

B. Management

1. No action taken
2. Pre-emptive removals
3. Cultural practices
4. Systemic pesticides
5. Bio-control
6. Disposal of infested wood
7. Community wood

C. Restoration

1. Ecosystem restoration
2. Diversity
3. Bio-control research
4. Resistant cultivars
5. Seed storage

RESULTS

The following policy is a dynamic document. It is in a form prepared to be removed and printed for use at the Morris Arboretum of the University of Pennsylvania. N.B. This report may be shared with the University of Pennsylvania, who is urged adopt this or a similar plan. According to the most current tree inventory, the university has 171 ash trees (Morris Arboretum Tree Inventory Files).

Morris Arboretum of the University of Pennsylvania
Official arboretum of the Commonwealth of Pennsylvania

Morris Arboretum Emerald Ash Borer Readiness Plan
May 2011

The emerald ash borer (EAB), *Agrilus planipennis* is a wood boring beetle native to Asia that feeds on and singularly kills both healthy and stressed ash (*Fraxinus* spp.). Since its identification in Michigan in 2002, millions of ash trees have been lost. As the EAB has been established in Pennsylvania since c.1997, it is imperative that the Morris Arboretum of the University of Pennsylvania have a plan for its imminent arrival and the significant threat to its collections and natural areas of the garden. Communication within the arboretum and among area landowners becomes ever more critical as more emerald ash borer infestations are found.

This readiness plan lays out comprehensive initiatives. It is instructive in assessing resources, minimizing risk, indentifying early infestations and partnering to treat and contain infestations as much as is feasible. Thereafter, a planning team will continue to update information as further research is published and cooperate to implement best management practices.

I. Pre-Arrival Strategies

A. ***Administrative Readiness:***

1. Assemble Working Group: *Morris Arboretum Emerald Ash Borer (EAB) Task Force:* This task force has been created to facilitate preparedness before the emerald ash borer is detected on Morris Arboretum grounds, and to manage and direct scouting, infestations, controls, removals and replanting after detection. This readiness plan's main objective is not eradication of this pest, but to attempt to delay its introduction and establishment and to minimize its impact at Morris Arboretum. The *Morris Arboretum EAB Task Force* will include the Morris Arboretum Director of Horticulture and Curator, the Associate Directors of Urban Forestry, the Chief Horticulturalist, the Morris Arboretum Arborist and the Plant Propagation Intern (Appendix A, Fig. 3).
2. Select a chair person: The chair person at Morris Arboretum will lead the task force and coordinate and implement the plan. The *Morris Arboretum EAB Task Force* will be supervised by the Gayle E. Maloney Director of Horticulture and Curator, a title currently held by Anthony Aiello. The chair person has the authority to delegate tasks to both the Education Department (Public Programs) and the Development Department for assistance in supporting the goals of the plan.
3. Inventory all Fraxinus species on Morris Arboretum grounds: There are approximately 111 ash trees on Morris Arboretum's grounds. Of these, the majority (51%) are non-accessioned native trees found in natural areas. Of those that are accessioned, 35 (32%) are exotic and 19 (19%) are native to North America (Appendix B)
4. Identify Budgetary Resources: Budget for protection (recurrent application of insecticides), or removal and replacement. This section is subject to discussion and approval by the *Morris Arboretum EAB Task Force.*
   a. Morris Arboretum Operating Budget:
   b. Government funding resources, applications and deadlines:

Effort will be made to develop funding for protection of valuable trees, for removals both pre-emptive and post senescent, to lead education for employees, volunteers and visitors, and to plan for replacement of lost trees, long-term plant diversification, and sustainability. Resources such as these ebb and flow as funds are available. When the emerald ash borer's population makes it necessary for increased funding for its management, external grants will be researched and written.

5. Reference prepared plans and assure policies are relevant and achievable:
   a. Plans from Morton Arboretum, of Lisle, Illinois, and plans from the states of Iowa, Minnesota, Wisconsin, and Pennsylvania have been thoroughly researched. Relevant information has been incorporated and positioned into the Morris Arboretum Emerald Ash Borer Readiness Plan.
   b. The Coalition for Urban Ash Tree Management fundamentally endorses ash tree conservation as a component of integrated pest management of the emerald ash borer in residential and urban landscapes (Appendix E). http://www.emeraldashborer.info/files/conserveash.pdf
6. Understand government funding applications and requirements:
   Since EAB management will incur unanticipated costs, it will be vital to secure additional funding from outside sources. The U.S. Forest Service provides competitive grants to nonprofits that may be available to Morris Arboretum for management and restoration following EAB infestation. The Morton Arboretum in Lisle, IL has joined with area mayors and other agencies to work together in a focused effort. It would be advantageous if the mayors' group in the Delaware Valley (Metropolitan Caucus) would come together to join resources.

B. Educational Readiness

<u>*Morris Arboretum EAB Task Force*</u> will take the lead in communicating current and accurate information quickly to support the technical team, thereby allowing early detection and intervention.

1. Issue media alerts: raise public awareness via media bulletins
2. Brochures, pest alerts, and wallet ID cards displayed and readily available
3. Educational programs
   Valuable information is available from "Emerald Ash Borer University", a collaborative effort jointly sponsored by Michigan State University, Ohio State University, and Purdue University. Information is given in the form of educational webinars that are available on demand at http://www.emeraldashborer.info/eab_university.cfm
   a. Educate professional horticulture and volunteer staff with current and accurate information.
   b. Educational programs for visitors
   c. Promote "Project Learning Tree" for school age children http://www.emeraldashborer.info/files/edpacket.pdf
   d. Morris Arboretum Urban Forestry School of Arboriculture curriculum
   e. Greater Philadelphia Gardens Collaborative forum http://www.greaterphiladelphiagardens.org/

1. Plant Clinic Initiatives
   a. Web page posted to the plant clinic web site (Appendix E)
   b. Include GDD information collected by the Plant Propagation intern: (emerald ash borers emerge at 550 GDD, simultaneous with bloom of black locust *Robinia pseudoacacia*)).

c. Bar introduction of ash plant material to the Morris Arboretum and to Plant Clinic unless contained securely.

2. Pay strict attention to firewood movement strategies
   a. Do not move ash firewood.
   b. Buy firewood at destination when necessary, leaving remainder behind

C. Technical Readiness

Technical Readiness will assure decisions, actions, and education initiatives are guided by the best and most current science.

1. Draft centralized plan of action (i.e. this readiness plan)
2. Allow for systematic reporting
   a. Plant propagation intern will scout regularly for emerald ash borer signs and symptoms. (e.g. increased wood pecker activity beginning after Thanksgiving into winter, including patchy bark loss from feeding).
   b. Log sheets for trained staff and volunteers will be accessible in the plant clinic for reporting purposes (Appendix C).
3. Classify accessioned and non-accessioned ash species belonging to the Morris Arboretum of the University of Pennsylvania (Appendix B). Categorizing inventory before impact will facilitate comparisons now and management later. The Morris Arboretum's curator, Anthony Aiello, has determined that existing numbers will be used for plants currently accessioned. If there are any unaccessioned plants placed on the 'Save' list, accessioning will be considered. For all other plants, a simple tagging system will work. If there are trees in the natural area previously tagged, those tags will be kept, as well as any new tags. Accessioned trees of value are considered critically important because of crucial germplasm or aesthetic significance. The following lists differentiation within the inventoried plants:
   a. Collected from wild: (germplasm of Asian species)
   b. Large mature trees
   c. Valued as part of design
   d. Non-accessioned trees in natural areas
   e. Some trees must be left unmanaged due to budgetary constraints. As there is no flagship ash tree in the garden, decisions will largely be based on staff and visitor safety. An inventory list has been prepared that covers all ash within the main garden, and paths in natural areas adjacent to paths and main roads (Appendix B).

D. Early Detection

The U. S. Forest Service monitors state wide, using purple traps and trap trees (Appendix D). On a more local basis, Morris Arboretum will perform regular visual scouting, as follows:

1. Scouting must be done on a regular basis. Survey forms for Morris Arboretum trained staff are available (Appendix C).
   a. Exit holes
   b. Canopy dieback
   c. Bark splits
   d. Epicormic growth
   e. Woodpecker activity
   f. Look-a-like insects/disease
   g. First Detector Training:
   h. Follow up on suspected sightings
2. Quarantines: No wood or ash nursery stock may be moved beyond state or federal quarantine boundaries. For example, although the state quarantines that fully

encompass Pennsylvania and Ohio allow ash material to be moved intrastate, it would violate federal quarantines to move ash material across state lines.

a. Entry or exit of ash nursery stock is prohibited except from inspected and compliant sources.
   b. No ash plant material may be given as gifts outside quarantined areas.
   c. All firewood used on Arboretum grounds or taken from the property for outside activities must be sourced as from a compliant facility, including Morris Arboretum. Pennsylvania's Department of Conservation and Natural Resources will establish compliant ash receiver sites, for which information is not yet available. (Reference Illinois' quarantines directives for familiarity with possible procedures (http://extension.entm.purdue.edu/eab/pdf/quarantines.pdf).
   d. Since EAB control methods change over time, the Arboretum chairperson will review currently recommended control measures on the EAB website and make management decisions based on best EAB management practices.

