PREPARING PLANT COLLECTIONS FOR BIOLOGICAL INVASIONS: A STUDY OF THE EFFECTS OF EMERALD ASH BORER (*AGRILUS PLANIPENNIS* FAIRMAIRE) THROUGH CASE STUDY ANALYSIS

by

Andrew T. Gapinski

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Andrew T. Gapinski

Approved: ____
Robert E. Lyons, Ph.D.
Professor and Director, Longwood Graduate Program

Approved: ____
Blake C. Meyers, Ph.D.
Chair of the Department of Plant and Soil Sciences

Approved: ____
Robin W. Morgan, Ph.D.
Dean of the College of Agriculture and Natural Resources

Approved: ____
Debra Hess Norris, M.S.
Vice Provost for Graduate and Professional Education

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ABSTRACT

United States history has documented the tremendous environmental and economic destruction that biological invasions like chestnut blight and Dutch elm disease have caused. In more recent years the exotic, Asian-introduced emerald ash borer (EAB; *Agrilus planipennis* Fairmaire) has decimated North American ash populations. If public horticulture institutions are to ensure the long-term survival of core collections from such threats, the vulnerability of these holdings, and the institution in general, must be recognized and actions taken to protect and preserve these valuable resources.

This research investigated the destructive impact of EAB on plant collections and natural areas at public gardens in the U.S. Great Lakes region, to articulate and publicize the lessons learned from this exotic pest. Furthermore, this research reports the management strategies utilized by affected institutions, the preparation initiatives of institutions that reside in EAB's impending range, and the involvement of institutions in additional activities pertaining to EAB. This study also documents analogous cases of biological invasion, such as hemlock woolly adelgid (*Adelges tsugae* Annand), sudden oak death (*Phytophthora ramorum* Werres et al.), and Asian cycad scale (*Aulacaspis yasumatsui* Takagi) that are affecting institutions in other regions of the United States. To aid in research initiatives, such as resistance breeding pertaining to the EAB invasion, this study also sought to investigate the current state of *ex situ Fraxinus* collections globally.

Research methodology primarily included qualitative, semi-structured, on-site interviews with staff at four public garden case study sites. Secondary phone interviews were conducted with staff at additional institutions affected by EAB, with institutions dealing with analogous cases of biological invasion, and with professionals involved in collaborative initiatives. Furthermore, the current state of wild origin *Fraxinus* holdings was explored through the utilization of on-line survey tools and submission of collection inventories by participating institutions.

Beyond the decimation of collection and natural area specimens and the resulting effects on aesthetics, reported impacts included shifts in resource allocation, extensive secondary environmental implications, mandated operational changes, financial losses due to unrealized revenue, stress on donor relations, and effects on visitor morale and experience. The collective analysis of the reported preparation and management strategies, involvement in additional initiatives, and lessons learned revealed 13 critically important recommendations in three overarching categories including: Institutional Planning, Collections and Natural Areas Stewardship, and Collaborative Efforts by the Public Garden Community and Beyond. Recommendations include: greater prioritization of collections, secondary storage of vitally important holdings, the fundamental value of documentation and mapping, the essential need for explicit monitoring, the clear benefits of collaborative efforts, and the imperative merits of advocacy and education. These recommendations are to be considered by institutions to better prepare for future threats.

A preliminary account of *Fraxinus* collections globally yielded 37 institutions submitting *Fraxinus* inventories. Over 800 wild origin *Fraxinus* accessions, representing over 50 reported species are recorded in these findings.

Chapter 1

INTRODUCTION

Fueled by globalization at an accelerating rate (Barnard and Waage, 2004), it is estimated that there are currently 50,000 invasive plants, animals, and microbes in the U.S., and an additional 500,000 throughout the rest of the world (Pimentel et al., 2007). These species are having a profound impact on biodiversity and ecosystems as well as on the economic and societal services that those systems and species provide (Charles and Dukes, 2007). As stated by the USGS (U.S. Geological Survey) Invasive Species Program, “the current annual environmental, economic, and health-related costs of invasive species exceed those of all other natural disasters combined” (USGS, 2009). Alien species compete for resources and, in some cases, can overwhelm native populations, leading to the displacement of natives in the invaded habitats (Nentwig, 2007). Wilcove et al. (1998) reported that of the top threats to biodiversity in the U.S., competition or predation by alien species is ranked second only to habitat destruction, affecting 49% of native imperiled species. Secondary negative effects from invasives include chemical pollution due to control measures, erosion issues, and water contamination (Nentwig, 2007). In addition to environmental concerns, Pimentel et al. (2005) estimated that the annual cost of the impact and controls associated with invasive species in the U.S. was approximately $120 billion per year. More specifically, the impact of introduced insects and pathogens on U.S.

agriculture and forest product industries is estimated to be almost $40 billion annually, with an additional $3.5 billion spent for their control in lawns, gardens, and golf courses (Pimentel et al., 2005).

U.S. history has documented the tremendous environmental and economic destruction that invasive species have caused. In the early 1900's, chestnut blight (*Endothia parasitica* Murr.), a disease indigenous to China and Japan, completely destroyed the American chestnut (*Castanea dentata* Marsh.) population. These majestic trees once dominated the eastern deciduous forests of the U.S. and comprised 25% of the canopy in its native range (Griffin and Elkins, 1986). The estimated 4 billion trees that spanned over 200 million acres from Maine to Florida, served as a vital food source for wildlife, and an economically important timber and edible nut species for rural communities (TACF, 2010). The blight organism is thought to have been originally introduced to New York City in 1904 via infected nursery stock from Japan. In the 40 years that followed its discovery, it is estimated that 3.5 billion trees died (Griffin and Elkins, 1986).

Similarly, Dutch elm disease (*Ophiostoma ulmi* (Buism.) Nannf.) is noted as one of the most destructive tree diseases in North America (Schreiber, 1993). Prior to the 1930's, the graceful, vase shaped American elm (*Ulmus americana* L.) dominated the cultivated American landscape. The tree lined streets and graced parks throughout the U.S., exploited for its quick growth rate and urban tolerance (USDA Forest Service, 2010). First discovered in Ohio in 1934, the pathogen is thought to have been introduced from Europe via diseased elm logs imported for veneer production (Schreiber, 1993). By 1976, only 34 million of the estimated 77 million elms used in the urban landscape remained, and that number continues to decline (USDA Forest Service, 2010). As of 1993, the disease was prevalent throughout most of the U.S., infecting natural and cultivated populations in 42 of the 48 contiguous states (Schreiber, 1993).

In more recent decades, hemlock woolly adelgid (HWA; *Adelges tsugae* Annand) has become a significant pest. Originally reported in 1916 in Vancouver, British Columbia (Chrystal, 1916), this insect was not found in the eastern U.S. until its discovery in Virginia in the 1950's (Gouger, 1971). Native to Asia, HWA did not raise serious concerns until the 1980's, when it started destroying Canadian hemlock (*Tsuga canadensis* (L.) Carrière) populations in the U.S. mid-Atlantic region (Del Tredici and Kitajima, 2004). Virginia's Shenandoah National Park has reported that as much as 80% of its hemlock population has died due to HWA, and further impact to forest ecosystems could surpass the decline of the American chestnut (NPS, 2008).

The most recent in this string of alien invaders is the emerald ash borer (EAB; *Agrilus planipennis* Fairmaire). Since its discovery in Michigan in the summer of 2002, EAB has been responsible for the death of tens of millions of ash trees in southeastern Michigan alone. This insect most likely arrived in the U.S. via wood packing materials originating from its native range in Asia (USDA Forest Service et al., 2010). Unlike native borers, like the bronze birch borer (*Agrilus anxius* Gory), that tend to colonize stressed trees, EAB attacks completely healthy trees, having a catastrophic impact on native and cultivated North American ash (*Fraxinus* L.) populations (Herms et al., 2004). The introduced beetle has now spread from Michigan to Ohio, Illinois, Indiana, Pennsylvania, West Virginia, Maryland, Missouri, Wisconsin, Virginia, Quebec, Ontario, and as of the spring of 2009, has been reported in Minnesota, Kentucky, and New York (USDA Forest Service et al., 2010). Anulewicz et al. (2008) reported that of the four ash species native to the current distribution of EAB, (green ash (*F. pennsylvanica* Marsh.), white ash (*F. americana* L.), black ash (*F. nigra* Marsh.), and blue ash (*F. quadrangulata* Michx.)), all have succumbed to the EAB infestation. The remaining 12 species of U.S. native ash are also at risk if current trends continue (USDA-APHIS, 2008). Although no U.S. native, non-ash species have been reported as susceptible, there is concern for the possibility, given that hosts of other *Agrilus* species (synonymous with *A. planipennis* (EAB) by some sources) reportedly extend beyond the genus *Fraxinus* in their native range (Anulewicz et al. 2008).

In addition to the devastation of natural ash populations and their ecosystems, there is concern for the tremendous associated economic impact to municipalities, forest product industries, property owners, and nursery operators. Recent studies of the economic impact of EAB in Ohio alone, shows that a complete loss of Ohio's urban ash population could cost the state between $1.8 and $7.5 billion for the removal and replacement of ash trees in parks, private landscapes, and along streets (Sydnor et al., 2007). EAB is equally devastating in Russia, causing much alarm for the possible impending threat to European ash populations (Baranchikov et al., 2008). There are three species of native European ash (common ash (*F. excelsior* L.), narrow-leaved ash (*F. angustifolia* Vahl), and manna ash (*F. ornus* L.)), of which *Fraxinus excelsior* is commonly used as a street tree and is found in native populations throughout most of Europe (FRAXIGEN, 2005). If European ash species have as little resistance to EAB as the North American species, the insect would have serious implications for biodiversity and ecosystem services that are already apparent in the U.S. (Baranchikov et al., 2008).

The living collections that public gardens and arboreta curate are equally at risk, and as globalization increases, so does the threat to these valuable holdings from exotic plant pathogens and insect pests. Although much research has addressed management policies and recommended actions for botanical gardens and arboreta regarding invasive plant species (Hohn, 2008; Reichard and Hamilton, 1997), there is relatively little information pertaining to collections management that focuses on the threat of invasive insects and plant pathogens. Recent cases in which collections and natural areas have been challenged by biological invasions (Michener, 2008; Schulhof, 2007) as well as other natural disasters (e.g. hurricanes; Maunder, 2007; Evans, 2003) have brought increasing awareness to the issues of sustainability and vulnerability of living plant collections. Although there have been a few studies (Bergquist, 2009; Burghardt, 2000) that do address issues of natural disaster planning at public gardens, the focus of these studies is on abiotic threats (e.g. fire, hurricane, flooding), with no mention of biological invasions.

Although lacking for living collections and public gardens specifically, more extensive disaster readiness planning resources do exist from other sectors of the museum world (Bergquist, 2009). Furthermore, the American Association of Museums (AAM) Museum Accreditation Program requires the submission of an “emergency/disaster preparedness plan (covering staff, visitors, and collections)” for participating institutions (AAM, 2004). According to the AAM (2007),

> Museums care for their resources in trust for the public. It is incumbent upon them to ensure the safety of their staff, visitors, and neighbors, maintain their buildings and grounds, and minimize risk to the collections that they preserve for future generations. Conscious, proactive identification of the risks that face people and collections, and appropriate allocation of resources to reduce these risks is a vital part of museum management.

Although the Accreditation Program represents 779 museums of all types (AAM, 2010a), only 2% of AAM accredited institutions identify themselves as an arboretum or botanical garden (AAM, 2010a). Similar to the AAM Program, the American Public Gardens Association (APGA) does have a program in place, namely the North American Plant Collections Consortium (NAPCC), with one of its primary goals being to recognize a high-level of collections stewardship within its member institutions; but NAPCC does not go as far as to include recommended standards for, or requirement of a disaster readiness plan for involvement (Allenstein, 2009).

Richard Schulhof (2007), Former Deputy Director of the Arnold Arboretum proclaims,

> Responding to invasive species in ways that safeguard people, plants, and the larger environment demands that we more wisely manage the uncertainties of a rapidly changing world. The story of hemlock woolly adelgid… at the Arnold Arboretum recounts the lessons learned in addressing the rarely predictable, often irreversible consequences of biological invasion.

If public horticulture institutions are to ensure the long-term survival of core collections from such threats, the vulnerability of these holdings, and the institution in general, must be recognized and actions taken to protect and preserve these valuable resources. This thesis has several objectives and pragmatic purposes to aid in this goal. The primary objective is to investigate EAB’s destructive impact on plant collections and natural areas at public gardens and arboreta in the United States, so as to articulate and publicize the lessons learned from the effects of this invasive pest. In addition, the research seeks to report the management strategies utilized by affected institutions, the preparation initiatives of those who reside in the pest's impending range, and the involvement of institutions in external activities pertaining to EAB. This study also documents analogous cases of biological invasion, such as hemlock woolly adelgid (*Adelges tsugae* Annand), sudden oak death (*Phytophthora ramorum* Werres et al.), and Asian cycad scale (*Aulacaspis yasumatsui* Takagi*)* that are affecting institutional collections in other regions of the U.S. Through the collective analysis of the reported preparation and management strategies, involvement in additional initiatives, and lessons learned from affected institutions, this study ultimately includes recommendations for public horticulture institutions to better prepare for future exotic insect and disease introductions.

Through a preliminary survey of *Fraxinus* collections at selected public horticulture institutions globally, representative taxa and geographic origins of documented, wild origin specimens held in collections were identified. It is the intention that results from this study will contribute to the initiatives of the North America-China Plant Exploration Consortium (NACPEC) and other organizations, to better focus future exploration efforts targeting *Fraxinus* species, identify *Fraxinus* species that are available for EAB resistance breeding, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

Chapter 2

LITERATURE REVIEW

Biological Invasions at Public Gardens

In recent years, publications have emerged from botanical gardens and arboreta addressing the impacts that exotic pests have had on plant collections and native populations. Richard Schulhof (2007), former Deputy Director of the Arnold Arboretum of Harvard University, published the article *Managing Biological Invasion: Introduced Pests and Pathogens*. The article addresses the management challenges regarding the infestation of hemlock woolly adelgid (HWA) at the institution. Although preventative and eradication chemical methods have been utilized to preserve the Arboretum's historic natural hemlock stand known as Hemlock Hill, many trees have been lost due to HWA, and secondary effects including the invasion of exotic plant species into forest gaps, remain an ongoing management issue. While the stewardship of this treasured remnant stand is of utmost importance, the institution is aware of the larger environmental implications of its maintenance.