II. Post-Arrival Strategies

A. Rapid Response

Call the Pennsylvania Department of Agriculture *1-866-253-7189*
or E-mail: *Badbug@state.pa.us*

B. Management

1. Follow established Pest Response Guidelines: The Department of Conservation and Natural Resources (DCNR) manages EAB infestations once a newly infested site has been identified and confirmed by the Pennsylvania Department of Agriculture. Management strategies are constantly updated with new research subsidized by the United States Forest Service Research Stations. All management must take a multi-faceted approach.
2. No Action Taken: If no action is taken and there are no efficacious EAB management techniques, all native ash trees will die and Fraxinus will become extinct. Exotic species from Asia have some ability to withstand attack from EAB but with high pest pressure, they may also succumb. The Environmental Protection Agency (EPA) has registered three systemic insecticides for control. These insecticides have been approved by the Coalition of Urban Ash Tree Conservation (www.emeraldashborer.info/files/conserve_ash.pdf), a group of university researchers, municipal arborists, and urban foresters who believe an integrated approach using good inventory methods, along with treatment and tactical removals will retain the integrity and value of the urban forest).
3. Preemptive Removals: In order to reduce insect pressure or to retain visual sightlines in the garden, some Fraxinus may be removed preemptively. Removal of infested trees is desirable and most advantageous in winter and early spring before the adults emerge to reduce population pressures. Review tree limb and branch collection programs and determine where such materials are currently being disposed. Cutting the trees and stacking the logs as firewood will not kill the beetles. If trees are to be removed, cutting and chipping them before May 1st is desirable to prevent adults from emerging.

4. Cultural Practices: Ash trees in areas where the borer is active must be mulched and watered during dry spells to avoid drought stress. This activity is one facet of integrated pest management.
5. Systemic Insecticides:
   a. Imidicloprid11,12,13,14 for trunk injection or soil application. Imidicloprid products can be used with a surfactant (Pentra-Bark) that opens lenticels, improving penetration through periderm. Atomization is not required, eliminating the possibility of drift.
   b. Dinotefuran (Safari, a neo-nicotinoid)[1,2,3,4] basal trunk bark or soil application. *Dinotefuran* products can be used with a surfactant (Pentra-Bark) that opens lenticels, improving penetration through periderm. Atomization is not required, eliminating the possibility of drift.
   c. Emamectin benzoate (TREEäge) for trunk injection only1,2,3,4
6. Bio-Control
   a. USDA rears three species of wasps as biocontrol agents for EAB, including two species that kill EAB larvae. Tetrastichus planipennisi (Yang) adults find and insert their eggs into EAB larvae, producing 56-92 offspring from a single EAB host. Spathius agrili behaves similarly except that the wasp eggs and developing wasps are attached to the outside of the EAB larvae. The developing wasps feed on and eventually kill the EAB larvae. Egg parasitoid, Oobius agrili, discovered in Jilin province, China in 2004, inserts their eggs into EAB eggs on ash bark. The developing wasps feed on and destroy the eggs. Bio-control is still in the research stage, and will become one more facet of integrated pest management.
   b. Cerceris fumipennis, a native ground-nesting wasp, can monitor and assist in EAB detection. This wasp does not significantly reduce EAB populations, but preys on the adult emerald ash borers and other native beetles, carrying the paralyzed beetles back to its burrow where they are stored as food for the wasp's larva.
7. Disposal of Infested Wood: Infested ash material must be de-barked to ½ inch depth below the bark (to sapwood), burned, buried, or double chipped to pieces less than one inch in two directions.
   a. As the Morris Arboretum is located within an EAB-quarantined area, any service provider contracted by the Arboretum must use disposal yards with a

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[11]Article by Hahn J, Herms, D. and McCullough, D. “Frequently Asked Questions Regarding Potential Side Effects of Systemic Insecticides Used to Control Emerald Ash Borer” http://www.emeraldashborer.info/files/Potential_Side_Effects_of_EAB_Insecticides_FAQ.pdf)

[12] Many arborists are reluctant to inject insecticides directly into trees, fearing adverse side effects but according to a two year study by Doccola and Smitley et al. (2011), “all trees successfully compartmentalized injection wounds.”

[13] McCullough, Deborah (MSU) and Herms, Daniel (OSU) Webinar discussion of controls (2011) http://breeze.msu.edu/p39122319/?launcher=false&fcsContent=true&pbMode=normal

[14] See Appendix F: Guidelines for Cost of Treatment

current EAB compliance agreement in place. It will not be necessary for the Morris Arboretum to be concerned when crossing county boundaries for ash wood disposal (i.e. Northwestern Avenue that divides Philadelphia and Montgomery counties) due to whole Pennsylvania state quarantine. Therefore no compliance agreement will be required.

b. Work with Springfield Township to keep mulch yard free of pests; double grind all mulch and wood waste. Mulched pieces must be smaller than one inch in two directions.

8. Community Wood: Salvaging ash resource is a strategy beneficial to whole communities. "Removal and utilization of ash trees, either before or after an infestation, may help slow the spread of EAB and reduce EAB populations" (USDA Forest Service 2010). Wood can be used for known valuable forest products such as tool handles, furniture and basket making. This has proved a more economic use of ash wood compared with burning or landfill options. The Wood Education and Resource Center (WERC) has partially supported these efforts in the past. http://www.emeraldashborer.info/files/E-2940.pdf

C. *Restoration*

1. Research: Remove and replace lost *Fraxinus* with resistant species or varieties.
    a. Retrogressive Hybridization: Introgressive hybridization may produce hybrids similar to those bred for resistance to chestnut blight. In Gapinski's (2010) interview with R.A. Larson, nursery manager at The Dawes Arboretum in Newark, Ohio, he states that although *Fraxinus mandshurica* and *Fraxinus chinensis* are very resistant to emerald ash borer, they have both been found to be difficult to cross with North American plant species. The North American China Plant Exploration Consortium (NACPEC) a network of arboretums and botanical gardens that includes the Morris Arboretum focuses on collecting and preserving plant germplasm. Collections in China and Korea coincide with the native range of EAB (Appendix 1. Fig. 5).
    b. Transgenic Hybridization: Fraxinus exhibiting resistance to attack by the EAB is currently being researched by the USDA Forest Service (Du and Pujit) to propagate transgenic ash plants containing the *Bacillus thuringensis* (*Bt*) toxin specific to the EAB. *Bt* is a naturally occurring bacterium used in commercial biological preparations to control larval forms of agriculturally important insect pests. Future studies will be to examine the use of sterility genes to further modify transgenic ash in a way that would prevent their hybridization with native ash populations once introduced into the landscape.
2. Seed Collection: Seeds of the largest Fraxinus are currently being stored in Fort Collins, CO. According to the USDA (2009), some ash seed has been stockpiled in the past for conservation and timber purposes but, to date, there has little need to collect ash seed from the wild. Arrival of the EAB, however, has created the need to gather wild germplasm to be stored long-term for future research and restoration. Dave Ellis, of the Plant Genetic Resources Preservation Program at the National Center for Genetic Resources Preservation (1111 South Mason Street, Fort Collins, CO 80526 elvis@ars.usda.gov) has been collecting ash seed since 2006. See "Recommendations for the Collection, Storage and Germination of Ash (Fraxinus spp.) Seed" http://www.emeraldashborer.info/files/Fraxinuscollection.pdf

3. Diversification of Forest and Urban Canopy: Anthropogenic impacts continue to cause devastation to ecosystems world-wide, including southeastern Pennsylvania. Another incursion of an invasive wood boring insect forces a re-examination of species used, possibly over-used, in urban and suburban areas, and whether the choices on recommended tree planting lists are diverse enough to withstand future onslaughts of invasive pests. Not too far in the future, impacts *on Acer, Betulus, and Platanus*, susceptible to Asian long horned beetle (*Anoplophora glabripennis*), an insect causing damage in New England, will become more apparent. In this age of global marketing and trade, our urban forests must be resilient through superior planning and diversified plantings. Many tree species have limited ability to grow and prosper in the limited root spaces of city streets where *Fraxinus* has shown toughness and tolerance for these environments. In natural areas, ash is a pioneer species, able to germinate in canopy openings and tolerate shade when young. Without this genus, our natural areas will need long-term sustainable management to enable viable ecological economies. Planting diversified alternative species is the only way to help mitigate the profound impact the loss of ash species will have.

a. Wildlife Trees: Where tree-related hazards are low or nonexistent, senescent ash trees will be left standing for wildlife, to remain part of the ecosystem community as long as possible (see Discussion below).

b. Remnant Stumps: Remnant stumps in natural areas can be left to re-sprout for education and research. This approach will also accomplish the goal of retaining soil structure and health. The EAB kills the living above-ground portion of trees, not the roots. Therefore, root sprouts will continue to return, growing to a size attractive to emerald ash borers before succumbing again, similar to the chestnut tree resprouting still seen in eastern North America.

[End of Morris Arboretum Emerald Ash Borer Readiness Plan Document]

DISCUSSION

Fraxinus americana, (*Oleaceae*) is a good example of the value of native ash to North American forest ecology. "White ash is a pioneer species… characteristic of early and intermediate stages of succession. Although mature white ash is classified as shade intolerant, the seedlings are shade tolerant. A seedling can survive at less than 3 percent of full sunlight for a few years allow(ing) the species to regenerate in gaps. White ash is an important source of browse and cover for livestock and wildlife. The samaras are good forage for the wood duck, northern bobwhite, purple finch, pine grosbeak, fox squirrel, and mice, as well as many other birds and small mammals. White ash is browsed mostly in the summer by white-tailed deer and cattle. The bark of young trees is occasionally used as food by beaver, porcupine, and rabbits" (Griffith 1991). The white ash also forms trunk cavities readily if the top is broken and its large size at maturity makes it valuable for primary cavity nesters such as red-headed, red-bellied, and pileated woodpeckers. Once a cavity is completed, the hole becomes an excellent habitat for secondary nesters such as wood ducks, owls, nuthatches, and gray squirrels (Griffith 1991).

The wood of ash species is exceptional: hard and light, yet flexible and suitable for many uses in commerce such as basket making, tool handles, and fine furniture (Boom and Kleijn). Ash species are urban tolerant, making them good street trees and have been used to a great extent, significantly as a replacement for the elm. Approximately sixty species occur throughout the northern hemisphere, distinguished between "flower" ashes and "leaf" ashes, the former blooming a month later with petals that are lacking in the leaf ash form (Boom and Kleijn). Of the American ashes, the white ash (*Fraxinus americana*), and green ash (*Fraxinus pensylvanica*) are most common and important in cultivation.

History of EAB in the US

EAB, *Agrilus planipennis* (Fairmaire) was first detected in July 2002 in southeastern Michigan and shortly thereafter in neighboring Windsor, Ontario, Canada. It is believed that EAB arrived in ash crating or pallets from China at least fifteen to twenty years ago (Herms 2007). As a non-native in North America, this borer does not have natural controls such as parasites, predators or disease that it has in its native range. This vastly increases its destructive ability in North America since host plants have not evolved effective defenses against them. With the advantage of anonymity and having gained access to an unlimited store of most desirable resource, EAB populations have soared. The EAB attacks all North American native ash populations from small saplings to mature forest trees. They attack healthy trees as well as weak, vulnerable ones, making infestations particularly devastating. Infestation of known ash species includes green ash (*Fraxinus pensylvanica*), white ash (*F. Americana*), black ash (*F. nigra*) and blue ash (*F. quadrangulata*). Ash species primarily attacked in Asia include Manchurian ash (*F. mandshurica*) and Chinese ash (*F. chinensis*). It is not yet known how resistant Asian species will be in North America where pressure will be greater.

Taxonomy and Life Cycle

The emerald ash borer, an exotic invasive wood boring insect, is a member of the order *Coleoptera* (*Buprestidae*), that also includes the native two-lined chestnut borer (*Agrilus bilineatus* Weber), the bronze birch borer (*Agrilus anxius* Gory) and the ash lilac borer (*Podosesia syringae* Harr). As a group, these beetles feed on a wide variety of diets, inhabit all terrestrial and fresh-water environments, and exhibit a number of different life styles but all undergo complete metamorphosis where the young have a different form from the adult. Many borer species are herbivores, variously adapted to feed on the roots, stems, leaves, or reproductive structures of their host plants (Meyer 2011). Borers only attack living trees, dead trees not being colonized.

EAB life stages, as in all beetles, include egg, larvae, pupa, and adult. Individual adults live for a few weeks, during which females, after mating, locate the upper canopy of the nearest large ash tree and lay individual eggs in bark crevices on the trunk and branches. Seven to ten days later, larvae from hatched eggs chew through the bark into the cambium, where they feed for several weeks in the phloem and outer sapwood. Extensive "S"-shaped galleries are formed, becoming progressively wide as the insects enlarge. As noted by Peters and Iverson (2009), most trees had exit holes on the south and west aspects of the trees. It is thought that the warmth of sunlight aids in the development of larvae. The galleries are packed with fine, sawdust-like frass and often extend 7.87 to 11.81 inches in length (Schneeberger and Katovich 2007). By autumn, feeding is completed and the prepupal larvae overwinter in the thick outer bark of the tree. In late April or May pupation begins. "Newly enclosed adults often remain in the pupal chamber for 1 to 2 weeks before emerging head first through a small, 0.12- to 0.16-inch D-shaped exit hole" (Schneeberger and Katovich).

Typically producing one generation per year, some larvae require two seasons to mature. This is particularly true of early infestation in a healthy ash (McCullough and Siegart). Adult borers emerge in late May at 548 growing degree days (GDD), (beginning January 1, base 50) along with the onset of bloom of black locust (*Robinia pseudoacacia*) at 550 GDD. Adult beetles emerge from ash trees throughout the summer but are mostly present in June and July. Insect development and, therefore, adult emergence, is temperature dependent. Adults are most active on warm, sunny days (Schneeberger and Kotovich). Damage by an individual larva is minimal, but, as a tree is repeatedly attacked, the population buildup of thousands of insects quickly overwhelms the ability of the tree to defend itself. Tree decline and death can be rapid, but it often takes several years for EAB populations to build enough for tree symptoms to appear. According to Schneeberger and Katovich, these factors may help explain why new infestations are often undetected for several years. There is minimal evidence of beetle infestation in the first year until the canopy begins to show signs of dieback in the second year. During the second growing season after invasion, the tree declines quickly and is usually dead by the third (IL EAB readiness Plan, Makra, Ed. 2006)

Ash trees are a resilient species and can overcome small amounts of cambial damage. However, as larval numbers escalate, increased woodpecker activity may be noticeable beginning in early winter (after Thanksgiving). As damage increases during the next season, more reparative tissue is formed, leading to distinct bulges in the trunk which soon splits as internal growth exceeds the capability of bark to cover it. Soon after, as nutrient and water supply is cut off to the upper canopy, epicormic branches appear in a desperate effort to restore foliage for photosynthesis of sugars. Borer exit holes are initially found in the upper canopy and difficult to see. By the time exit holes, bark cracks, and epicormic branches are evidenced at eye level, the likelihood of tree survival is very low. There must be at least fifty percent cambial integrity remaining in an untreated ash tree for a positive response to systemic controls to be expected. Any insecticide must be able to move up the tree into all tissues in order to be successful (McCullough 2011).

Visual symptoms associated with EAB infestations are nearly identical to those often seen on ash that are infested or infected by other commonly found pests and diseases. For example, crown dieback can result from multiple stressors including drought stress, soil compaction, ash yellows, or verticillium wilt. Therefore, as Wisconsin's EAB Information Source advises, it is important to look for a combination of at least two or more symptoms or signs https://onlineservices.datcp.wi.gov/eab/index.jsp. "A rosette or witches broom on ash [is] caused by the ash yellows phytoplasma. Ash trees affected by ash yellows develop this classical dense, highly branched but stunted shoots and foliage which is distinctly different from the lush, large shoots on trees affected by EAB"(Roberts 2007).

Economic and Ecological Impact

EAB has the potential to eliminate *Fraxinus* from North America, a dominant genus in forests and cities, creating dramatic changes to plant and animal communities as well as entire ecosystems. Devastation in Canada and US: "…killed tens of millions of ash trees in southeastern Michigan alone, with tens of millions more lost in Illinois, Indiana, Kentucky, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Tennessee, Quebec, Virginia, West Virginia, and Wisconsin." (http://www.emeraldashborer.info/) In Pennsylvania, ash comprises 3.6% of the forests, with more than 300 million trees throughout the state (about 10,800,000 ash trees) http://www.dcnr.state.pa.us/forestry/fpm_invasives_eab.aspx

It has been determined that EAB is officially the most destructive insect pest to arrive in North America in terms of dollar cost and number of trees lost. An economic study done in 2010 projecting the spread and ensuing costs to remove and replant lost trees over ten years (2009-2019), determined the cost to be at least ten billion dollars in urban areas alone. If suburban areas are included, that cost will exceed twenty billion dollars (McCullough).