> Finding a balance among stewardship, education, and public service goals, we protect hemlocks that are of sufficient vigor to recover and that grow in conditions that are favorable for treatment and do not present risk of water contamination (Schulhof, 2007).

Schulhof (2007) points out, "invasives require that we stay abreast of new methods and information, not only to improve the efficacy of our management measures but to do so with ever diminishing environmental impacts." By using an Adaptive Management (Holling, 1978) strategy, where data is gathered on the effectiveness of treatment methods and keeping up-to-date on new information from the research community, the Arnold Arboretum has been able to maintain its hemlocks and focus its resources for more effective management of HWA (Schulhof, 2007).

The even more recent effects of the emerald ash borer (EAB) on living collections and the management lessons that can be learned from the devastation are beginning to surface. Near the epicenter of the discovery of the insect, the Matthaei Botanical Gardens & Nichols Arboretum (MBGNA) at the University of Michigan has experienced the tremendous impact of EAB on its once extensive research collection and native stands of *Fraxinus*. With the exception of a few specimens still producing basal suckers, the entire collection and native population is dead (Michener, 2008). In the article, *Lessons from the Death of a Reference Ash (Fraxinus) Collection*, David Michener, Associate Curator, highlights the lessons the institution learned from the devastation, posing five questions for other institutions to consider in the preservation of their core collections:

(1) "What assumptions are you making in regard to your own living collections?" Noting that biological invasions have already destroyed extensive populations of American chestnut, elm, and many other species, and therefore institutions should not use the current overall condition of a collection or surrounding native population as an indicator of their health tomorrow and in the future. "My take-home lesson: We should evaluate our collections and prioritize those of such

importance that they warrant inclusion in regional or national collections –this should be a basic part of our planning processes” (Michener, 2008).

(2) “Are you making the same assumption that local back-up is adequate for your absolutely core materials?” Stressing that the backing-up of living collections through on-site duplication or at nearby locations, is an irrelevant approach with disasters, such as the invasion of EAB, that are not restricted to a single event. “My take-home lesson: For key collections, local “backup,” even in natural populations, may be insufficient. Joining a collection consortium may be the only means of protection” (Michener, 2008).

(3) “To what extent do you rely on sister gardens to back up or complement your critical collections, and is this sufficient?” Pointing out that 40-million ash trees have been killed in the surrounding region, and therefore sharing accessions with local sister-institutions would have been of no help. “My take-home lesson: Key collections should be replicated in another region that is suitable but ecologically isolated from yours, and/or germplasm storage needs to be explored” (Michener, 2008).

(4) “If you do have disaster plans, are they only for short term disasters, and have you considered the implications for institutional programs related to your collections?” Michener explains that much of the institution’s ash collection’s value was in its use for breeding programs. Long-term seed storage does little to help reestablish breeding stock that takes decades to develop in an area that basically can not be reused, at least until resistant ashes are developed. “My take-home lesson: Our missions need to be robust enough to allow us to institute programs with a new focus.

We should at least be aware that taxonomically-restricted missions may have to be totally reconsidered" (Michener, 2008).

(5) "What resources (including endowment) are needed for a collection to be truly sustainable? By what logic can your institution identify its core materials?" Michener explains that the core issue is that institutions need to take a realistic look at their collections and determine the relevance of each specimen to that institution's mission. By planning ahead and addressing such issues on a continual basis, an institution does not put itself in a "reactive mode" to save what it can in the face of such disasters. "My take-home lesson: To protect our vital plant heritage, we need to think about what criteria would induce us to collaborate with other gardens as part of a national collection such as NAPCC" (Michener, 2008).

From these lessons, the MBGNA is currently evaluating its remaining collections and identifying those of utmost value, taking the appropriate steps to ensure their long-term survival. In addition, it has become apparent to the institution that partnerships such as the multi-institutional collections of the North American Plant Collections Consortium (NAPCC) may better enable survival of their core collections from future invasions (Michener, 2008).

Initiatives at Public Gardens Regarding Biological Invasions

Beyond managing the destruction, botanic gardens and arboreta have played a key role in understanding insect and pathogen invasions, and have provided the knowledge and plant material resources to address pest management and plant breeding efforts for resistant taxa. The Morton Arboretum maintains the largest elm collection in the United States, and with extensive inventories of Asian, American, and European taxa, the Arboretum was key in the development of Dutch elm disease (DED) resistant hybrids. Through its tree improvement program, led by Dr. George Ware, introduced cultivars such as ‘Morton’ (Accolade™ elm; *Ulmus japonica* (Sarg. ex Rehder) Sarg. x *U. wilsoniana* C.K. Schneid.), have expanded the tree diversity available for use in the ever-expanding urban forest, as the cultivated American elm population has been lost to DED (Mittempergher and Santini, 2004).

Bentz et al. (2002) of the U.S. National Arboretum made controlled pollinations among five hemlock species of North American and Asian origin to test for breeding compatibility. Crosses between the HWA-susceptible North American hemlock (*Tsuga caroliniana* Engelm.) and the more HWA-tolerant Chinese species (*T. chinensis* (Franch.) E. Pritz.) yielded 59 true hybrids. The study also determined that an incompatibility barrier exists between the eastern hemlock (*T. canadensis* (L.) Carrière) and its Asian relatives (Bentz et al. 2002). Furthermore, field trials conducted at the Arnold Arboretum evaluated the potential resistant properties of Asian hemlock species, identifying a high degree of HWA resistance in *T. chinensis*. The study also showed the species to be fully cold hardy at USDA Zone 6, having rapid growth rates and shade tolerance, making it a feasible replacement for *T. canadensis* in the cultivated landscape (Del Tredici and Kitajima, 2004). More recent studies by researchers at the U.S. National Arboretum and USDA-Forest Service showed that “the nature of the host resistance [in *T. chinensis* to HWA] is both non-preference (antixenosis) and adverse effects on biology (antibiosis)” (Montgomery et al., 2009). Furthermore, recent collecting expeditions to five Chinese provinces yielded more than 20 hemlock accessions now under evaluation at the National, Morris, and Arnold Arboreta for possible use in similar breeding initiatives (Havill and Montgomery, 2008). In 2008, a similar expedition by the North America-China Plant Exploration Consortium (NACPEC), which included researchers from the Morton, Morris, and National Arboreta, traveled to China's Shaanxi Province to focus on collecting *Fraxinus* seed to test for EAB resistance and use in similar breeding programs (Bachtell, 2008). It has been noted by past studies that the resultant collections developed for breeding efforts, such as in the case of Dutch elm disease, have also resulted in the *ex situ* conservation of collected taxa, taxonomic clarification within the genus, and a better understanding of host-pathogen-vector interactions (Mittempergher and Santini, 2004).

A clear example of research that has benefited from the development of botanical collections is highlighted by Havill and Montgomery (2008). Starting in 1999, USDA researchers sought to understand the evolutionary relationship between HWA and its host species. While the study focused on utilizing plants growing in their native environment, Havill and Montgomery (2008) report,

> We also made extensive use of cultivated hemlocks growing in various botanical gardens around the world… The living collections and herbaria at these institutions have proved to be an invaluable resource for us in developing an evolutionary context for understanding hemlock resistance to HWA. In addition, the records and herbarium specimens from expeditions sponsored by the Arnold Arboretum – from the time of E.H. Wilson and Joseph Rock through the Sino-American Botanical Expedition of 1980 – were invaluable in helping us to pinpoint where to look for hemlock specimens in southwest China.

The researches used hemlock samples from the wild and from arboreta-based cultivated plants in DNA sequencing to “reconstruct the evolutionary relationships and biogeographic history of hemlock,” to shed light on how to best manage HWA (Havill and Montgomery, 2008).

> Without the resources and expertise at the Arnold Arboretum, the U.S. National Arboretum, Morris Arboretum, Longwood Gardens, Chollipo Arboretum, Hangzhou Botanical Garden, and the Royal Botanical Garden at Edinburgh, this research would not have been possible. By highlighting the vital contributions that botanical gardens have made to the development of ways to control this devastating pest, hopefully we have reinforced the need for their continued commitment to research (Havill and Montgomery, 2008).

Gardens have also played a role in public education and outreach, as well as statewide readiness planning for biological invasions. The Arnold Arboretum has used the destruction of its historic Hemlock Hill as a teaching opportunity to build public awareness of the threat of exotic pests. Through school group studies, special visitor tours, community presentations, and use of media outlets, the Arboretum shares with the public the resulting disturbance to native ecosystems and management challenges that such invasions cause (Schulhof, 2007). Similarly, The Morton Arboretum organized efforts to minimize the effects of EAB in Illinois, establishing the Illinois Emerald Ash Borer Readiness Team in 2003, and educating the public on the then impending threat. The Team, made up of 40 private and public organizations, worked collaboratively to bring together resources, using initiatives by already affected states as models to aid in Illinois’ readiness planning process (EAB Readiness Team, 2006).

Effects and Lessons from Other Natural Disasters at Public Gardens

Beyond the epidemic outbreaks of insects and pathogens that increasingly threaten the integrity of our living plant collections, more has been written of the destructive force of other abiotic natural disasters, as well as the added impact of climate change fueling the occurrence and force of such events. Hurricanes, wildfires, and tornados, to name a few, have wreaked havoc on U.S. plant collections and the institutional facilities that are fundamental to their care. Fairchild Tropical Botanic Garden (FTBG), located on the southeastern coast of Florida, is no stranger to such events. On August 24, 1992 the Garden felt the tremendous impact of Hurricane Andrew, after a 26-year lull in severely destructive storms. With FTBG suffering total devastation, Evans (2003) reports eight "lessons" that were pulled from the wreckage: (1) "Proper Tree Care," noting that providing adequate staff and financial resources to properly maintain specimens is key. "Many tropical tree species produce extremely dense canopies that, if not thinned, make the tree highly susceptible to severe breakage and blowing over" (Evans, 2003). (2) "A Clear Plan," reporting that in the storm's aftermath a "triage" approach was taken. Staff most familiar with the grounds and collections identified the highest priority trees, those of lower priority, and specimens that could simply be removed. (3) "Importance of Plant Records," stating that the Garden's up-to-date collections database and mapping system allowed staff to quickly identify rare specimens to better focus rescue efforts. (4) "Publicity," regarding FTBG's fate, brought in waves of monetary support, material donations, and volunteer commitment. (5) An assigned "Coordinator" to direct and support the needs of volunteer forces is key. (6) Clear "Communication" is key. Assigning a staff person to communicate with contractors, the ordering of material and supplies, while maintaining internal communications with staff is vitally important. (7) Having the "Vision" to find value in the wreckage. Utilization of the wood, in some cases from extremely valuable species, raised the institution $40,000. Furthermore, permanent and temporary art displays were developed, and the newly opened spaces provided an opportunity for landscape improvements including restoring overgrown vistas and clearing space for more botanically significant specimens. (8) Finally, a "Hurricane Manual" was prepared to instruct staff to back-up important files, assign responsibilities for the next catastrophic event, ensure inventory of needed materials are in place, and prepare contact lists (Evans, 2003).

As highlighted by Maunder (2007), former Director of the FTBG, The United Nations Intergovernmental Panel on Climate Change (IPCC) "predicts a 7 to 23 inch rise in sea level in 95 years… [and] increases in sea surface temperatures, which are expected to fuel hurricane frequency and intensity." Maunder (2007) goes on to say as a public garden community, "We need to prepare our institutions and collections for change, and we need to invest our time and energy into slowing the impacts of climate change." To meet the challenges of increasingly intense and frequent storms and the threat of raising sea level to this coastal garden, FTBG is preparing for the future by: "Storm Proofing the Institution," through the development of a procedural manual for such events and installation of automatic generators; "Storm Proofing the Collections," by recognizing the vulnerability of living specimens, ensuring proper maintenance is performed, promoting long-term storage of germplasm (e.g. seed), and utilizing the collections to their fullest potential as long as they persist; “Refocusing Educational and Interpretive Messaging,” to teach about the impacts of climate change; “Reducing Our Carbon Footprint,” by reducing water and energy use; and finally “Supporting the Conservation of Tropical Wetlands” by influencing policy makers, partnering with other conservation-minded organizations, and championing the preservation and restoration of tropical forests themselves, the deforestation of which is the second leading cause of climate change (Maunder, 2007). “Botanic gardens look for ways to be relevant to society. Climate change, for all its unsettling enormity, is an arena for botanic gardens to make and demonstrate our relevance to society as a whole” (Maunder, 2007).

It also has been noted that beyond raising sea levels and increasing storm intensity, “warming temperatures will likely enable HWA and other temperature-limited invasives to expand [their] ranges of infestation and more quickly reach lethal densities on host species” (Schulhof, 2007).

Disaster Readiness Planning in the Museum World

Natural disasters like hurricanes and biological invasions, or disasters of human cause, such as building fires and terrorism, can have catastrophic impacts on all types of museums, their staff, visitors, facilities, and the collections they are entrusted to steward. Although few resources are available to aid public gardens in the disaster planning process specifically for living plant collections, planning examples from other segments of the museum world (e.g. art museums), are robust (Bergquist, 2009).

Bergquist (2009) concluded only 18-31% of American public gardens have some form of a natural disaster plan to safeguard holdings through preparatory actions and/or reactive steps to aid in the plant recovery process. Three recommendations are made by Bergquist (2009) to reduce the vulnerability of and safeguard living collections from disasters. These include the need to “Document,” in that specimen identification before and after an event allows for “comparisons of affected plant material, which not only assists collections management… but also impacts potential insurance claims.” Institutions should “Prioritize” their holdings, so that post-disaster recovery steps can be taken immediately. Finally, a “Disaster Planning” process should be initiated, posing a number of questions for institutions to consider including:

> What are the collections’ strongest features? Are there any threats to the collections that the garden is unprepared for? Are there any maintenance practices in need of attention for plant health and protection? What other gardens in the region or country have or do not have our rare specimens (Bergquist, 2009)?