CONCLUSION

Ecosystems in the 21st century are threatened constantly for many reasons, EAB from Asia being only the latest of many yet to come. Development of a plan to reduce the imminent threat to ash populations at the Morris Arboretum favors everyone who uses the beauty of the gardens for pleasure or takes advantage of its educational wealth. Ash resources can survive with an integrated pest management approach using cultural, systemic and bio-controls in the short-term and with the addition of hybridized introductions in the long-term. This readiness plan will help delay its introduction and establishment and minimize its impact at the Morris Arboretum.

There are multiple desired outcomes achievable through this management plan: preparedness for detrimental effects through education and technical strategies, a management plan providing tools and resources necessary to respond to invasion, and approaches to retain ecosystem function and to restore lost resources.

As many as twenty-one species of *Fraxinus* are distributed throughout the United States. EAB is known to feed on all four major ash species in the northeast, but whether it will feed on other ash species or adapt to other areas in the US is not well known at this time and will not be known until or if the beetle arrives in [other] regions (Parsons 2008). Because ash seedlings and small trees are very common in forests, small woodlots, and rights of way, it unlikely that EAB will ever disappear from any area where it has become established (Herms et al. 2009). In this age of global marketing and trade, our urban forests must remain resilient through superior planning, diversified plantings and proper management. Natural areas need long-term sustainable management in order to enable viable ecological economies.

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APPENDIX A: Figures 1-6

Fig.1. Yggdrasil of Norse mythology

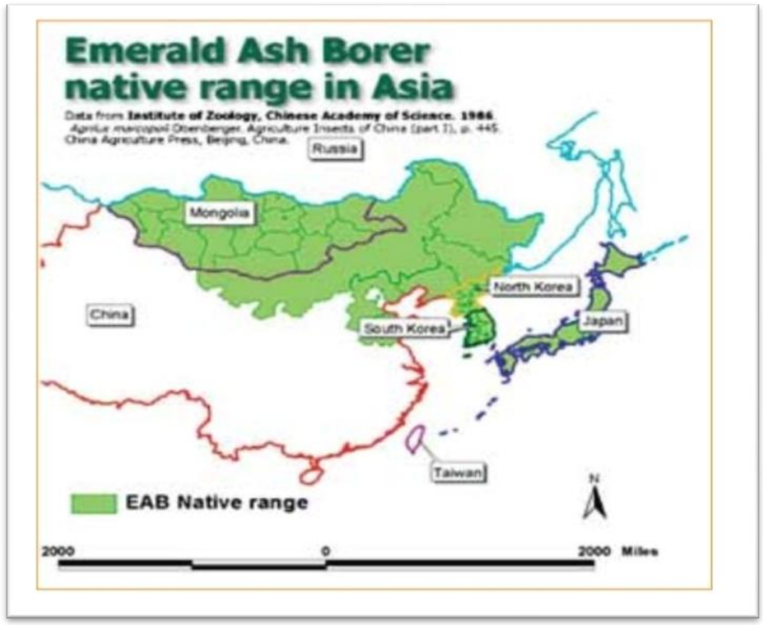


Fig. 2. Emerald Ash Borer native range

Fig.3. Emerald Ash Borer (EAB) Readiness Task Force

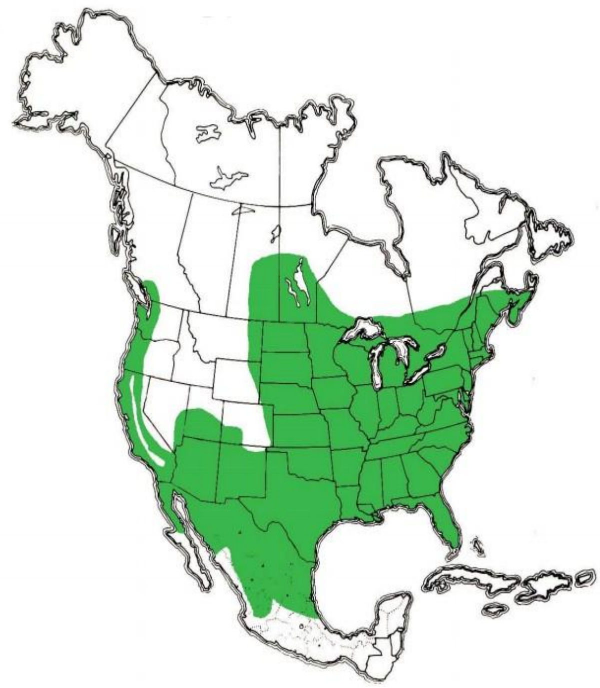
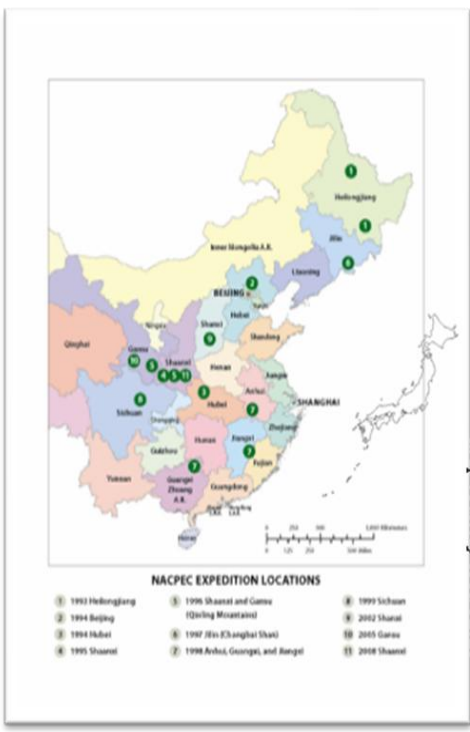


Fig.4. Range of native *Fraxinus* spp. in North America
USDA Forest Service Map
http://plants.usda.gov/java/profile?symbol=FRAM2p



map courtesy of A. Aiello

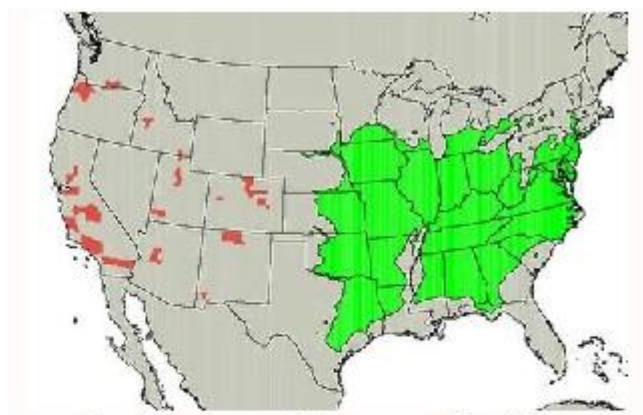


Fig.5. North American China Plant Exploration Consortium (NACPEC) a network of arboretums and botanical gardens focus on collecting, and preserving plant germplasm from all over the world.

APPENDIX B: Tree Inventory and Classification Spreadsheet

Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
2006-094*A				Fraxinus americana	American ash	N12		53	29	35				
32-2411*A				Fraxinus americana	white ash	D17		99						✓
54-0607*A				Fraxinus americana	white ash	E19		103						✓
54-0751*A				Fraxinus americana	white ash	F18		132					over pedestrian walkway	
54-1079*A				Fraxinus americana	American ash	H10		144					hollow shell w/ stump sprouts (+ catalpa within)	
82-063A				Fraxinus americana	American ash	F8	3'	109						
39-8557A				Fraxinus americana 'Ascidiata'		F7		48	48				very poor	
53-237C				Fraxinus americana 'Ascidiata'		F8		60	86					
2000-348*C				Fraxinus americana var. biltmoreana	Biltmore ash	G17							new planting: not assessed	✓
94-644C				Fraxinus bungeana	Bunge ash	H8	18"	19	12	8	8			
81-0504I				Fraxinus chinensis var. rhynchophylla	Korean ash	F7		41						
81-0504K				Fraxinus chinensis var. rhynchophylla	Korean ash	F7		38						
81-0504M				Fraxinus chinensis var. rhynchophylla	Korean ash	F7		36						
81-0504O				Fraxinus chinensis var. rhynchophylla	Korean ash	F7		16						
81-504*C				Fraxinus chinensis var. rhynchophylla	Korean ash	B21	3'	56						
81-504*D				Fraxinus chinensis var. rhynchophylla	Korean ash	B21	3'	68					no label	
81-504*G				Fraxinus chinensis var. rhynchophylla	Korean ash	B21	3'	60						
81-504F				Fraxinus chinensis var. rhynchophylla	Korean ash	F8	18"	23						
81-504H				Fraxinus chinensis var. rhynchophylla	Korean ash	F7		23	18					

Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
81-504J				Fraxinus chinensis var. rhynchophylla	Korean ash	F8		35					PI on trunk	
99-045A				Fraxinus chinensis var. rhynchophylla	Korean ash	J9		10						
99-045B				Fraxinus chinensis var. rhynchophylla	Korean ash	J9		11						
99-045C				Fraxinus chinensis var. rhynchophylla	Korean ash	J9		9						
37-7690A				Fraxinus holotricha	Balkan ash	F9		132						
97-261A				Fraxinus mandchurica	Manchurian ash	J9		10						
97-261B				Fraxinus mandchurica	Manchurian ash	J9		14						
99-046B				Fraxinus mandchurica	Manchurian ash	H9		15						
99-046C				Fraxinus mandchurica	Manchurian ash	H9		12						
2000-125A				Fraxinus 'Northern Gem'	Northern Gem ash	H9	18"	26						
2000-125B				Fraxinus 'Northern Gem'	Northern Gem ash	H9		15						
56-260A				Fraxinus ornus	flowering ash	K6	2'	17	29				remove:hollow decayed base with sucker	
91-014A				Fraxinus ornus	flowering ash	K6	base	46						
92-175*B				Fraxinus ornus	flowering ash	L16		32						
92-175*C				Fraxinus ornus	flowering ash	C20		42						
92-175*F				Fraxinus ornus	flowering ash	B20	4'	21						
92-175*G				Fraxinus ornus	flowering ash	E21		26						
92-175*H				Fraxinus ornus	flowering ash	J23-BED-8		25						
93-102*A				Fraxinus ornus	flowering ash	E19	18"	35	22					
93-102B				Fraxinus ornus	flowering ash	K7	3'	26	14	14	13	12	smooth bark	
93-108*A				Fraxinus ornus	flowering ash	L14		23						
32-2811*A				Fraxinus pennsylvanica	red ash	B20		95						✓
54-0608*A				Fraxinus pennsylvanica	red ash	D17		105						✓
81-280*A				Fraxinus pennsylvanica	red ash	F20		19	47					✓
75-141A				Fraxinus pennsylvanica var. lanceolata		G6		83						
36-4980*B				Fraxinus quadrangulata	blue ash	J10		55						
48-819B				Fraxinus quadrangulata	blue ash	G9		48						
94-155*B				Fraxinus sieboldiana	Siebold ash	L17	base	11						

Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
94-155D				Fraxinus sieboldiana	Siebold ash	K6							new planting : not assessed	
2001-069*A				Fraxinus texensis	Texas ash	H17							new planting : not assessed	✓
2002-197A				Fraxinus sp.	ash	H2		39	36					
2006-089*A				Fraxinus sp.	ash	P12		66						
2006-112*A				Fraxinus sp.	ash	N12		57						
82-064A				Fraxinus sp.	ash	F8	18"	108					old veteran, +Lonicera + groundhog	
82-065A				Fraxinus sp.	ash	F8		79						
	401			Fraxinus sp.	ash	K2		45						
	402			Fraxinus sp.	ash	K2		34	46	14				
	403			Fraxinus sp.	ash	H1		18						
	404			Fraxinus sp.	ash	H1		17	16					
	405			Fraxinus sp.	ash	H1		15						
	406			Fraxinus sp.	ash	H1		18						
	407			Fraxinus sp.	ash	H1		29						
	408			Fraxinus sp.	ash	H1		9						
	409			Fraxinus sp.	ash	G1		36						
	410			Fraxinus sp.	ash	E4		52						
	411			Fraxinus sp.	ash	H1		24						
	412												tag not used	
	413												tag not used	
	414			Fraxinus sp.	ash	E3		65						
	415			Fraxinus sp.	ash	E4		68						
	416			Fraxinus sp.	ash	E4		37						
	417			Fraxinus sp.	ash			72						
	418			Fraxinus sp.	ash	F5		66						
	419			Fraxinus sp.	ash	E5		15						
	420			Fraxinus sp.	ash	E5		25						
	421			Fraxinus sp.	ash	E8		38						
	422			Fraxinus sp.	ash	F6		26	28	88				
	423			Fraxinus sp.	ash	F6		32						
	424			Fraxinus sp.	ash	F11		24						
	425			Fraxinus sp.	ash	E6		56	34	39				
	426			Fraxinus sp.	ash	G16		80						
	427			Fraxinus sp.	ash	G17		102						

Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
	428			Fraxinus sp.	ash	G17		18					wound at 5', borer holes	
	429			Fraxinus sp.	ash	G16		54						
	430			Fraxinus sp.	ash	G16		60						
	431			Fraxinus sp.	ash	G16		95						
	432			Fraxinus sp.	ash	G16		44						
	433			Fraxinus sp.	ash	F17		64						
	434			Fraxinus sp.	ash	G17		85						
	435			Fraxinus sp.	ash	G17		69						
	436			Fraxinus sp.	ash	F16		90					CR- bulge/decay where limb ripped out @ 10'	
	437			Fraxinus sp.	ash	F16		42						
	438			Fraxinus sp.	ash	F16		76						
	439			Fraxinus sp.	ash	H17		72						
	440			Fraxinus sp.	ash	H17		62						
	441			Fraxinus sp.	ash	G16		47						
	442			Fraxinus sp.	ash	E6		62						
	443			Fraxinus sp.	ash	E7		82						
	444			Fraxinus sp.	ash	E7		59	65	39				
	445			Fraxinus sp.	ash	E7		89						
	446			Fraxinus sp.	ash	E7		36	42					
	447			Fraxinus sp.	ash	E7		56						
	448			Fraxinus sp.	ash	E7		36						
	449			Fraxinus sp.	ash	E7		52						
	450			Fraxinus sp.	ash	E7		59						
	451			Fraxinus sp.	ash	E7		72						
	452			Fraxinus sp.	ash	E7		22						
	453			Fraxinus sp.	ash	E7		18	24	36				
	454			Fraxinus sp.	ash	F7		48	33					
	455			Fraxinus sp.	ash	E8		60	79					
	456			Fraxinus sp.	ash	E8		78						
	457			Fraxinus sp.	ash	E8		32						
	458			Fraxinus sp.	ash	E8		55						
	459			Fraxinus sp.	ash	E8		43						
	460			Fraxinus sp.	ash	E8		21					grape vine stems	

Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
	461			Fraxinus sp.	ash	E8		56						
	462			Fraxinus sp.	ash	G9		77					lg. hollow base 15' resprouting; remainder fallen	
	463			Fraxinus sp.	ash	E8		70						
	464			Fraxinus sp.	ash	E8		58						
	465			Fraxinus sp.	ash	E8		69						
	466			Fraxinus sp.	ash	E8		40	25	35				
	467			Fraxinus sp.	ash	E8		47						
	468			Fraxinus sp.	ash	E8		64						
	469			Fraxinus sp.	ash	E8		50						
	470			Fraxinus sp.	ash	E8		50						
	471			Fraxinus sp.	ash	F9		44						
	472			Fraxinus sp.	ash	F9		27						
	473			Fraxinus sp.	ash	F9		17	14					
	474			Fraxinus sp.	ash	F9		27	24					
	475			Fraxinus sp.	ash	F9		13						
	476			Fraxinus sp.	ash	G9		41						
	477			Fraxinus sp.	ash	H9		56						
	253	253		Fraxinus sp.	ash	G11		117					AB Project #	
	479			Fraxinus sp.	ash	E8		28	46				inaccessible: no tag applied	
	480			Fraxinus sp.	ash	G11		128						
	481			Fraxinus sp.	ash	F11		42	16	19	19			
	482			Fraxinus sp.	ash	H16		76						
	483			Fraxinus sp.	ash	H16		57						
	484			Fraxinus sp.	ash	H16		44						
	485			Fraxinus sp.	ash	H16		84						
	486			Fraxinus sp.	ash	H16		64						