Beyond specific natural disaster planning tools for public gardens, many resources exist to help prepare museums for disasters in general, which are summarized by Bergquist (2009). For example, the American Association of Museums (AAM) provides extensive direction to external resources related to “Emergency/Disaster Plan Development” and “Emergency Preparedness & Recovery” (AAM, 2010b). Furthermore, the AAM Museum Accreditation Program recognizes “museums’ commitment to excellence, accountability, high professional standards, and continued institutional improvement” (AAM, 2010a). The Program requires submission of an “emergency/disaster preparedness plan (covering staff, visitors, and collections),” for an institution to be considered for accreditation, but does not provide guidelines for such a document (AAM, 2004).

Cases of Collections Assessment

Many surveys have been developed to evaluate the completeness of a particular genus or plant group held in collections. These surveys have evaluated the conservation value of particular collections, informed acquisition efforts by identifying gaps in current holdings, evaluated issues in taxonomic verification, and supported certain program initiatives. Furthermore, such an inventory can identify plant material that is available for research initiatives, such as resistance breeding. Researchers with the USDA Forest Service and the Ohio State University suggest that a current barrier to successful hybridization of EAB-resistant ash taxa is a lack of known species with EAB resistance, as well as a limited, genetically diverse sampling of those species for use as parents in breeding programs (Koch et al., 2007).

A 2001 study surveyed palm species held in 35 botanic gardens across 20 countries, to evaluate the differing roles of temperate versus tropical *ex situ* collections. The study concluded that the value of temperate region palm collections in conservation initiatives is limited, and should focus efforts on “display and fundraising, towards supporting in-country conservation activities in the tropics” (Maunder et al., 2001). Similarly, a 2002 survey of medicinal plant specimens held in U.S. herbaria evaluated 14 institutions for the presence of 42 specific taxa of economic importance. “Recommendations are made for usage of virtual herbaria and expanded usage of traditional herbaria for identification of plants used in health care” (Flaster, 2004). In addition, a survey of 105 European botanic gardens in 29 countries was conducted to examine their holdings of threatened European plant species. In all, 308 taxa (53%) of the 573 listed by the Bern Convention on the Conservation of Wildlife and Natural Habitats were represented in the collections surveyed. Of the 4,417 specimens that were reported, 39% were recorded to be of wild-origin (Maunder and Higgens, 1998).

In more recent years, Botanic Gardens Conservation International (BGCI) released results from two completed surveys, one at the family level for Magnoliaceae (Magnolia family; BGCI, 2008) and the other at the genus level for *Quercus* (oaks; BGCI, 2009a). Both surveys were completed as the first step to accomplish the outlined objectives of the BGCI and FFI (Fauna & Flora International) 2007 publications *The Red List of Magnoliaceae* (Cicuzza et al., 2007) and *The Red List of Oaks* (Oldfield and Eastwood, 2007). These reports call for ensuring that specific taxa for each group, listed as Critically Endangered or Endangered, are conserved. The surveys were completed to identify which of these taxa are currently represented in *ex situ* collections globally in order to better focus future conservation efforts (BGCI, 2009a; BGCI, 2008).

Furthermore, the development of multi-institutional collections through consortiums such as the NAPCC, has led to a better understanding of what is currently held in collections, identifying gaps in holdings, allowing for the sharing of resources and expertise, and advancing the public gardens' role in plant conservation as a whole. Allenstein and Conrad (2004) reported that duplication often results when institutions work independently, leaving many species unprotected, while "collaborative efforts coordinated on a national level can help identify these duplications and gaps in the collections and maximize the potential value of collections at individual gardens." The recent addition of the multi-institutional *Quercus* collection to the Program is comprised of 15 botanical institutions that represent 168 of the estimated 373 *Quercus* taxa known worldwide (Collins, 2008). NAPCC states that these partnerships “make germplasm available for taxonomic studies, evaluation, breeding, and other research” (APGA, 2010a).

Technology is advancing such measures to tie institutional databases together making collection evaluation efforts, as described previously, that much easier. PlantCollections™ a collaborative effort led by the Chicago Botanic Garden, partnering with APGA, University of Kansas, and 15 U.S. gardens,

> … will allow information from multiple institutions currently in a variety of incompatible database formats to be accessed and integrated into comprehensive inventories. The results can then be analyzed to identify gaps and redundancies in holdings, a first step in coordinating a continent-wide approach to plant germplasm preservation (APGA, 2010b).

Many similar projects are currently in place or under development around the world (BGCI, 2010a; RBGE, 1997; V.B.T.A. vzw, 2007).

Chapter 3

MATERIALS AND METHODS

<u>Research Approach</u>

Qualitative data was collected to investigate the impacts of emerald ash borer (EAB) and other invasive species on living collections and natural areas at public gardens and arboreta in the U.S. Great Lakes region, to articulate and publicize the lessons learned from these exotic pests. Qualitative methods were also used to investigate the preparation and management strategies utilized by affected institutions and those residing in the pest's impending range. These data were primarily obtained through four case studies at institutions currently experiencing or preparing for the effects of EAB. Secondary phone interviews were also conducted with individuals at similarly affected institutions and/or individuals involved in initiatives related to these invasions.

Quantitative methodology was used to inventory and evaluate the current state of *ex situ Fraxinus* holdings at public gardens and other germplasm repositories worldwide. To aid in the development of this survey, data were also collected to identify specific information needed by plant professionals engaged in various fields of work regarding a plant specimen, which would then be obtained in the succeeding *Fraxinus* inventory.

Human Subjects Review Board

This study followed the research guidelines, regulations, and institutional procedures outlined by the University of Delaware's Human Subjects Review Board (HSRB). The investigator conducting this study attended institutional Human Subjects Training on the use of human subjects in research on December 9, 2008. A complete description of the research methodology utilized in this study including participants involved, interview and on-line survey questions employed, informed consent forms, and data analysis techniques were submitted for review to HSRB. Exemption from Human Subjects review was granted in all cases due to the subject matter of this research. See Appendix A for HSRB approval letters.

Qualitative Research Methods

Case study design

Semi-structured on-site interviews were conducted at four case study sites based on a multiple-case study, two-tailed design (Yin, 2009). Case studies, as defined by Creswell (2009),

> … are a strategy of inquiry in which the researcher explores in depth a program, event, activity, process, or one or more individuals. Case studies are bound by time and activity, and researchers collect detailed information using a variety of data collection procedures over a sustained period of time.

A two-tailed design seeks to represent "different types of conditions and the desire to have subgroups of cases covering each type" (Yin, 2009). This type of design, "should still have at least two individual cases within each of the subgroups, so that the theoretical replications across subgroups are complemented by literal replications within each subgroup" (Yin, 2009). With two distinct subgroups within this study: (1) institutions that have identified and are currently, or have dealt with the effects of EAB on their grounds, and (2) institutions preparing for, through a variety of initiatives, the inevitable spread of EAB to their location, the multiple-case two-tail design described above, allows for investigation and comparison between these two subgroups. For purposes of replication two institutions were selected representing each subgroup.

Case study site selection

Case studies were selected using non-random purposive sampling (Johnson and Christensen, 2000). Given that timely information about the spread of EAB is readily available via the "emerald ash borer" website (USDA Forest Service et al., 2010), several institutions within and outside the insect's current range could be identified and contacted. The American Public Gardens Association's (APGA) Public Garden Search feature on their website (APGA, 2010c) aided in this process, by identifying institutions by state. Informal phone discussions with potential institutions' directors, curators, directors of horticulture, or individuals in similar positions, were conducted to determine the current status of EAB at these institutions.

Selection of case study institutions was determined by the following criteria as ascertained from informal phone discussions:

- Presence of emerald ash borer at the institution
- Extent of the institution's *Fraxinus* holdings

- Expanse of forested natural lands owned and managed by the institution and percentage of cover that is or was *Fraxinus* species
- Extent of management strategies utilized if EAB present
- Extent of preparation strategies if EAB is yet to be located on the grounds
- Involvement in additional internal and/or external initiatives related to EAB (e.g. educational, research, seed collection, collaborative efforts, etc.)

Ultimately, selected case study sites were finalized by the availability and willingness of the institution to participate, travel feasibility for the researcher, and geographic location of the institution relative to the others selected. Accordingly, the following four institutions were selected as case study sites for this study:

- Institutions having located EAB on their grounds:
    - Matthaei Botanical Gardens & Nichols Arboretum at the University of Michigan, Ann Arbor, MI
    - W.J. Beal Botanical Garden and Campus Arboretum of Michigan State University, East Lansing, MI
- Institutions located in the impending range of EAB:
    - The Morton Arboretum, Lisle, IL
    - The Dawes Arboretum, Newark, OH

Case study data collection protocol

Data took the form of interview recordings and notes, digital images, relevant organizational documents, and field observations made by the researcher; which was collected over a two-day period at each institution.

Semi-structured, in-person interviews at each site were conducted with select staff, as determined in advance by suggestions provided by the primary contact at each institution. Depending on the institution, interviews were conducted with curators, directors of horticulture, natural lands managers, plant records managers, arborists, researchers, and others involved in EAB initiatives. Participants were provided, via email, with an interview protocol and informed consent form (Appendix B) for review prior to the researcher's visit. The interview protocol contained the research title, opening description of the research objective, and 20 multiple-part questions. Questions sought to capture perspectives from participants in three general areas:

- Collections and natural areas information and effects of EAB
- Readiness planning, preparation and/or management strategies utilized, and involvement in additional initiatives
- Lessons learned from the impacts of EAB and preparing for future biological invasions

Interview protocols for institutions where EAB has already been found on the grounds and those institutions in EAB's impending range can be found in Appendices C and D, respectively. Each interview lasted 45 to 120 minutes and all were recorded on a digital voice recorder, followed by transcription.

Supporting phone interviews

Phone interviews were conducted:

- To obtain additional and supporting perspectives from institutions dealing with and preparing for EAB. The institutions selected included:
    - Minnesota Landscape Arboretum of the University of Minnesota, Chaska, MN
    - Hidden Lake Gardens of Michigan State University, Tipton, MI
- To capture perspectives on other biological invasions affecting public gardens in other parts of the U.S. The institutions selected included:
    - The Arnold Arboretum of Harvard University, Boston, MA
    - Montgomery Botanical Center, Coral Gables, FL
    - University of California Botanical Garden, Berkeley, CA
- Obtain perspectives from professionals involved in collaborative initiatives involving public gardens, but not employed at such institutions. Selected organizations included:
    - North American Plant Collections Consortium (NAPCC), Kennett Square, PA
    - North Central Regional Plant Introduction Station (NCRPIS), Ames, IA

Phone interviews were conducted with one individual from each institution above. Interviews with individuals at public gardens to gain additional perspectives on EAB, utilized the same interview protocols (Appendix C and D) as in the case studies. Interviews with individuals at institutions affected by analogous invasions employed a similar, but more generally worded interview protocol, which can be found in Appendix E. Finally, for interviews with professionals involved in collaborative initiatives involving public gardens, a unique interview protocol was utilized. This protocol included 16 interview questions exploring the individual's current objectives pertaining to EAB, coordination of these efforts, public gardens' role in meeting these objectives, and the lessons learned from the EAB invasion and implications for dealing with future pests. This interview protocol can be found in Appendix F. All individuals were provided with the interview protocol and informed consent form (Appendix B) prior to the interview. Phone interviews were also digitally recorded and later transcribed to written form to ensure accurate data collection. Each phone interview lasted approximately 60 minutes.

Qualitative data analysis

Using Creswell (2009) as a guide, data were initially organized and prepared by transcribing digitally recorded interviews and field notes into typed form and grouped by respective institutions. All data, including institutional documents provided by each organization, were reviewed to note emerging trends and common thoughts among participants (Creswell, 2009). All data were then coded based on emerging themes (Creswell, 2009). A detailed narrative of the themes and interconnection between each theme was used for interpretation of the data (Creswell, 2009). Finally, recommendations for institutions to better prepare for future biological invasions were developed basis on these findings.

Quantitative Research Methods

Survey design

A global Survey of *Fraxinus* Collections at selected public horticulture institutions and other germplasm repositories, aimed to identify the representative taxa and geographic origins of collection specimens of wild documented origin. Two on-line surveys were constructed and administered to meet this objective. A preliminary survey referred to as the “User Group Survey” sought to identify specific information about individual plant specimens that is needed by plant professionals engaged in various fields of work. It was the intention that results from this survey would identify information about individual accessions that should be collected in the succeeding “Survey of *Fraxinus* Collections,” to be of value to the “users” of such an inventory. Both surveys were administered using the University of Delaware’s on-line survey software account with Qualtrics.com.

User Group Survey

Participants of the “User Group Survey” were selected non-randomly and included breeders, geneticists, entomologists, pathologists, biologists, ecologists, nursery professionals, forest product researchers, and public horticulture professionals. Potential participants were identified using on-line searches of U.S. Department of

Agriculture (USDA) agencies such as the Forest Service and Agricultural Research Service (ARS), universities, the APGA, and other institutional websites. In addition, a primary source of potential participants were individuals known to have relevant experience by the investigator and supporting Graduate Committee. In all, 60 individuals were identified and invited, via email, to participate in the on-line questionnaire.

The invitation email was sent in late April 2009 and was followed by weekly reminder emails to non-responders. The survey remained open for a one-month period. The content of the questionnaire included questions related to the participant's work position and objectives, information needed regarding plant material for it to be of value to their objectives, and the benefit that a global collections inventory, of a particular plant group, would provide in meeting their objectives. The questionnaire also contained an introductory statement regarding the purpose of the study and survey instructions, and a closing message upon submission. The complete survey contents can be found in Appendix G. Results of this study were used in the development of the succeeding "Survey of *Fraxinus* Collections."

Survey of *Fraxinus* Collections

To identify potential participants for the "Survey of *Fraxinus* Collections," Botanic Gardens Conservation International (BGCI), was contacted and asked to supply institutional information for organizations in the USA, Europe, China, Russia, Mexico, Canada, and Japan reporting *Fraxinus* holdings according to the © Copyright BGCI Garden Database (BGCI, 2009b). Specifically, for each institution it was requested that BGCI provide the investigator with institutional information including name, location, and contact information for the director, curator, and manager of plant records. Given that contact information for these positions was not available in all cases, subsequent searches of institutions' websites to obtain the information were then performed. In addition, the list was expanded by searches of other on-line databases including the Database of Asian Plants in Cultivation (Quarryhill Botanical Garden, 2007), and PLANTCOL (V.B.T.A. vzw, 2007), as well as institutions known to have *Fraxinus* holdings by the investigator and supporting Graduate Committee. In all, 151 institutions were identified and invited, via email, to participate in the on-line questionnaire.

The invitation email was sent in late May 2009 and was followed by reminder emails that were sent at two-week intervals to non-responders. The survey remained open for a three-month period. The content of the questionnaire included questions related to the institutions' living plant, seed, and herbarium *Fraxinus* holding, specimen verification systems utilized, and contact information for the institution. In addition, participants were asked to submit the primary record information for each of the institutions' *Fraxinus* accessions. The questionnaire also contained an introductory statement regarding the purpose of the study and survey instructions, and a closing message upon submission. The complete survey contents can be found in Appendix H.

Quantitative data analysis

Total response rate for each survey was determined. Quantitative data were described, summarized, and conclusions drawn using descriptive statistics (Johnson and Christensen, 2000). Submitted primary record information for each institutions' *Fraxinus* accessions where compiled into a Microsoft® Excel® spreadsheet and additional descriptions of these data were made using descriptive statistics.

Chapter 4

RESULTS: DESCRIPTIONS OF CASE STUDY SITES & SUPPORTING PHONE INTERVIEWS

This chapter presents findings from the four institutional case studies and seven phone interviews that were conducted. Each institutional description includes general organizational and historical information, discussion of the institution's mission, collections and natural areas information, status of EAB or other exotic pest at the institution, impact of the biological invasion, preparation and management strategies utilized, and descriptions of additional initiatives the institution reported to be involved in. The reported lessons learned from these invasions are presented in the succeeding Chapter.

Case Studies: Institutions Having Located EAB on Their Grounds

The University of Michigan Matthaei Botanical Gardens & Nichols Arboretum

Located in Ann Arbor, Michigan the Matthaei Botanical Gardens and Nichols Arboretum (MBGNA) is at the epicenter of the emerald ash borer (EAB) introduction. Originally started as a small pharmacy garden in 1907, the institution has expanded to oversee the management and operations of four properties including the grounds of the Arboretum, the Botanical Gardens, Mud Lake Bog, and Horner-McLaughlin Woods, totaling approximately 700 acres. The Arboretum, on 123 acres, is on the northeast side of main campus, and runs along the bank of the Huron River.

Considered to be the collections-based property and built for the students and citizens of Ann Arbor, the historic landscape is an O.C. Simonds design with cultivated plants at the ground's two main entrances turning ever more natural as the topography drops 175 feet to the bottom of the river valley. The design "was to preserve the sense of natural Michigan as well as display appropriate exotica from around the world" (Michener, 2009). One of the Arboretum's most valued holdings is its historic peony collection, representing over 260 cultivars with approximately 700 plants (Michener, 2009).

The Botanical Gardens, on its fourth physical site in the last century, is located six miles northwest of main campus on 350 acres, the majority of which would be considered natural areas. The institution's main facilities, including a conservatory containing representative species from about a fifth of the world's plant families, are located at this site. The Gardens' grounds sit on a modest upland slope that rises from the floodplain corridor of Fleming Creek. This site and the two other properties managed by the institution, "… were chosen for their floristic richness and between the three sites… have about a fifth to a third of the entire native diversity of the state," due largely to unique permutations of ground water in the glacial moraines of the region (Michener, 2009).

Given the tremendous natural and cultural heritage that these sites represent and the students and community that it serves, the institution's mission is in "Promoting environmental enjoyment, stewardship and sustainability through education, research, and interaction with the natural world," with core values to:

> … inspire and enrich people's lives through contact with plants and nature; recognize the restorative value of nature and beautiful gardens; engage scientists and artists in research, teaching, and outreach activities; apply ecological principles in our horticulture and land stewardship; advance sustainable practices and the conservation of biodiversity, particularly that of the Great Lakes Region (MBGNA, 2010).

As the institution continues to grow and develop its collections, Associate Curator, Dr. David Michener (2009) believes that in addition to maintaining,

> … the matrix of historic collections, vistas, and intent of the designers… probably the most valuable thing we can do is conserve native genotypes of native plants and manage them so that people can have an idea of what was here.

Fraxinus at the institution

"So for an institution that is focusing on stewarding natural diversity, we are sitting on at least, we think, about a quarter of the state's… floristic diversity. Losing a keystone species in a forest is a critical one" (Michener, 2009). In the natural areas of the institution and this region of Michigan, ash was generally an important component of the natural landscape. Historically the region was dominated by ash and elm, known as the Lake Plain Forest region, with wetland and swamp forests the predominant features of the landscape in pre-settlement times (Taylor, 2009). Even in modern times, ash remained an important forest species in this region making up 20-35% of the forest canopy locally and an even greater percentage of the canopy in areas of the grounds that are open to the public (Michener, 2009). Four *Fraxinus* species, including red (*F. pennsylvanica*), black (*F. nigra*), blue (*F. quadrangulata*), and white (*F. americana*) ash were all represented on the grounds and according to Jeff Plakke (2009), the institution's Natural Areas Manager, "Ash was definitely a pretty important species in terms of forest composition in a number of different communities on all properties… in some areas the ash population was more than 50%" of the canopy. The area with the largest ash population was on 120 of the 350 acres at the Botanical Gardens site. In this floodplain corridor of Fleming Creek, ash was one of the top three dominant tree species in an area that was an entirely shaded forest (Michener, 2009). "It was a huge population, and a lot of large plants" (Plakke, 2009). Many of the large specimens that were lost were between 20-26 in. DBH and 80 years plus in age, with the largest of the trees reaching upwards of 34-36 in. DBH (O'Dell, 2009).

> As far as generic representation, one of the things we're trying to do is have at least representatives in our natural or planted areas of all the major genera and plus the key species of our bio-region… and so it's a real loss and so we're just going to have to use it as a teaching point, as with the elms, something's missing, but it's kind of hard to teach with a void (Michener, 2009).

In addition to the ash that occurred naturally on the grounds, collection and research specimens were also maintained at the institution. The extent of the ash collection was approximately 20 accessioned individuals, all North American species, located in the main valley of the Arboretum as part of the family and generic groupings of the historic O.C. Simonds landscape. In addition, Dr. Sylvia Taylor, Researcher at the University, maintained a research collection on the grounds to study the genetics of North American ash.

> Sylvia's work, where you have somebody who has spent forty years trying to build a stock of known [wild] hybrids… plus all the decades of her breeding work, that was all part of this faculty, what I called heritage collections, of what was of interest at the time, as a basis for

> what someone might want to work with later. And you saw by looking at it, that's caput (Michener, 2009).

Disaster readiness planning prior to the EAB introduction

The Gardens did not have a disaster readiness plan in place specifically for its collections prior to the EAB introduction, but other readiness plans did exist.

> We have a staffing plan for what happens if the staff gets an epidemic, which the University has required. If half the staff couldn't come to work… what are the core, critical functions, and how would we handle it? It's actually specified… by position name, who handles what. And we've done that, but that's more being driven by the University… (Michener, 2009).

Although this disaster readiness plan does not prepare the collections directly, it does focus on maintaining the functionality of the Gardens' Conservatory, and therefore indirectly addresses the preservation of the collections that are housed in that facility.

> We're about a half-acre under glass. Here you're just looking at… $1.4 million worth of glass replacement and environmental controls… But all the disaster planning to date, including responding if there's a disaster at the University, in terms of epidemics, is stabilizing this collection. Since this is the most difficult one to replace in a several year period. The natural areas… if something horrible happens… supposedly they should be resilient enough to ride it out other than in an epidemic like this (EAB). But a point-caused problem such as a staffing failure or a turning off of the power grid, or a loss of fuel, is to heat this enough (the conservatory) to keep it going (Michener, 2009).

History of EAB at the institution

Probably originally introduced to a landfill only 10 kilometers from the institution, EAB was first discovered at the Gardens in 2003 (Michener, 2009). Tom O'Dell, Collections and Natural Areas Specialist, first noticed the decline of one of Taylor's ash in her research plot.

> I was the very first to discern presence of EAB here at the Botanical Gardens… it was a rather small… white ash… maybe 6 inch diameter, 20 feet tall, and one summer it just started to decline… and this was shortly after… they began to identify EAB. Because I can remember prior to this, like the previous year or two, they came up with what they were calling "ash decline" because they didn't know what it was and they had just recently identified a beetle they felt was the true agent… So I'm looking at this tree and it's yellowing and it is starting to lose leaves at the top… all the other ash around it seem fine, we didn't have a drought or anything unusual to account for, so at that time they said that to check for ash borer remove a section of bark and take a look. Well I removed a post card section… and there were like eight of these larvae, just within that little… 5 x 7 index card sized area… the interesting thing is when I noticed the decline in that tree, well it was just, obviously the pathogen had been here for a while, because shortly after, within the next year or two everything started showing up, all the other ash began to show problems (O'Dell, 2009).

The Gardens' staff suspects that the beetle came into the institution via a new housing development across the street that was planted with infested ash from nurseries located near the epicenter of the EAB introduction to North America (O'Dell, 2009).

Impact of EAB and other biological invasions

Other than suckering stumps and young seedlings that continue to emerge, the institution has experienced the complete loss of its mature native stands of *Fraxinus* and collection specimens (Michener, 2009). In addition to the tremendous impact that this and other biological invasions have had on individual plants, it has also had significant secondary ecological, financial, aesthetic, and an emotional impact on visitors. Michener (2009) explains the incredible loss of key canopy species to biological invasions in the natural areas over many years:

> The institution was also here because this was a great American elm floodplain forest… Dutch elm disease took'em all out. So that was the first epidemic through, the second epidemic, you can see all the dead

> larch trees, we've lost over 95% of our larches, which was another important floodplain tree here… we lost that to European case-bearers starting in the early to mid '90s. Ashes had clearly moved in as a real important component of the forest, and then we've lost all of them to emerald ash borer. So, we've had three major devastating epidemics coming through… so we've lost all of the dominates of the native forest in the wetlands. All within what? Within 50 years?.. As an institution, we have not yet created any internal policies… this has finally woken us up.

Secondary effects of the destruction in these natural areas have been immense. Invasive plant species, a rising water table, increased sun exposure, and rising creek temperatures have all been noted by staff at the institution and continue to degrade the ecology of this system. In particular, *Rhamnus frangula* L. (glossy buckthorn), an extremely invasive species on the properties of the institution, has moved into these areas with the loss of the ash.

> We also have a lot of invasive species that have become established, and are now spreading, and then losing that ash canopy… in forestry terms, is like releasing the seed bank of the exotics, and actually the exotics that are already growing are now getting more sunlight, so that can be problematic… and something that we will probably be dealing with for many years (Plakke, 2009).

Furthermore, without the extensive root systems of the ash trees along Fleming Creek, there is a huge reduction in the transpiration-driven absorption of water from the Creek's floodplain. Dr. Burton Barnes (2009), Professor Emeritus of Forestry and Forest Botanist for the Gardens explains that the loss of these trees,

> … raises the water table, and so you get the water table standing in the growing season, and many plants can't stand that, so it has a terrific indirect effect on other species. That would not happen in the upland, but since the black ash and the red ash are in wetlands then those [ecosystems] are impacted by the emerald ash borer.

Additionally, rising creek temperatures from the loss of the canopy shade are also having detrimental implications. O'Dell (2009) explains:

> A result or a fact that came from the demise of the ash is that you lose that canopy and the temperature of this creek has risen, and… there's a watershed council that monitors the river for different variables, one of them being temperature. And, they know this temperature has increased a lot since we lost that overhead canopy, and they said had it not been for that, they would probably have found trout in the stream, but it's just too warm now for trout.

When asked about the future of these natural areas and up-coming concerns, Michener (2009) points to the remnant patches of white (*Quercus alba* L.) and bur (*Q. macrocarpa* Michx.) oak that cling to drier soil pockets on higher ground along the Fleming Creek floodplain, as the water levels have risen.

> My concern, and you can see from the senility of the oaks on the island in the floodplain… is just what's going on. I think we're just looking at the beginning edge of the chaos of invasive exotics, plus global climate change, plus climate shifts in general. It's like what do you do? Is this like the equivalent of watching the buffalo herds… with the railroads coming (Michener, 2009)?

The institution's collection and research specimens have also seen complete mortality. Michener (2009) describes the loss of Taylor's research plots as "like talking about artwork that was burned in the war." The records of her studies will ultimately end up in the University's archives (Michener, 2009). "So it's definitely had a major impact, EAB did, and we will probably be trying to determine what that is for sometime, and actually seeing its effect for quite a while" (Plakke, 2009).

Beyond the physical destruction, the financial and staffing burden, as well as stress on donor relations has been serious. Michener (2009) explains:

> From a property management perspective… look at all of the resources that have to be diverted, like all gardens, we don't have nearly enough people to run the programs… probably in the six figures at this point over the years, to have trees dropped just so people can walk on the path (Red Trail along Fleming Creek).
>
> The irony of the whole thing, is just before the larch and the ash damage got really bad, we were in discussions with a private donor about making the trail… a walk through the major trees of Michigan… and so they gave the gift… and now… we don't have the canopy anymore, so all of these different groves with the sub-canopies don't make a whole lot of sense. They are very patient with us… about how to put back a demonstration landscape of major plants of Michigan, the major trees in ecologically appropriate ways.
>
> I mean you lose the canopy that you plan on growing up, and then as a result like this donor who gave the $5 million, you can't even move forward with the privately funded projects because it's no longer ecologically feasible to put this stuff out there… and that's why I sound so frustrated about it, and we finally woke up (Michener, 2009).

Furthermore, there has been a significant impact on the aesthetics of the affected areas and in turn, an impact on the Gardens' visitors.