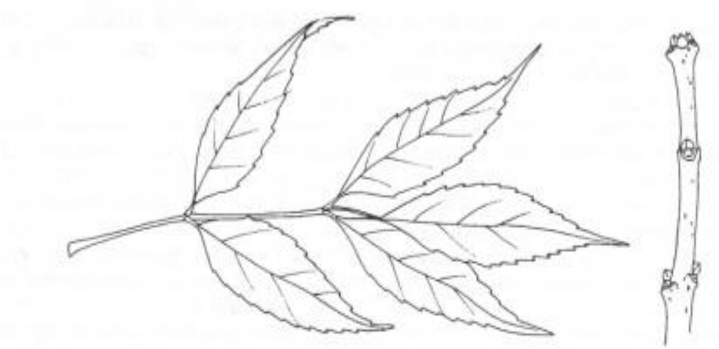
Accession #	EAB #	AB #	2 B Acc. ?	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***	Treat
	487			Fraxinus sp.	ash	H16		144					HAZARD TREE:DEAD; tree is 50'(H): <35' to path belowground bulging upper side	
	488			Fraxinus sp.	ash	H16		52						
	489			Fraxinus sp.	ash	G16		86						
	490			Fraxinus sp.	ash	H16		30					canopy difficult to see	
	491			Fraxinus sp.	ash	H16		56						
	492			Fraxinus sp.	ash	H16		49						
	493			Fraxinus sp.	ash			106					large lower trunk cavity creek side	
	494			Fraxinus sp.	ash	G16		58						
	495			Fraxinus sp.	ash	G16		45						
	496			Fraxinus sp.	ash	G16		38	25					
	497			Fraxinus sp.	ash	F16		68						
	1254			Fraxinus sp.	ash	G12		34	27	30				
	1255			Fraxinus sp.	ash	G13		141	31					
	1256			Fraxinus sp.	ash	G13		120	16					
	1257			Fraxinus sp.	ash	G13		17						
	82	82		Fraxinus sp.	ash	G12		124					AB Project #; hollow; ash anthacnose	
	262	262		Fraxinus sp.	ash	G11		124					AB Project #	
	1258			Fraxinus sp.	ash	H12		19					yellow ribbon	
	1259			Fraxinus sp.	ash	H14		15						

APPENDIX C: Emerald Ash Borer First Detector Survey Form

Ash or *Fraxinus* spp. belong in *Oleaceae* or the olive family. They are deciduous trees that leaf out very late in the spring.

Leaves: opposite, compound, 5-7 lance-shaped to oval leaflets, rounded teeth at the margin (white ash) or sharply toothed (green ash); leaves are thick, almost leathery.
Leaf Scar: *Fraxinus americana,* white ash; U-shaped scars on twigs with a lateral bud above
Fraxinus pensylvanica, green ash: D-shaped scars on twig ('D' is lying on its side) with a lateral bud above.
Twigs: **s**tout, rounded, smooth, grayish or greenish-brown often with a slight bloom; flattened at nodes at right angles to leaf scars.
Flowers: small and inconspicuous on separate male and female trees.
Seeds: are dry samaras shaped like canoe paddles.
Bark: gray to gray brown, furrowed into diamond shaped areas separated by narrow interlacing ridges.


*Paul Wray, Iowa State University



▲ ash bark ▲ white ash leaf and twig ▲ green ash leaf and twig

Look for signs and symptoms of EAB damage (start with ash trees that have poor overall health).
Are there any EAB signs listed below that can be observed? Use the table on the next page to check off the symptoms you observe.

• **Crown thinning** – tree branches dying from the top down, especially high in the crown.

• **Woodpecker damage** – on the tree's trunk and branches. Increased activity may be noted in early winter, after Thanksgiving.

• **Small D-shaped holes** – (1/8 inch) indicating adult EAB exit sites (flat on one side, but can be oriented in any direction).

• **S-shaped or serpentine tunnels** – just under the bark, sometimes with larvae in them.

•**Bark Splits** - after heavy larval tunneling vertical splits in the bark can occur. This can sometimes reveal the tunnels under the bark.

• **Trunk sprouts -** leafy sprouts growing from the trunk or base of the tree

• **Adult EAB** – metallic green, ½ inch long, bullet-shaped beetles about 1/8 inch wide (pictures left and middle)

• **EAB larva** – white, inch-long flat "worms" with distinct bell-shaped segments (picture on right)

Morris Arboretum: Emerald Ash Borer First Detector Survey Form

1) Surveyor name and contact information:

2) Date(s) of survey

3) Tree Information

	Name of tree or accession number	Location in Garden	Crown thinning/ Branch dieback	Wood pecker activity	D-shaped exit holes	Serpentine galleries	Vertical bark splits	Trunk sprouts	Sample
1									
2									
3									

Submit completed form to Plant Clinic
(May 2011)

APPENDIX D: Purple Traps and Trap Trees

1. Adult Purple Traps

Because emerald ash borers are difficult to detect in the early stages of ash tree infestation, the U.S. Forest Service uses sticky traps to monitor new areas for possible invasion. Traps are placed on a grid about twenty-five feet from the edge of a woodlot or forested area. These consist of triangular purple traps (12" x 24") made out of corrugated plastic panels embedded with a volatile compound (one lure, a green leaf alcohol, is a primary volatile associated with ash leaves; the other lure, Manuka oil, contains many of the chemicals emitted by ash bark and wood, simulating a stressed tree). The trap is covered with 'Tanglefoot', a sticky material that traps any insect venturing onto the trap. Past research has shown that the color purple is attractive to the family *Buprestidae*. Beetles are very visual, not only preferring purple but also are more likely to colonize trees in sunny locations (http://www.emeraldashborer.info/files/developsurveytrap.pdf). According to Dr. Houping Liu (USDA Forest Service, Pers. Communication) although traps will likely be placed in southeast Pennsylvania this spring (2011) they are placed in specific 1.5 mi^2 grid which may preclude Morris Arboretum's property.

2. Trap Trees

For the same reason that sticky traps are used, ash trees can be made to attract early EAB arrivals in order to monitor numbers. This is done by intentionally stressing or girdling trees. Girdling is accomplished by removing a six to eight inch strip of bark down to the phloem in the summer, disrupting the flow of nutrients made by photosynthetic activity. As stress increases, volatile compounds are emitted and perceived by emerald ash borers. The change in color, that is, light reflecting from the leaves is also said to be attractive to the borers (www.emeraldashborer.info/files/handoutforpdf.pdf).

Because emerald ash borers are arriving from the west and attack open or edge canopy trees, and green ash (Fraxinus pensylvanica) preferentially, a green ash is usually designated as a trap tree. Bark must be stripped to the cambium in order to stress the tree, making it more attractive to emerald ash borers. It would then be felled in the fall and assessed for larval numbers.

EMERALD ASH BORER: COMING TO A TREE NEAR YOU

Above: emerald ash borer- a small green beetle from Asia Below: Purple sticky trap used by USDA to monitor

INTRODUCTION: As global trade has increased, more goods are coming in from overseas, sometimes bringing with them accidental cargos of destructive insects and other organisms. Shipments of U.S. food imports from China more than tripled in value between 2001 and 2008 (USDA 2009). Five hundred million plants are imported to the U.S. each year, and about 30 new invasive insects are discovered annually in the U.S., up sharply over the last decade (Maher 2008). An estimated 50,000 plant and animal species have been introduced into the U.S. throughout history, many accidentally (Maher, K. *The Wall Street Journal*, 2010). Without the natural controls present in their native ranges, it is no wonder that some insect populations grow exponentially and ravage their new environment. Just as smallpox decimated indigenous Americans when it was brought from Europe, so the emerald ash borer (EAB) is decimating millions and millions of ash trees in the United States. First introduced in Michigan in the 1990's, the emerald ash borer (EAB), (*Agrilus planipennis* Fairmaire) was identified in 2002. It is believed to have been transported in shipping material from Asia. Devastation in Canada and US has killed more than 50 million trees, causing extensive economic and environmental damage (USDA Forest Service 2010). Closer to home, ash trees make up 3.6% of the 300 million forest trees in Pennsylvania, about 10,800,000 trees. That's a lot of trees. The movement of this deadly insect is being monitored carefully. Interestingly, it seems to move primarily along highways. From this we can deduce that campers and others are taking firewood containing the larvae with them

▲Natural area in Michigan where ALL ash trees were killed by the emerald ash borer. cfs.nrcan.gc.ca/images/9872 from a known infested area to another site where the borer has not yet found its way. Unknowingly a camper may have brought the beetle to a new site as most campers leave unused firewood behind when they leave, firewood that is possibly infested with emerald ash borer. The emerald ash borer has been found in central Pennsylvania as well as eastern New York state and Maryland. We would best be prepared.

LIFE CYCLE: From late May (when black locust trees bloom (at 550 growing degree days), through September, adults from last year's larvae emerge from ash trees through D-shaped holes in the bark. Bright metallic green and only about ½" long, adults live about 3 weeks, feeding on the leaves of nearby ash trees, foliar feeding that in no way hurts the tree. The female lays her eggs on the surface and crevices of ash tree bark. In 2-3 weeks, when the eggs hatch, the larvae begin chewing their way through the outer bark to the phloem, the living, growing portion of the tree, where water and nutrient transport occurs. The larvae live and develop here, making S-shaped tunnels, disrupting tree activities and resting until the next spring when they emerge and the cycle resumes. It takes 2-3 years before noticeable symptoms appear on a tree. At first, the top one-third of the canopy begins to look bare. Water and nutrients are blocked so there can be no growth, no life. The upper canopy is where the insect lives in the early stages making the tiny D-shaped exit holes that are difficult to see. Additionally, no frass (insect debris consisting of woody remnants and waste) is produced that could alert an observer on the ground. Suckers will appear at the base of the tree or anywhere along the trunk as the tree attempts to produce more leaves for photosynthesis. The trunk swells and splits as new wood is put down in an attempt to heal the damaged portions. Woodpecker activity increases as the insects multiply, noticeable in winter, beginning at Thanksgiving. Ash trees die within 2-3 years of infestation.

CONTROL: As of now, there is no cure. Insecticides, injected annually, are effective but expensive long term projects, although this is the best option while research on integrated strategies continues. Biological control (biocontrol) is a better way. It is the best option for cost-effective, long-term EAB population reduction. Scientists have traveled to the insects' homeland, China, to identify natural enemies. Three species of parasitic wasps have been found that can destroy 50 to 90 percent of the ash borer eggs or larvae they encounter (USDA-APHIS 2010). The wasp's young feed on the EAB eggs or larvae, eventually killing them. The USDA has determined that the wasps are not a threat to anything other than ash borers. Whether they will survive cold winters and predation in the US remains to be seen. Meanwhile insecticides can be used to prolong the lives of important ash trees, until biocontrols are known to be effective. Standard insecticides like Imidacloprid, or Emamectin benzoate (TREE Äge) can be applied annually or biennially, respectively.

WHAT IS TO BE DONE?

Ashes are large shade trees; they have been used to replace the elms in cities and towns. Elms replaced the chestnuts, another native North American tree that was destroyed by an introduced fungus. There is 100 percent mortality of all native North American ash trees following EAB infestation. That's 300 million trees in Pennsylvania. The beetle moves by both natural and artificial (human) movement. If an infested tree is found, the entire county must be quarantined. Quarantines prohibit the movement of potentially infested items such as ash limbs, branches, and logs out of affected counties without a permit. Wood cannot leave the quarantined areas without treatment by kiln drying, fumigation, or debarking, including removal of ½ inch of the tissue under the bark.

By far, the principal method of transport for the emerald ash borer has been movement of firewood. Buy local firewood when you arrive at your destination and leave any unused portion behind when you leave. Movement of nursery stock and wood packing materials are the next most often cited reasons for the spread of emerald ash borer.

Wood from ash trees is used for baseball bats, handles of sporting equipment, furniture and basket-making, among other things. If you wonder why baseball bats break more frequently than they used to, it's because they are now more often made from maple, a strong but more brittle wood, compared to ash.

In Pennsylvania, we have the advantage in knowing about the insect and how to identify infestations. Commercials are introducing the public to EAB. So far, it has not been found in the Philadelphia area but it will arrive soon, as it was found in Carlisle, PA in 2010. Keep your eyes open starting in May when the black locusts bloom. Morris Arboretum's ash collections contain several species of oriental ash that may show some resistance to EAB. Tony Aiello, Director of Horticulture at Morris Arboretum, is actively collecting Asian ash species that may contain resistance that could be bred in into our native American ash trees in the future.

To report possible infested trees in Pennsylvania, contact:
The Pennsylvania Department of Agriculture 1-866-253-7189
1015 Bridge Road, Collegeville, PA 19426, (610) 489-1003

◄EAB is a very small beetle

◄Dead ash struggling to recover using carbohydrate reserves stored in the roots and trunk. It's too late. www2.dnr.cornell.edu

FOR MORE INFORMATION:

Emerald Ash Borer www.emeraldashborer.info
USDA-APHIS (Animal and Plant Health Inspection) www.www.aphis.usda.gov ›
Coalition for Urban Ash Tree Conservation www.emeraldashborer.info/files/conserv.ash.pdf
Pennsylvania Department of Conservation and Natural Resources
Penn State University

References:

Cesa, Ed et al. 2010. "Integrated Program Strategy for Reducing the Adverse Impacts of Emerald Ash Borer Throughout the Northeastern Area." USDA Forest Service, Northeastern Area State and Private Forestry- Forest Health and Economics. Accessed 19 April 2011.

Maher, K. "The Vexing Bugs in the Global Trading System" The Wall Street Journal. 15 Jan 2010. Accessed 10 September 2010. http://www.dcnr.state.pa.us/forestry/fpm_invasives_eab.aspx.

USDA–APHIS/ARS/FS. 2010. Emerald Ash Borer, *Agrilus planipennis* (Fairmaire), Biological Control Release Guidelines. USDA–APHIS–ARS-FS, Riverdale, Maryland. http://www.aphis.usda.gov/plant_health/plant_pest_info/emerald_ash_b/downloads/EAB-FieldRelease-Guidelines.pdf Accessed 19 April 2011.

USDA Economic Research Bulletin 52, July 2009. Imports from China and Food Safety Issues. http://www.usda.ers.gov Accessed 19 April 2011.

by Rebecca Bakker, Urban Forestry Intern, May 2011

APPENDIX F: Guidelines for Cost of Treatment

Accession #	EAB #	2 B Acc. ?	Latin Name	Common Name	*Grid#*	*Meas*	*Cbh 1*	*Cbh 2*	*Dbh 1*	*Dbh 2*	*Total Dbh*	*Rate*	*Cost to treat/ 2 yrs*	*Comments*
32-2411*A			Fraxinus americana	white ash	D17		99		31.5		32	$12/in	$384.00	
54-0607*A			Fraxinus americana	white ash	E19		103		33		33	$12/in	$396.00	
2000-348*C			Fraxinus americana var. biltmoreana	Biltmore ash	G17									To be determined
32-2811*A			Fraxinus pennsylvanica	red ash	B20		95		30		30	$12/in	$360.00	
54-0608*A			Fraxinus pennsylvanica	red ash	D17		105		33		33	$12/in	$396.00	
81-280*A			Fraxinus pennsylvanica	red ash	F20		19	47	3	15	18	$10/in	$180.00	
2001-069*A			Fraxinus texensis	Texas ash	H17									To be determined
												TOTAL	$1,716.00	
			TREE-Äge -$10/inch for trees <20 inches D. Higher for larger trees, up to $16 per diameter inch in jumbo trees (over 40 inch diameter.)											
			Imidacloprid Trees <8 inch diameter may be treated by basal soil drench or ground injection											

APPENDIX G: Thousand Cankers Disease (TCD)

Black walnut (*Juglans nigra*), is one of the largest hardwood trees found in the US, and is valued economically and ecologically for its wood and edible nuts. Native to the deciduous forests of the eastern United States (US), from Massachusetts to Florida and west to Minnesota and Texas, black walnut also occurs naturally in southern Ontario, Canada. Thousand cankers disease, vectored by the walnut twig beetle (WTB), is a lethal insect-fungal pest complex native to western United States and only occurs on walnut species (*Juglans*). It coincides with and is tolerated by the western Arizona walnut (*Juglans major*), as a minority pest. Since the introduction to western landscapes of *Juglans nigra*, an eastern species, dieback and mortality of the eastern species has become severe. Also, preliminary pathogenicity tests have shown that of two other species within the walnut family exposed to TCD, butternut *(Juglans cinerea)* developed cankers but pecan (*Carya illlinoinenesis)* did not. Appendix A, Fig.6 shows the US native range of black walnut in green with known TCD infestations in red. In late July 2010, eastern black walnut trees in Tennessee were found to be infested with TCD and confirmed in four counties near Knoxville. It was the first discovery of this disease within the native range of eastern black walnut. Based on the level of deterioration of the infested trees, experts suspect that TCD has been in Tennessee for several years. However, it is too soon to be certain how this disease may act in the walnut's native range. (http://www.ohiodnr.com/LinkClick.aspx?fileticket=cHEIm%2FPkNt0%3D&tabid=5320).

Because TCD is not yet a federally quarantined pest, it is up to individual states to make decisions to restrict movement of black walnut wood. Tennessee along with others states, has a TCD quarantine. However, as a valuable hardwood, oversight is difficult. Today, most actions plans consider rapid detection and removal of infected trees as the primary means of control.
NB: The portion of this readiness plan that relates to thousand cankers disease consists of mapping *Juglans* spp. on Morris Arboretum grounds only. The management plan itself remains to be completed as a modified form of the EAB Readiness Plan when appropriate.