> It is definitely an aesthetic difference, and I think when people come out there and go for a walk in the woods, when they think of woods, they think of large trees, and it was nice to have some very statuesque tall trees and we had some incredible tall forest ash… out there, which gave you a sense of being in an older growth forest… but it has put a very different look to the landscape… we have had tens of thousands of visitors every year on the property, and a good portion of those people were here for the trails and trail tours for school groups and on the one hand this has provided an opportunity for education as far as an exotic pest is concerned, we had to of course explain what had happened to these trees… so that whole idea of invasive and exotic plants and animals the public has become more aware of that issue now, it's a tough way to do it, but there has been an awakening (O'Dell, 2009).
>
> It's hard to measure, but a lot of people… will walk through the Arboretum on a regular basis, and get very attached to areas and the

> trees and I think for them it was really difficult to see a lot of these trees dying and then us removing all these trees. There were a lot of people that were really upset and frustrated and they could see why we were removing them once they understood the whole story of this invading insect, but I think initially it was really shocking to see their favorite areas changing, dying so dramatically (Plakke, 2009).

<u>Preparation and management strategies utilized</u>

Located only miles from the introduction point of EAB into North America, the staff of MBGNA had no time to prepare for the pest's introduction. By the time EAB was first discovered at the institution, the grounds were pretty well infested (O'Dell, 2009). Additionally, Plakke (2009) explains:

> And I think it made it tough for us because we were one of the first areas to get hit so there really were no control options, there were a lot of people trying to experiment with things… but there wasn't anything proven that would work and so even in our Arboretum where we had some really beautiful specimens… at that time there really wasn't anything we were confident would work and so putting the resources toward it was a real gamble, so we really just lost everything that was out there… it was sad to see that all go.

Given the institution's position, the management of EAB became a story of tree removals, management of invasive species, and efforts to help in the recovery of the natural areas.

Tree removals:

Removals were done with a "public risk management approach," where anything that could have been a hazard to visitor safety, such as a tree along a trail, was removed (Michener, 2009). What did not pose as a threat was left standing for wildlife habitat and to reduce any mechanical impact, such as soil compaction, that removals may have caused. Wood from removals was salvaged when possible for use in refurbishing an old barn on the grounds (O'Dell, 2009). In the natural areas, remaining stumps were left to regenerate. Barnes (2009) reports,

> … there is no lack of ash regeneration right now, the thing is how will the borer kill the understory stems… Kind of like the American elm, which has made a big come back because of the crash of the insects, and they live now for 30, 40, 50 years… and so my thought was perhaps it will be the same thing with the ash borer… that these ashes would have a chance to grow up and perhaps reach reproductive size.
>
> But hopefully… these trees will develop resistance naturally or they will live long enough, maybe the next infestation will be far enough down the road, 20-30 years plus and may be these trees will have a chance to reach some size and people will have an opportunity to see… what a good size ash tree looks like (O'Dell, 2009).

In addition, Taylor has placed fencing around a hand-full of the sprouting ash stumps that once made up her ash research plots. She points out,

> There was a couple of nice sprouts coming up, one of them is a very nice male ash tree, the best one… and if you just spent the money on keeping that one going, and it is a hybrid, there is enough pollen there to make a whole study… if we wanted to spend the money to protect that one tree, that could be the basis for forest improvement studies… (Taylor, 2009).

Natural areas management:

Furthermore, the institution is making efforts to aid in the recovery of the natural areas. The institution continues to battle the invasive plant species that have taken over with the loss of the ash. Cutting back the brush, chemically treating the stumps and burning in some cases, are the control measures (O'Dell, 2009). Barnes (2009) also explains his efforts to aid in the recovery of the water table:

> I developed a project out there now to plant thousands of elms… the idea is that if you planted… thousands of plants you would suck the water out of there and that would gradually get the regime that the

> American elm and other species would tolerate, but now it is a shrub patch with high water tables.

One additional initiative the institution still hopes to complete in the natural areas is to map the stumps of dead ash and larch as a baseline for future research. Michener (2009) explains:

> Just GPSing the centers of all the dead ashes. In terms of where was it, because like right now, other than the words "cathedral elms" on the map, because the stumps are all rotted out… no one did a map of where are the trees in terms of looking at forest dynamics.

Taylor (2009) adds, "And that is very important… there were gaps in the stand, where the tamaracks are now, where it was just a little too wet for them (elms), and it would have been nice to know that pattern."

<u>Additional initiatives</u>

Located in one of the first areas to be affected, the institution did have an opportunity to aid in collaborative efforts by allowing researchers from other institutions, such as Michigan State University, to utilize the grounds and facilities for investigation. These relationships, along with opportunities for interpretation of the destruction, public education, and sharing the lessons learned with other gardens, were also valuable actions taken by the institution.

Research initiatives:

Given that the Gardens have a relatively small staff, collaborative efforts were key in addressing EAB and are a vital component for the functions of the institution in general. Michener (2009) explains,

> … since Michigan State [University] has such an active function with it (EAB), and we would ultimately be redundant… we'll let them… lead

> with it, just like we were the site for them, being within the quarantine zone, but given the small size of the staff here, our university-wide functions, what we're looking for in all projects is who's the collaborator, how do we engage them… It's got to be networked, or else it's going out of here.

Visiting researchers were provided with laboratory space, research plots on the grounds, and were given full cooperation from MBGNA staff, producing valuable information pertaining to the insect and potential control measures (Taylor, 2009). O'Dell (2009) explains that these partnerships,

> … certainly have given us the benefits of what they have learned, as far as what is effective… treatment, what's practical… and they have been very forthcoming with interpretive material for spreading information to the public… we served as somewhat like an extension service, and people have all sorts of questions, and with the ash borer we have given them state handouts, additional first hand information on what to do, and share the information that comes out of the MSU research.

Education and outreach:

Other collaborative efforts included working with *Game of Logging*, a timber harvesting training program to provide safety training to the public (O'Dell, 2009), utilizing the expertise of Taylor (2009) to teach visiting researchers the identifying characteristics of different ash species, and general information sharing with professionals and researchers nationwide (Michener, 2009). So as to inform other public gardens of the loss that the institution suffered and the threat of biological invasions to collections in general, Michener (2008) published *Lessons from the Death of a Reference Ash (Fraxinus) Collection* in Public Garden.

Furthermore, the loss of ash at MBGNA did present an important opportunity for visitor interpretation regarding EAB and effects of biological invasion in general. Interpretive signage pertaining to Dutch elm disease, larch case bearer, and emerald ash borer, are found on the trails along Fleming Creek, to teach about the loss of this once forested area.

W.J. Beal Botanical Garden & Campus Arboretum of Michigan State University

Founded as part of Michigan State University in the early 1870's, the W.J. Beal Botanical Garden and Campus Arboretum is located in East Lansing, Michigan and is currently in the peak of the front wave of the EAB infestation (Telewski, 2009). As "the oldest continuously operated university botanical garden of its kind in the United States," the institution operates under the following mission:

> Reflecting the philosophy of a land-grant institution, the W.J. Beal Botanical Garden is an outdoor laboratory engaged in teaching, collection development, research, conservation and public service. These activities focus on a theme of natural plant diversity, economic botany, ecology, and plant conservation with emphasis on the Great Lakes region (W.J. Beal Botanical Garden, 2010a).

Although the site of the actual Botanical Garden is relatively small, the Garden is administered by the University's Campus Planning and Administration Department, which also oversees the development of the woody plant collections that make up the Arboretum, spanning over the 2,100 acres of the University's main campus. In addition, the Garden and Arboretum's Curator, Dr. Frank Telewski, also sits on the Campus Natural Areas Committee, which oversees the management of the 700 acres of Campus Natural Areas. The primary collections hosted at the Garden site include a Wetland Plant Collection, Economic Plant Collection, Endangered and Threatened Species (MI) Collection, Forest Communities Collection, Systematic Collection, and a Non-Flowering Vascular Plant Collection (W.J. Beal Botanical

Garden, 2010b). In addition, the Garden sits along the riparian corridor of the Red Cedar River. Areas along the River are managed as semi-natural, encouraging native vegetation to minimize erosion (Telewski, 2009).

In addition to the Garden site, the Campus Arboretum, utilized for instruction, research, conservation, and enjoyment purposes holds extensive collections of woody plants. Included are historical specimens planted by the Garden's founder, Professor William James Beal, and notable holdings of *Malus* (crabapples), *Cornus* (dogwoods), and *Fraxinus* (ash), among many others, especially Michigan natives (Telewski, 2009). Furthermore, the goal of the Campus Natural Areas, represented by 27 sites, is to "provide important examples for our rich natural heritage and represent significant, accessible resources for teaching, research, demonstration and nature appreciation" (W.J. Beal Botanical Garden, 2010c). These sites are broken up into three categories based on the level of usage that is allowed to take place (Telewski, 2009).

Fraxinus at the institution

> A lot of the trees that are older… on this campus are natural… native to the area, and most of those are going to be white ash… So we've got a really good genetic basis for *Fraxinus americana* and I would say we have a breeding population of *Fraxinus*. So a conservation collection, with actual conservation value (Telewski, 2009).

As Telewski (2009) described, the institution maintains an extensive collection of mature native white ash trees as well as significant holdings of green and blue ash. Ash is as well a dominant component of the landscape along the Red Cedar River, with some specimens reaching 4 to 4.5 ft DBH. In addition to the surviving mature ash that naturally occurred on campus, historically important specimens of white and blue ash that are original plantings of Professor Beal's, still survive from the 1870's. From a curatorial perspective, Telewski (2009) reports,

> … my objective for *Fraxinus*, was like for any species, to get as diverse a collection of documented, wild-sourced material, as well as cultivated varieties, to increase the diversity of the collections. Taxa that would be hardy in this area, so that we would have material for teaching and possible research. That's why I collected the [*Fraxinus*] *rhynchophylla* over in Korea… this is the beauty and strength of collections… you don't know when somebody's going to come in and find use for that collection.

Ash was also a commonly planted street tree on campus in the years leading up to the EAB invasion, selected for its aesthetics and urban tolerance (Telewski, 2009).

Prior to 2005, the total number of accessioned ash on campus was 1,019 trees, which included numerous trees that naturally occurred along the Red Cedar River, but did not include those found in designated natural areas or populations in small re-growth stands. The accessioned specimens represented 28 taxa including horticulture varieties (Telewski, 2009).

Ash is also an important component of the campus' natural areas. One of the most highly valued parcels, Toumey Woodlot, represents 24 acres of old-growth American beech – sugar maple forest, and since 1976 has been listed on the National Park Service Register of Natural Landmarks. Other than beech (*Fagus grandifolia* Ehrh.) and maple (*Acer saccharum* Marsh.), basswood (*Tilia americana* L.), black cherry (*Prunus serotina* Ehrh.), red oak (*Quercus rubra* L.), and white ash are listed as the most important tree species on the site (W.J. Beal Botanical Garden, 2010c). These natural areas are utilized extensively for teaching purposes and student research projects (Telewski, 2009).

Disaster readiness planning prior to the EAB introduction

Prior to the EAB invasion the institution had no disaster readiness plan in place for its collections. The institution had more of a disaster recovery point of view; "… if we get hit by a disaster, we lose our trees, we get a windstorm… an ice storm or something like that… we deal with it and try to replant to maintain diversity in the collections… just take it and clean up afterwards" (Telewski, 2009).

History of EAB at the institution

The institution is currently at the peak of the EAB infestation with ash trees in mass decline throughout the area. Telewski (2009) describes the introduction:

> The thing with emerald ash borer is that when it started… radiating out from the Detroit area… initially nobody really knew what it was. They kind of thought it was a wilting disease, or some kind of dieback… And finally, some of our researchers here at Michigan State [University] discovered that there was actually a beetle and identified it as being the emerald ash borer from Asia. And that set the whole dynamic rolling.
>
> Well, at this point in time… it started rolling right through Ann Arbor… wiped out most of the University of Michigan's ash trees before they could really do anything… We just didn't have any idea what to do to control this insect. The main thing we were trying to find out was to learn something about the biology.

Learning from the destruction suffered in places like Ann Arbor, the institution began to monitor for the insect at the campus' edges (discussed further in succeeding "*Monitoring for EAB*" section) in hopes of confronting the pest head-on.

First discovered in 2005 in the core of campus near the football stadium, the insect is suspected to have been brought into the area via infested firewood from a sports spectator. Even though there was a proactive approach in place for monitoring the campus, the trees on which the insect was first located are thought to have been infested for a year or two prior to the discovery (Telewski, 2009).

Impact of EAB and other biological invasions

Of the 1019 accessioned *Fraxinus* specimens, 120 individuals have been removed as a direct result of EAB. An additional 88 individuals have been removed as an indirect result (discussed further in the succeeding "*Tree removals*" section) of the invasion. Telewski (2009) reports that unless they are resistant species, "I don't think there's an ash tree in our area that hasn't been impacted by emerald ash borer in some way… either they're dead, or they're declining, or they're being treated."

In addition to the death of individual trees, the ecological costs from the loss of the ash are also visually evident along the banks of the Red Cedar River where ash was a key species. Telewski (2009) explains:

> So one of the consequences that we have of losing the ash trees along the bank of the Red Cedar… is that with the banks destabilization… we are losing a lot of those active root zones that would have helped to prevent erosion, so that is just going to accelerate the erosion problem now. So there's a complicating factor, can you account for additional problems if you don't preserve a species?

Due to environmental concerns, trees immediately adjacent to the River are not chemically treated and thus are left to decline, exposing the banks, which continue to erode. Additionally, no control measures have been taken to save ash in the campus' designated natural areas due to policy and funding restrictions, and thus "we'll probably end up losing all of our ash trees, our mature ash trees in the natural areas" (Telewski, 2009). Telewski (2009) points out that this approach does allow for research and instruction on the sites. In certain areas if researchers "who studied emerald ash borer in natural woodlots and got funding to do injections, we'd say class two or class three natural area, absolutely." "The unfortunate news is that by doing nothing we may be radically changing the… ecology of the native flora" (Telewski, 2009).

Furthermore, Paul Swartz (2009), Campus Arborist, points out the economic costs of treatments and removals from such an invasion:

> Just right here look at how many trees we have seen, and look at the costs… to remove these trees, you're talking thousands of dollars… at the beginning… our state was telling people not to treat the trees, it wasn't worth it… It was costing them (City of East Lansing) $1,500 to remove the tree, and then… [replacement], so $2,000 to $3,000 per tree that they lost because they didn't treat them.

<u>Preparation and management strategies utilized</u>

Learning from the effects that EAB was having on fellow gardens, and ash trees in general to the south, the Garden had time to prepare by developing a monitoring and management strategy to protect its collections. The intent was to save as many healthy accessioned trees as possible by chemical means.

Monitoring for EAB:

Working with Michigan State University Professor of Forest Entomology, Dr. Deborah McCullough, a leader in EAB research, the institution setup monitoring stations at the edges of campus in the years before EAB had arrived on the grounds. These stations included artificial pheromone traps and trap trees, in which live trees are stressed by removing a girdling section of bark making it more susceptible to invasion. Telewski (2009) explains:

> So, we had a great plan… we had a trapping station here on the east side of campus because the one [EAB] wave front was coming from… Detroit/Ann Arbor. We had another trapping area… because there was an introduced/outbreak in South Lansing that was approaching us from the southwest. So we had an approaching wave from the southwest… from the east, so… we put our radar stations out there.
>
> So as a first alert, this would be our first warning. And the first time that we would trap any emerald ash borer… approaching the campus from two major outbreak areas… that's when we would start our treatments.

In addition, a heightened visual monitoring program was put in place, and was ultimately the way EAB was first encountered in the heart of campus, in the football stadium parking lot. Telewski (2009) describes this discovery:

> One day Paul [the Campus Arborist] and I are doing an inventory… just the usual campus [survey]… looking at trees, evaluating trees… And we noticed that there was an ash tree… that was beginning to die… We began to look at other trees. And there's a huge old mature ash tree… along the riverside... D-shaped holes, it was starting to show decline… "we've got emerald ash borer"… And we've had it for probably at least a year, maybe two years before we ever even knew it. And the only thing that we can think of is that somebody from an infected area came to a football game… unfortunately, bringing firewood for their grill.

Prioritizing the collections:

In the years before the 2005 discovery of EAB on the grounds, the institution began to prioritize its holdings and develop a treatment plan to protect its *Fraxinus* collections. An initial proposal was approved, identifying four overarching areas of concern on the grounds as well as a specific list of areas and individuals of historical, educational, conservation, and/or aesthetic value to receive preventative treatments.

> And so we kind of took a triage approach… which trees do we definitely want to save, which trees can we not save, and which trees can we allow to go over a period of time, if we don't have a biological control that becomes available in terms of maintaining the cost of injecting the trees. So we tried to take into consideration the cost of treating all the trees, the duration of time that we would think appropriate while a biological control becomes available. And sort of down to the top list of trees that we, under all those circumstances we don't want to lose, we want to maintain.
>
> The initial approach that many people at the University took was "let's save all the old trees." They're all beautiful trees, they're big trees, they're dominant trees… my feeling was, well we need to save the old trees, but we also need to value the young trees. Because the old trees are eventually going to die from old age regardless… so we want to keep a good mix… And so that was kind of the strategy we took to try to balance it out between the old dominant trees… versus younger trees (Telewski, 2009).

This proposal triggered the institution to complete a more comprehensive survey of its ash resource. Telewski (2009) explains:

> We had been systematically moving across the campus inventorying all trees… for the last fifteen years, but when we got word of emerald ash borer, we sort of dropped the general inventory, and said… we're going to stop the systematic approach… we're going to look at the whole campus for ash trees.

Through this process the institution doubled the number of *Fraxinus* accessions to over 1,000. Many of the newly accessioned plants were naturally occurring individuals along the Red Cedar River, which prior to the invasion were of lower priority to have accessioned and recorded in the database (Telewski, 2009).

Tree removals:

120 trees have been removed as a direct result of EAB. In addition, it was determined that given the EAB threat, ash trees that were in areas in which construction projects were underway or proposed would simply be removed. Under normal circumstances these trees would potentially be protected.

> [If] we want to conserve that mature tree, we put protection around there and we have constraints that the construction companies need to work with. All trees are evaluated in the construction site for their value to the collection. If a tree is a low-value tree… even if it's a tree that's relatively low abundance in the collection, but it's in really bad condition, we'll let it go… if it's a very rare tree… we'll actually make the effort to move that tree. Because of the introduction of emerald ash borer, if an ash tree is in a construction zone… It's a removal because… we already have a lot of ash on campus and the effort to save that tree, with the possibility that it's going to be weakened by the construction… root pruning and everything else, may make it increasingly more susceptible to emerald ash borer (Telewski, 2009).

In all 88 additional trees have been removed under these circumstances (Telewski, 2009). Removed trees are milled and the lumber is used for various purposes (Swartz, 2009).

Chemical treatments:

> This was kind of our learning lesson of how to deal with an outbreak on campus… is there something that we can do? And as soon as we found out from the researchers that we can actually do some sort of injection to try to control it, then we were all geared up to be able to do that. When Ann Arbor got hit, they weren't even sure that Merit® would work… (Telewski, 2009).

The majority of the institution's *Fraxinus* accessions still survive today due to the "emergency treatment program" the Garden has implemented (Telewski, 2009). This program, started when EAB was first discovered on the grounds, continues to maintain over 800 specimens through chemical application. The main chemical treatments used in this program are Tree-äge™ (Emamectin benzoate) and Merit® (Imidacloprid). Merit® is applied using a soil injection technique on specimens smaller than 9-inch DBH on a yearly basis. Soil application is used in this case to eliminate damage caused by trunk injections, on these younger specimens. Any specimens over 9-inch DBH are injected with Tree-äge™ using the ARBORjet™ delivery system (trunk injection). Trees are treated with this system every 3-4 years, and the staff indicates that research is showing that the treatment interval maybe able to be pushed even longer. The institution has found Tree-äge™ to be 100% effective when applied properly. Human error, such as improper spacing of injection sites on the trunk, has led to the possible decline of some trees. Applications of both chemicals start in May and continue through the growing season until completed (Swartz, 2009).

Although the institution is proud of its efforts and the resulting preservation of its *Fraxinus* holdings, Telewski (2009) describes his main concern with the institution's aggressive treatment program, and anyone treating ash, as follows:

> My feeling is if we can actually come up with a biological control, something that would be more effective, rather than having to do constant insecticide treatments… in the long-term we have a viable means of maintaining the collection. But my concern is if we maintain a collection… by treating them with an insecticide, are we also creating an island population of emerald ash borer.
>
> So, in other words… I don't think it's possible to eradicate emerald ash borer from a collection, we're probably trying to reach a balance point… once the front wave… has swept through an area and you get so many miles… two-hundred miles away from it, can you start replanting in the core area, where there's no residual ash to attack? In the case like what we're doing here on campus, one of the questions

> that we're very aware of, are we actually creating an island reservoir of emerald ash borer?

Additional initiatives

Research initiatives:

Being at one of the leading universities involved in EAB research, the Garden staff has been able to put novel research into practice in a timely matter. This internal collaborative relationship allows for continuous evaluation and feedback to researchers regarding on the ground observations.

> So this is part of the experimental process too… putting into practice some of these things that we are learning, it's just nice being at a university and a land grant institution, where we actually have the researchers that can give us feedback, and then we can try to apply it, under semi-controlled conditions… (Telewski, 2009).

Staying abreast of new treatment information that arises from such research, the institution is continuously updating its treatment policy to reflect these findings. Telewski (2009) comments that institutions should,

> Have a good monitoring program so that you're evaluating, keeping track of your injection program, so you know what trees have been injected, how much, when? With what treatment? And then go back on an annual basis and evaluate that tree to see if it is declining or maintaining, or how well it's growing and then if you have to remove it. Because otherwise you don't know how effective your program is.

In addition, McCullough and other researchers, including from the USDA, have utilized the Garden's holdings for various EAB research, such as feeding preference studies of Asian and North American *Fraxinus* species and other genera in the family Oleaceae. Furthermore, researchers at the University have been involved in studies to locate the insect's point of introduction, to explore the life history, biology and spread of the beetle, and to identify potential treatment options (Telewski, 2009).

Education and outreach:

As part of a collaborative effort with the academic base of campus, Garden staff has participated in sharing information with professionals through conference presentations, bulletins, and websites regarding their dealings with EAB and new research findings as information becomes available. Telewski (2009) explains that working with University personnel, such as McCullough, "we maintain this good network and we're all participating and getting that word out as best we can about what we are finding." Additionally, public awareness activities are also underway including fielding questions and working with their sister institution, Hidden Lake Gardens, in educating the public on topics such as firewood movement, alternatives to planting ash, and treatment options (Telewski, 2009).

Case Studies: Institutions Located in EAB's Impending Range

The Morton Arboretum

Having yet to physically locate EAB on the grounds, The Morton Arboretum sits on the cusp of the spread (Kim, 2009). The Arboretum is located in Lisle, IL, covers over 1,700 acres and is bisected by the East Branch of the DuPage River. Being on the outskirts of the City of Chicago, the institution is a green oasis for the urban communities that surround it. Started in 1922, the Arboretum's grounds were originally the estate of Joy Morton, founder of Morton Salt Co., and son of Julius Sterling Morton, the originator of Arbor Day. Today the Arboretum is "Dedicated to the planting and conservation of trees," maintaining outstanding collections of "trees, shrubs, and other plants from around the world" (The Morton Arboretum, 2009a). The institution's 182,000 specimens represent plants from 40 countries of northern temperate regions. These holdings are displayed on the grounds in five categories: "taxonomic collections (e.g. elms and oaks), geographic collections (e.g. trees and shrubs from China), special habitats (e.g. Plants of Acid Soils), horticultural collections, and collections of rare and endangered plants" (The Morton Arboretum, 2009b). In its collections the Arboretum hosts four NAPCC (North American Plant Collections Consortium) Collections including the multi-institution collections of *Acer* (maples) and *Quercus* (oaks) and the single-site collections of *Malus* (crabapple) and *Ulmus* (elms; APGA, 2010d). Furthermore, the institution maintains the 100-acre Schulenberg Prairie, one of the oldest planted prairies in the midwestern U.S., as well as remarkable woodlands and meadows (The Morton Arboretum, 2009c).

With approximately 600 acres devoted to collections, and an additional 900 acres preserved as natural areas (Kim, 2009),

> The mission of The Morton Arboretum is to collect and study trees, shrubs, and other plants from around the world, to display them across naturally beautiful landscapes for people to study and enjoy, and to learn how to grow them in ways that enhance our environment.
>
> Our goal is to encourage the planting and conservation of trees and other plants for a greener, healthier, and more beautiful world (The Morton Arboretum, 2009d).

Beyond displaying its collections, and preserving and restoring the natural lands that it oversees, the Arboretum fulfils its mission through extensive work in conservation, tree health and improvement research, plant introductions through breeding and selection, plant exploration activities, educational opportunities, and community outreach initiatives (The Morton Arboretum, 2009a).

Fraxinus at the institution

Although the Arboretum's *Fraxinus* holdings would be considered a "secondary collection" to the institution (Bachtell, 2009), the genus definitely plays an important role in supporting its mission (Kim, 2009). The institution's current accessioned *Fraxinus* holdings represent 50 taxa, 134 accessions, and 308 individual specimens, representing species from all over the world (Kim, 2009). In addition to the collections, the extensive 900 acres of natural areas support an ash population around 6 to 8% of the canopy (Bachtell, 2009). Although the density of ash in the Arboretum's woodlands is relatively low, Kris Bachtell (2009), Vice President of Collections and Facilities, points out that the loss of any species, even those at low population numbers, can have significant impacts on an ecosystem, many times "different reactions that you don't often times see." Beyond the Arboretum's grounds, recent research looking at the density of ash in the forest preserves of a neighboring county, determined the ash population to be on average, 20 to 30% of the canopy (Miller, 2009).

Kunso Kim, Head of Collections and Curator at the Arboretum, describes the value of *Fraxinus* in meeting the institution's mission in several ways:

> (1) For the general public it is a great collection of woody plants, particularly the fall colors… of some of the species that are really intense… very important as part of the Arboretum landscape.
>
> (2) And we have such a diversity of collections representing different parts of the temperate regions of the world, it is a great genetic resource

> to evaluate and select and potentially in choosing to market any desirable species… that is a really important objective…
>
> (3) The other role that collections serve is the research purpose. Because of the diversity of the collection, it is very useful for… taxonomic work. Otherwise, you really have to contact many different places and go to their native habitat to collect them, but here at the Arboretum, 50 different taxa is an incredible opportunity. So if anybody wants to study, we are willing to collaborate to support that research…
>
> (4) Of course we are using the collections for the educational purpose as well. Educational programming may involve the teaching of native flora… urban street tree uses… or other classes. But educational use is also pretty important.
>
> (5) The importance… for *ex situ* plant conservation is another aspect that is highly, highly valued, particularly in the face of these great infestations, the fact that we maintain… many species, here at the Arboretum, I think [our collections] serve as an important genetic resources for *ex situ* conservation.
>
> Again, I think it (ash) supports the mission of the Arboretum in a very important way (Kim, 2009).

Specifically, Dr. George Ware, Researcher Emeritus, renowned for his work in breeding Dutch elm disease resistance into American elm and work with the genus *Platanus* (sycamore), also had a particular interest in development of native and Asian *Fraxinus* species for use in the urban landscape (Bachtell, 2009).

<u>Disaster readiness planning prior to the EAB introduction</u>

Prior to the introduction of EAB to North America the Arboretum had no formal readiness plan in place for its collections. The institution did have overarching management principles that could have been considered the basis for a formal policy (Bachtell, 2009).

Preparation and management strategies utilized

Since the discovery of EAB in North America, the Arboretum has made great strides to prepare its collections for the arrival of the pest at the institution. In particular the institution has developed an EAB Action Plan, “to help us plan and implement proactive measures to protect and preserve the Arboretum’s valuable ash germplasm and related genera” (Kim, 2007).

The goals of the Action Plan are to:

> … detect signs of infestation, take appropriate measures for the infestation, treat selected accessions with the effective chemicals and delivery methods, propagate and preserve valuable ash germplasm, and provide outreach and educational programs (Kim, 2007).