The following spreadsheet lists all black walnuts (*Juglans nigra*) found on Morris Arboretum property. See CAD file for map.

Accession #	TCD #	AB #	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	**Comments**
2001-079A			Juglans nigra	black walnut	J4		98					
2006-078*A			Juglans nigra	black walnut	N12		71					no tag
2010-057A			Juglans nigra	black walnut	J4		83					
32-2050*A			Juglans nigra	black walnut	F20		49					
32-2407*A			Juglans nigra	black walnut	A18		105					
53-176A			Juglans major	Arizona black walnut	J16							
54-0090*A			Juglans nigra	black walnut	K21		71					
54-1432B			Juglans nigra 'Laciniata'	cutleaf black walnut	Q4		0					removed
60-275*A			Juglans nigra	black walnut	K21		84					
60-276*A			Juglans sp.	walnut	K21							
82-073A			Juglans nigra	black walnut	F9		103					lg. basal cavity N side
82-116A			Juglans nigra	black walnut	J3		86					
82-116B			Juglans nigra	black walnut	J3		75					double lead: 1 gone, hollow base
82-116C			Juglans nigra	black walnut	J3		92					mechanical wound lower trunk
82-116D			Juglans nigra	black walnut	J3		91					groundhog hole at base
82-204A			Juglans		J9							
	33	33	Juglans sp.	walnut	H11		44					AB Project #
	36	36	Juglans sp.	walnut	H11		57					AB Project #
	45	45	Juglans sp.	walnut	G11							AB Project #
	46	46	Juglans sp.	walnut	G11		38					AB Project #
	47	47	Juglans sp.	walnut	G11		36	36	37	42	34	AB Project #
	54	54	Juglans sp.	walnut	G11		21					AB Project #
	59	59	Juglans sp.	walnut	G11		21					AB Project #
	61	61	Juglans sp.	walnut	G11		47					AB Project #
	79	79	Juglans sp.	walnut	G11		71					AB Project #
	178	178	Juglans sp.	walnut	G12		24					AB Project #
	182	182	Juglans sp.	walnut	G12		??					AB Project #
	184	184	Juglans sp.	walnut	G12		73					AB Project #

Accession #	TCD #	AB #	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***
	191	191	Juglans sp.	walnut	G12		73					AB Project #
	195	195	Juglans sp.	walnut	G12		37					AB Project #
	1426	317	Juglans sp.	walnut	H9		27					AB Project #
	1425	328	Juglans sp.	walnut	H9		36					AB Project #
	1424	332	Juglans sp.	walnut	H9		47					AB Project #
	1427	364	Juglans sp.	walnut	G9		40					AB Project #
	1428	367	Juglans sp.	walnut	G9		28					AB Project #
	1423	379	Juglans sp.	walnut	G9		65					AB Project #
	1421	384	Juglans sp.	walnut	G9		20					AB Project #
	1401		Juglans sp.	walnut	H1		27					
	1402		Juglans sp.	walnut								removed
	1403		Juglans sp.	walnut	F3							removed
	1404		Juglans sp.	walnut	E4		130					at mill
	1405		Juglans sp.	walnut	E4		74					
	1406		Juglans sp.	walnut	E5		44					
	1407		Juglans sp.	walnut	E5		38					inaccessible: no tag applied
	1408		Juglans sp.	walnut			44					
	1409		Juglans sp.	walnut	E6		43					
	1410		Juglans sp.	walnut	E6		54					
	1411		Juglans sp.	walnut	E6		50					
	1412		Juglans sp.	walnut	E7		39					
	1413		Juglans sp.	walnut	E7		37	34				
	1414		Juglans sp.	walnut	F6		35					
	1415		Juglans sp.	walnut	E8		60					
	1416		Juglans sp.	walnut	E8		47					
	1417		Juglans sp.	walnut	E8		32					
	1418		Juglans sp.	walnut	E9		30					
	1419		Juglans sp.	walnut	E9		40					
	1420		Juglans sp.	walnut	E6		54					
	1422		Juglans sp.	walnut	G9		20					

Accession #	TCD #	AB #	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***
	1429		Juglans sp.	walnut	G11		15					
	1430		Juglans sp.	walnut	G11		20					
	1431		Juglans sp.	walnut	G11		19					
	1432		Juglans sp.	walnut	G11		40					
	1433		Juglans sp.	walnut	G11		17					
	1434		Juglans sp.	walnut	G11		29					
	1435		Juglans sp.	walnut	G11		25					
	1436		Juglans sp.	walnut	G11		25					
	1437		Juglans sp.	walnut	G11		32					
	1438		Juglans sp.	walnut	G11		23					
	1439		Juglans sp.	walnut	G11		36	44				
	1440		Juglans sp.	walnut	G11		44	50				Danger: metal bar between boles
	1441		Juglans sp.	walnut	G11		32	35	39			
	1442		Juglans sp.	walnut	G11		11	23				
	1443		Juglans sp.	walnut	F11		25					
	1444		Juglans sp.	walnut			47					
	1445		Juglans sp.	walnut	F17		100					
	1446		Juglans sp.	walnut	F17		79					
	1447		Juglans sp.	walnut	F17		26					
	1448		Juglans sp.	walnut			42					
	1449		Juglans sp.	walnut	E10							
	1450		Juglans sp.	walnut	E10							
	1451		Juglans sp.	walnut	E10		32					
	1452		Juglans sp.	walnut	E10		28					
	1453		Juglans sp.	walnut	F10		36	26	40			
	1454		Juglans sp.	walnut	F10		23	31	23			
	1455		Juglans sp.	walnut	F10		21	29				
	1456		Juglans sp.	walnut	E10		35					suspended over creek
	1457		Juglans sp.	walnut	F10		26	24	27			yellow ribbon
	1458		Juglans sp.	walnut	F10		18					
	1459		Juglans sp.	walnut	F10		22	22	17	8		yellow ribbon
	1460		Juglans sp.	walnut	F10		21	18	20			
	1461		Juglans sp.	walnut	F11		15					
	1462		Juglans sp.	walnut	F11		20	15	16			
	1463		Juglans sp.	walnut	F11		85					
	1464		Juglans sp.	walnut	F11		60					
	1465		Juglans sp.	walnut	F11		20					

Accession #	TCD #	AB #	Latin Name	Common Name	***Grid#***	***Meas***	***cbh 1***	***cbh 2***	***cbh 3***	***cbh 4***	***cbh 5***	***Comments***
	1466		Juglans sp.	walnut	G12		28					
	1467		Juglans sp.	walnut	F11		14					
	1468		Juglans sp.	walnut	F11		22					
	1469		Juglans sp.	walnut	F11		27					
	1470		Juglans sp.	walnut	F11		30	20	34			
	1471		Juglans sp.	walnut	F11		25					
	1472		Juglans sp.	walnut	F11		27	15	25	24		
	1473		Juglans sp.	walnut	F11		18					
	1474		Juglans sp.	walnut	F11		19					
	1475		Juglans sp.	walnut	F11		26					
	1476		Juglans sp.	walnut	G12		24	25				
	1477		Juglans sp.	walnut	G12		36	21				
	1478		Juglans sp.	walnut	G11		35	36				
	1479		Juglans sp.	walnut	G11		20					
	1480		Juglans sp.	walnut	G11		24					
	1481		Juglans sp.	walnut	G11		15	26				
	1482		Juglans sp.	walnut	G11		35					
	1483		Juglans sp.	walnut	G11		23					
	1484		Juglans sp.	walnut	G11		17					
	1485		Juglans sp.	walnut	G11		12					lower trunk scar/canker
	1486											tag not used
	1487		Juglans sp.	walnut	G11		17					
	1488		Juglans sp.	walnut	G12		24					middle of path, red ribbon
	1489		Juglans sp.	walnut	H11		11					
	1490		Juglans sp.	walnut	H12		52					
	1491											tag not used
	1492		Juglans sp.	walnut	H12		70					
	1493		Juglans sp.	walnut	H12		88					
	1494		Juglans sp.	walnut	H12		15					
	1495		Juglans sp.	walnut	G14		72					
	1496		Juglans sp.	walnut	G13		24	23				meas. 2'
	1497		Juglans sp.	walnut	G13		23					
	1498		Juglans sp.	walnut	G13		27					
	1499		Juglans sp.	walnut	H14		21					
	1591		Juglans sp.	walnut	H14		16					
	1592		Juglans sp.	walnut	J13		55					hollow base
	1993		Juglans sp.	walnut	J13		96	57	84			mystery species: *Juglans regia* ?