To meet these goals the institution has outlined seven action steps that they have and will use to prepare for and manage EAB. These steps include (1) visual survey, (2) detection tree survey, (3) propagation of valuable accessions, (4) application of systematic insecticides, (5) collaborative research, (6) public awareness, and (7) control options (Kim, 2007). Actions (1) through (4) and (7) relate directly to the management of collections and will be discussed in greater detail in this section. Actions (5) and (6) are considered “additional initiatives” for the purposes of this study, and are discussed more extensively in that section. It should be noted that the institution has taken the initiative to share this strategy with other gardens inquiring about their Plan (Bachtell, 2009).

Monitoring for EAB:

To monitor for the presence of EAB on the Arboretum’s grounds, the institution utilizes two approaches, a “visual survey” of all *Fraxinus* accessions held by the institution and a “detection tree survey” in which naturally occurring ash trees are physically removed and inspected for the presence of EAB.

The visual inspections are described as follows in the Action Plan:

> (1) Visual survey: the [Arboretum] collections staff will conduct visual surveys [of] all specimens in the collections. They will visually examine each accessioned ash specimen for crown dieback, woodpecker activity, vertical bark splits, epicormic sprouts, possible presence of flying adults, and D-shaped exit holes. Any specimens showing these signs will be given a thorough follow-up examination including drop and peel methods to detect larvae and galleries. This visual survey should be conducted during the growing season to detect more established infestations of one to three years with larvae being present (Kim, 2007).

Over the past several years, such surveys of the accessioned collections have been performed using *Fraxinus* inventories created from the institution’s database to ensure all specimens have been inspected (Kim, 2009).

Furthermore, over 20 “trap trees” along the institutions perimeter have been selected to detect for the presence of the insect. Selected individuals are artificially stressed through girdling their trunks by removing a large section bark completely around the trees’ diameter. This process is intended to attract the insect, if present in the area, by inducing stress, which make it a more attractive host for the beetle (Kim, 2009). This process is described in the Action Plan in the following way:

> (2) Detection tree survey: the staff will use detection tree surveys to detect recently established infestation. Detection trees will be established in May-June in areas where specimens are more vulnerable to EAB infestation. For example, these trees may be selected from the specimens along the edge of East Woods and those in isolated or open stands. Selected trees will be felled in September through November and peeled to look for larvae being present (Kim, 2007).

Dr. Fredric Miller, Professor at Joliet Junior College and Arboretum Research Associate, explains that trap trees are selected based on their location and surroundings and then stressed through this girdling technique because researchers believe the attraction of the insect to stressed trees is,

> … a combination, of not only… [chemical signals], but also a visual cue for the insect, either a silhouette of the tree or the color… there is some evidence that the insect will respond differently to different shades of green… a tree under stress, it's going to look different… And… trees out in the open… in full sun seem to be more prone to attack, then… ones in the middle of a forest (Miller, 2009).

Prioritizing the collection:

A key step for the institution in preparing for EAB has been to prioritize its *Fraxinus* holdings. Once prioritized, select high-priority specimens were propagated and/or selected for preventative chemical treatments. Others of lesser pedigree are left for evaluation purposes once the insect arrives, or have been removed in certain situations (Kim, 2009).

Kim (2009) explains the process of identifying the institution's priority *Fraxinus* holdings was to, "evaluate all the ash accessions that we have… come up with the value… and then select… taxa that are considered to be high priority."

> There are some criteria that I follow, (1) first is whether or not the species was collected in the wild. Wild provenance is very important. (2) And secondly, how many of them are… represented [in the collections]... So if you have a single species represented by a single accession and single specimen… that specimen has a higher priority than multiple specimens. (3) And also, there is a taxonomic consideration. Certain species seem to be more important in terms of taxonomy than others (Kim, 2009).

Additionally, the aesthetic value of all specimens known to be susceptible to EAB, was also evaluated beyond the criteria noted above. Established, mature individuals that are found in prime locations provide an important aesthetic value to the grounds, and thus the institution has decided to take actions to protect these trees (Kim, 2009).

Duplicating priority taxa:

Step (3) of the Action Plan is the duplication of priority specimens through asexual propagation techniques of taking cuttings and grafting or budding the material. The chosen priority specimens included mostly Asian, some European, and a very limited number of North American species (Kim, 2009). This step is described in the Action Plan as follows:

> (3) Propagation of valuable accessions: The collection staff has identified 26 genetically important priority taxa to propagate. These specimens were propagated through bud grafting during the summer of 2006. Any failed accessions will be rebudded in the summer of 2007. Successfully propagated plants will be maintained in the Arboretum's production facilities as backup plants before they are reestablished in the collections (Kim, 2007).

Three specimens per taxon (Kim, 2009) are currently being stored in propagation nurseries where they can easily be observed and chemically treated if necessary (Bachtell, 2009). The ultimate goal is to establish these propagated specimens in multiple locations (Kim, 2009).

Preventative chemical treatments:

Step (4) of the Action Plan pertains to the use of chemical treatments in protecting identified priority specimens. This step is described in the Action Plan in the following way:

> (4) Application of systemic insecticide: selected high priority ash accessions will be treated with effective systemic insecticide such as Imidacloprid to protect against EAB. The most reliable delivery method(s) will be employed for the application. One of them is soil drench. Staff may excavate the base of each selected ash specimen with an “air spade” to avoid root damage. The cavity will be filled with organic soil to induce fibrous root system development. The insecticide will be applied in late fall or early spring to facilitate easy absorption. Other effective preventative and control methods will be explored and employed (Kim, 2007).

Chemical treatment is currently being applied to known susceptible species, selected based on the criteria described in the “*Prioritizing the collection*” section above. To ensure chemical uptake is spread throughout the entire plant, preventative applications have been started, prior to known EAB establishment on the grounds. Currently, the preferred chemical application method for the institution is the use of a soil injector to apply the chemical (Imidacloprid) on an annual basis (Kim, 2009).

Tree removals:

Beyond the naturally occurring individual ash trees that have been removed in monitoring activities described above, removals of ash on the grounds have occurred in certain situations and have been influenced by the threat of EAB. If there is a choice to make, for example, during landscape renovation projects, and there is a landscape ash in question of lower priority or in poor condition, such plants are removed and simply replaced (Bachtell, 2009).

Management options once EAB found:

The final step pertaining directly to the collections that the Action Plan outlines are the two control options in step (7) that addresses measures to be taken once EAB becomes established on the grounds, depending on the severity of the infestation. Step (7) of the Plan reads as follows:

> (7) Control options: when the Arboretum's ash collections become infested with EAB, there are two options to be considered; 1) if infestation is minor, we will try to eradicate the insects by removing the infested specimens; 2) if infestation is significant, we will not control the insects. A major EAB infestation will provide the Arboretum with an opportunity to experiment with susceptibility of the Asian and European ash species, and other related plants represented in the collections. Release of parasitic wasps as a means of biological control will be considered for a heavy infestation for which any effective and practical chemical control methods may not exist (Kim, 2007).

<u>Additional initiatives</u>

Beyond the direct preparation of the institution's collections for EAB, the Arboretum has made incredible contributions to larger efforts surrounding this invasive pest. These efforts have included a collaborative expedition to China to collect Asian ash species, feeding preference research, development of the Illinois Emerald Ash Borer Readiness Plan, and continuous involvement in education and outreach activities pertaining to the pest.

Collection expansion:

The EAB invasion "prompted us to acquire [ash] species particularly from Asia, and China, and that are underrepresented in public gardens" (Kim, 2009). Given this directive, as part of the Arboretum's collaborative involvement in the North America–China Plant Exploration Consortium (NACPEC), Bachtell participated in a collection trip to Shaanxi Province, China in fall 2008. Researchers from the U.S. National Arboretum, Morris Arboretum, and Beijing Botanical Gardens were also part of the expedition that focused on the collection of seed from Chinese ash species. In all, seed from five different species was collected, a few of which are novel introductions to the Arboretum's ash collection. This initiative was intended to broaden the genetic representation of cold-hardy EAB resistant *Fraxinus* species available for breeding resistance into North American species (Bachtell, 2009).

In addition to Bachtell's 2008 trip, he continues to be involved in seed collection in China through researchers at the Beijing Botanical Gardens. Bachtell serves as the U.S. sponsor for USDA grants that are funding researchers from Beijing Botanical Gardens for additional collecting trips to 5 or 6 different areas in search of new ash germplasm. Bachtell (2009) reports "it's getting very difficult in China for westerners to collect… they've (China) got a lot of these province level rules; they can collect it and they can bring us the seed, but we can't be with them to collect…"

Research initiatives:

As a preliminary step in the development of new North American-Asian ash hybrids, Kim and Miller are utilizing the Arboretum's collections for a host plant preference study. This collaborative research is highlighted in step (5) of the Arboretum's EAB Action Plan as follows:

> (5) Collaborative research: with comprehensive ash germplasm in the collections, the Arboretum will seek collaborative research opportunities designed to find the least favored species or a resistant ash species to the insect. These ashes, if found can contribute to breeding work for resistant cultivars. Dr. Fred Miller, an Arboretum Research Associate is collaborating with a researcher at Michigan State University to conduct a feeding preference study using Asian ash species provided by the Arboretum (Kim, 2007).

Kim (2009) explains that the study includes 18 different species, 9 Asian and 9 European and,

> … by looking at the [feeding] preference of different species by the beetle, we can tell which ones are more [or less] susceptible… And the second part of the study… by looking at the number of egg masses of the emerald ash borer laid on the different species, we can understand which one the… borer favors or is less favorable.

The researchers are utilizing the Arboretum's extensive collections for these studies and will be involving samples that are currently growing in the Arboretum's production facilities from Bachtell's 2008 collection trip, in subsequent trials (Miller, 2009).

Miller is also involved in several additional research initiatives pertaining to EAB. Such activities include statewide monitoring programs that are funded by the state of Illinois, for which the Arboretum provides in-kind support, such as staff support and lab space (Miller, 2009).

Outreach and education:

The Arboretum has also undertaken extensive efforts to inform and educate the public, green industry, and communities of the EAB threat, identification of the pest, actions to reduce the spread, and BMP's (Best Management Practices). This initiative is action (6) on the Arboretum's EAB Action Plan and reads as follows:

> (6) Public awareness: the Arboretum will provide outreach and educational programs to raise public awareness about EAB and educating them how to respond if they are suspicious of an unknown insect. Plant Clinic staff will provide answers to EAB related questions over the phone. The staff will advise [the] public to bring [potential] samples to the nearest cooperative extension services for a positive identification. The Gatehouse attendants will try to intercept any samples being brought into Arboretum by any uninformed visitors, and

> make sure that the samples are kept in a sealed plastic bag or container. Plant Clinic posts helpful instruction on EAB [on] the Arboretum's website… (Kim, 2007).

In addition to the Arboretum's Plant Clinic responding to EAB questions, the institution has produced and distributed brochures, "alternatives to ash" tree lists, dedicated pages on their website, participated in numerous media promotions, and many other forms of advocacy to get the word out about the threat (Makra, 2009).

Statewide readiness planning:

Recognizing the need, the Arboretum took on the function as the lead organization in the development of the Illinois Emerald Ash Borer Readiness Plan for the entire state. The Plan's goals were in "organizing to minimize the risk of an EAB introduction into Illinois, to find it, and contain it quickly if it arrives" (EAB Readiness Team, 2006). Tasked with this effort, Edith Makra, the Arboretum's Community Tree Advocate, brought together "nearly 40 representatives from municipal, county, state, and federal governments, green industry professional associations, universities, and Chicago Wilderness (a coalition of public and private land management and educating organizations)" to identify resources, evaluate and compile existing EAB efforts and programs, and "work collaboratively towards overall health and sustainability of the forests, both urban and rural, throughout Illinois and northeast Indiana" (EAB Readiness Team, 2006). Taking the lessons learned from the development of the Readiness Plan for the state, Makra (2009) prepared a step-by-step guide entitled *Before the Bug Comes to Town: Developing a State or Regional Readiness and Response Plan for Exotic Invasive Insects*, to inform others of the process. This guide is available via the Arboretum's website (The Morton Arboretum, 2009e).

The Dawes Arboretum

The Dawes Arboretum resides in Newark, OH, 30 miles south of a sawmill where EAB has recently been found. The institution's Natural Resources Manager, Tim Mason (2009) reports, "… if it's not here already, within five years we'll start seeing the real impacts." Located on the western edge of the Appalachian foothills, the Arboretum was founded in 1929 by Bemen and Bertie Dawes, "… inspired by their love for trees and nature" (The Dawes Arboretum, 2010a). Today the Arboretum continues to convey the founder's passion to its almost 500,000 visitors annually (Payton, 2009), with a mission "Dedicated to increasing the love and knowledge of trees, history and the natural world" (The Dawes Arboretum, 2010b).

With close to 1,800 acres, the institution maintains nearly 17,000 living woody plant accessions, representing over 4,800 unique taxa (Payton, 2009). In the development of its holdings, the Arboretum's,

> … plant collection objectives are to provide the public, special interest groups and scientific community a well-documented, well-labeled, accurate and diverse collection. We strive to obtain as many representatives of families, genera, species and infraspecific taxa as can be grown in central Ohio. This serves to facilitate education, conservation and research. Our goal is to obtain certain genera in comprehensive collections, which include all species, lower ranks, and registered or published cultivars hardy, or suspected hardy, in this climate (The Dawes Arboretum, 2010c).

As part of its holdings, the Arboretum maintains two NAPCC collections, including the multi-institutional *Acer* (maples) collection and a genetic and taxonomic collection of *Metasequoia* (dawn-redwood; Payton, 2009). The largest repository outside of China, the institution's *Metasequoia* holdings includes nearly 360 individuals representing 50 parent plants of wild origin. Other well-represented collections include *Aseculus* (buckeye), *Ilex* (holly), and dwarf conifers among many others. Although originally collection development at the institution focused more on obtaining cultivars, increasingly the focus has been on the acquisition of material of documented wild origin (Payton, 2009).

In addition to its living collections, the institution also has a large focus on natural area conservation with over half of the institution's 1,800 acres held as woodlands, meadows, and wetlands (Mason, 2009). Located in what is considered the beech-maple region of Ohio (Mason, 2009), "… the Arboretum's native plant conservation efforts include conserving plants in their native habitats, inventorying native plant communities, and restoring and re-creating Ohio native ecosystems" (The Dawes Arboretum, 2010d).

<u>*Fraxinus* at the institution</u>

Although the institution's ash holdings would be considered a secondary collection, its accessioned *Fraxinus* include approximately 248 individuals within 140 accessions, representing 67 taxa, of which 22 are unique species (Payton, 2009). These accessions include an extensive representation of available cultivars of native species. The Arboretum's Nursery Manager, Rich Larson (2009) explains,

> … even down here [in Ohio] it was very valuable as a street tree. One reason why we acquired so many cultivars is because we considered them to be so valuable as a street tree and as something that we could recommend for people to use… a very significant tree because… at

> least green ash… it's a river bottom species, tolerates significant periods of water inundation, as well as drought, so its roots can survive low soil oxygen levels… Very useful for urban developments, so the loss of that, it is difficult to replace that.
>
> And I think you're getting really limited; you get to a point where you're limited to what you can plant to survive in those spots.

In addition, the institution maintains a large and actively developing collection of Asian species including mature specimens of *Fraxinus mandshurica* Rupr. (almost 80 ft in height) and *F. bungeana* DC. dating back to the 1930's, and recently acquired species such as *F. insularis* Hemsl., *F. paxiana* Lingelsh., and *F. spaethiana* Lingelsh. (Payton, 2009).

Beyond the collections, the Arboretum's wooded natural areas, used by visitors recreationally, amount to around 600 acres in which *Fraxinus* represents about 25% of the canopy. Typically, in the mature forested sections of the institution's natural areas, ash would represent 15% of the canopy, but in approximately 150 acres that were allowed to reforest naturally, ash and sugar maple are the dominant species (Mason, 2009).

<u>Disaster readiness planning prior to the EAB introduction</u>

Prior to the introduction of EAB to North America the Arboretum had no formal readiness plan in place for its collections. The institution did have overarching disaster recovery principles that could be implied if needed. Plant Records Manager, Greg Payton (2009) explains,

> … if a valuable collection plant is damaged [such as in a weather event], if it's possible to re-propagate it at that point, just a casual effort to… protect our collection plants, [we will]. But for the most part, cultivars and things like that can be replaced. But, if a plant were

> deemed unavailable elsewhere, then we would take higher priority to preserve that plant.

The institution has considered the development of such a policy and has investigated others gardens' plans (Payton, 2009).

Preparation and management strategies utilized

Monitoring for EAB:

The Arboretum has not established any formal monitoring program for EAB, but in general, the staff works together on a continuous basis, being observant of anything out of the ordinary. The Arboretum has allowed the state of Ohio to utilize the grounds for the statewide monitoring program, which has placed several pheromone traps on the property (Payton, 2009).

Tree removals:

In recent years the institution has taken a proactive approach to native ash tree removals in its collection areas. These actions aim to spread out foreseen monetary costs and mitigate safety concerns. Horticulture Department Head, Mike Ecker (2009) explains:

> Not having the emerald ash borer here yet we realized that it's only within 25-30 miles of us at this point. Eventually it will get here. We did not want all of the native trees presently in our collection areas to all be dying and having to come out at one time. So, it was purely an economic decision. We've done this over the past four years… These are all trees that are species… that have been here for years in fencerows and fields.
>
> And these were all trees that were big enough, or in areas where we felt we couldn't handle that with our staff. We've not taken out any of the cultivars, because most of them are such that we can remove them… we figured it'd be more economical for us to spread that cost out over

> years as opposed to all of a sudden finding out that we had trees over trails and roadways and have to take them down all at once.

In all, ten *Fraxinus americana* (white ash) and five *F. pennsylvanica* (green ash), upwards of several feet DBH have been removed (Payton, 2009). Trees in natural areas are not currently being managed in any fashion, but once declining, those posing a safety hazard, such as along trails, will be removed (Mason, 2009).

Preventative chemical treatments:

Thus far, the Arboretum has not made formal plans for the treatment of EAB susceptible species, but as new information regarding the efficacy and longevity of chemical applications continue to surface, these are considerations the institution explores. Ecker (2009) explains:

> See economically, that's another one of those decisions that this couldn't have happen at a worse possible time. The economics are just such, we're not sure in the next few years what we're going to be able to do. But, I agree with Rich [Larson], I think we should pick several of the native trees we've got [and protect them].

<u>Additional initiatives</u>

Collection expansion:

The institution has made great efforts to expand its collection of potentially resistant *Fraxinus* species that it was not holding or had limited genetic representation of in the collections. These collections have been acquired for use by staff and collaborating researchers in evaluation, breeding, and other research activities. Germplasm has been obtained by surveying current holdings at other institutions throughout the U.S., as part of the North Central Regional Plant

Introduction Station (NCRPIS) NC-7 Trials, direct contact with researchers in other countries, and collection efforts by the NACPEC. Payton (2009) explains,

> … we're actively collecting species that we know or suspect to be EAB resistant and we've planted some of those over in one of our plantation areas… easily accessible for researchers… So they're still fairly young trees, but we still have the opportunity to study and evaluate those.

Larson (2009) explains his initial approach to survey current U.S. based collection holdings:

> I was just trying to collect all the available germplasm of that species, especially [*Fraxinus*] *chinensis* and [*F.*] *mandshurica*, that I could get from this country… and I was grafting those and then, we were either putting them out in our trail beds, for potential hybridization later on, or we give specimens to USDA right there in Delaware, [Ohio], they take them and do their own work with them.

Other new acquisitions, such as *F. sieboldiana* Blume, which is less represented in U.S. collections than other species, was obtained directly from a Korean researcher. Furthermore, a lot of new material was received as a result of the 2008 NACPEC collection trip in China (Payton, 2009).

Research initiatives:

The Arboretum has been utilizing its expanding ash germplasm in collaborative research efforts focused on evaluation and breeding for EAB resistance. Horticulturist at the NCRPIS, Dr. Mark Widrlechner, coordinates a regional testing program that evaluates new trees and shrubs for the Midwest called the NC-7 Trials. Widrlechner (2009) reports, "The Dawes has been very interested in assisting with the development of resistant ash. They're a very good example of one of our NC-7 cooperators that have stepped up to the plate." As part of this program the Arboretum has been evaluating ash and many other taxa even before EAB (Payton, 2009). In addition to the NC-7 Trials, the institution participates in other evaluation programs, as well as collects data on their own field trials. As part of these efforts observations are made on individual specimens four times a year for numerous characteristics to evaluate such things as hardiness, survivability, appearance, pest damage, and aesthetic value (Payton, 2009). Participating in these trials allows the Arboretum to continue to expand its collections, particularly of wild collected material, that would otherwise be more difficult to obtain (Larson, 2009). Furthermore, these trials are a way for the institution to utilize the collections in the development of publications regarding regional performance of different taxa as a public service (Payton, 2009). Pertaining to its expanding *Fraxinus* holdings in particular, Payton (2009) believes that with EAB approaching it will be "… a great learning process for us, as to what species actually… outside of the lab, are affected in a standing environment."

In addition to utilizing the collections for field evaluations, Larson has been working closely with researchers on breeding initiatives at the USDA Forest Service Northern Research Station in Delaware, OH, in development of North American-Asian *Fraxinus* hybrids.

> In the beginning they were trying to find species of suspected resistance based on field trials in Michigan and the species that was most resistant was *Fraxinus mandshurica*. However, phylogenetically, it doesn't line up very well with our native species, so it is very difficult to cross our native species with that plant, or even [*F.*] *chinensis*, which is also quite resistant. So that's the difficulty right now that they're experiencing. They have a couple of putative hybrids that they're testing to see if there's actually been a successful cross (Larson, 2009).

Although crosses were originally made to existing specimens on the Arboretum grounds, environmental complications, such as ash-flower gall mite, expense, and the size of some of the trees, made for difficult conditions for breeding work.
Larson now grafts cuttings onto rootstocks, which forces flowering at a younger age. Crosses can then be made to these containerized plants, in the more controllable greenhouse environment at the USDA Station’s facilities using the grafted plants supplied by the Arboretum (Larson, 2009). The publication entitled *Development of Novel Ash Hybrids to Introgress Emerald Ash Borer Resistance into North American Ash Species* is a result of such collaborative studies (Koch et al., 2007).

Seed collection:

Taking their knowledge of the local forest communities of the county in which the institution resides, staff has made the effort to be involved in native seed collection and continues to identify valuable locations for future collection efforts. Payton (2009) explains that collections have been made,

> … throughout the county, we’ve done some specimens on the grounds [of the Arboretum], but the goal is just to gather at collection sites across the county. It’s being done in all of the counties, but we were taking care of this county. We travelled through some of the areas and found… primarily white ash. Green ash is much more difficult to find, there are some pockets of it…

These collections were made in collaboration with the ash seed collecting efforts of the USDA Forest Service Northern Research Station. The collections were made following outlined standards including submission of herbarium vouchers, photographs, GPS coordinates, and tree height and spread measurements, along with the seed collected (Payton, 2009). In the coming years, the Arboretum intends to continue the collection efforts, including from two isolated mature patches of *Fraxinus quadrangulata* (blue ash) that occur within the county (Mason, 2009).

Outreach and education:

The Arboretum has been actively involved in public awareness through the institution's plant clinic service, fielding calls from the public, signage on the grounds, articles in newsletters, and making available USDA promotional materials regarding EAB at Arboretum events. In addition, in 2008 the institution hosted an Ohio Department of Agriculture EAB informational event to educate public officials about the pest (Mason, 2009).

Phone Interviews: Additional Institutional Perspectives Regarding EAB

Hidden Lake Gardens

Located only 3 miles from one of the earliest EAB discover sites in 2002, Hidden Lake Gardens located in Tipton, Michigan has certainly felt the effects of the invasion. Owned and operated by Michigan State University, the Garden is a sister institution to the W.J. Beal Botanical Garden and Campus Arboretum (discussed previously) but is administrated by the division of Land Management separate from the Beal. The Garden, supported from its own admission and membership fees, endowments, and other gifts (Hidden Lake Gardens, 2010a), covers 755 acres and is maintained by a relatively small full-time staff of only 6 individuals, with help from dedicated volunteers and limited seasonal employees (Gentry, 2010). Serving the rural community of Tipton, an hour and a half south of the University's main campus, the Garden's mission is focused on educational opportunities for all ages.

> Our mission is to maintain and improve Hidden Lake Gardens for the benefit and education of the public. To instill an appreciation of plants, gardens, landscapes, and the natural environment. To display collections of plants that are of horticultural, botanical, and aesthetic value to the public and professionals of various disciplines. To interpret the collections and grounds, and utilize them for the educational benefit of the public. To preserve an undeveloped area of the scenic Irish Hills, providing a place of beauty and inspiration for public enjoyment (Hidden Lake Gardens, 2010b).

To fulfill this mission the Garden offers tremendous public programs and events for youths and families, adults, school and scout groups, and Master Gardeners of all ages. Many of these programs utilize the institution's living collections and natural areas (Hidden Lake Gardens, 2010c).

The most valued collections include the endowed Harper Collection of Dwarf & Rare Conifers hosting over 500 specimens, and the historical Benedict Hosta Collection representing over 800 varieties. In addition, the Garden's holdings include a collection of bonsai, a conservatory with temperate, tropical, and arid sections, a demonstration garden, and a 200-acre driving arboretum with formal tree and shrub collections including *Malus* (crabapples), *Quercus* (oaks), *Acer* (maples) and once *Fraxinus* (ashes; Gentry, 2010).

The formal ash collection was made up of around 75 accessioned specimens in two primary locations and represented North American, European and Asian species. As with all of the Arboretum's collections, these trees were primarily of value for educational purposes. Furthermore, the institution's approximately 500 acres of natural areas contained a limited naturally occurring ash population around 3-5% of the canopy. These areas are used for educational programs as well as recreational activities including hiking, biking, and cross-country skiing. As far as the staff is aware, all but two collection specimens, which are being treated on the grounds, have been killed by the borer. Other than heightened monitoring efforts, the institution had no disaster readiness plan for its collections in place prior to EAB, but now recognizes the potential need (Gentry, 2010).

Collections monitoring efforts for EAB started immediately when the beetle was identified in the state in 2002, and preventative chemical treatment the following year. Monitoring included visual inspection of collection specimens by staff, as well as trap-trees and other monitoring traps set up by University researchers. Although there were no visible signs of infestation at the onset, trees on the grounds are thought to have been infested from the start. Chemical treatment of selected specimens for aesthetic value and educational purposes began in 2003 using a soil drench of the insecticidal chemical Imidacloprid. Karen Gentry (2010), the Garden's Educational Director explains:

> I felt at the time really strongly because we were going to lose the entire ash collection, that we should keep a representative sample somewhere on the grounds if we could… I wanted that in the ash collection, but they were so heavily infested that by the time I started treating them… even though they didn't have visible signs… canopy thinning was occurring fairly quickly, so I just wasn't able to keep any of those trees… Because we don't have a tree crew here, so it was just me, basically, treating a few select plants.

A few specimens were salvaged closer to the institution's visitor center and are still maintained today. Beyond the unfortunate lack of time the institution had to react, Gentry (2010) explains the difficulties the Garden faced in making management decisions:

> I'd have to say that money is probably a deterrent for us… we did not have a director at the time, or a manager for the garden. So when all this was going on, we did not have a lot of direction… So… I just picked out some plants that I was going to treat with the money that I had.

Additionally, environmental concerns of treatment, public image, and a general institutional stance to limit chemical use in the Garden as part of the core mission, also played a role in determining that extensive chemical measures to save trees would not be used (Gentry, 2010).

Unless posing as a safety hazard along trails, roadways, or to adjacent collections, dying trees were left in place as wildlife habitat and for educational use. Trees that were removed were chipped, burned on site, or utilized. In collaboration with University Extension educators, the Garden set up a wood utilization fair that featured artwork, such as bowls and furniture, to bring further attention to EAB and educate the public about potential uses of their dying trees (Gentry, 2010).

Beyond wood utilization, in general the Garden played a leading role in education and outreach given its public education driven mission. Gentry (2010) explains that the *Fraxinus* collection became a key educational tool:

> I run the Master Gardener training program here, and… most of our… 250 volunteers, are all Master Gardeners, so that was a teaching tool that I would go out, bring them to the trees, show them all the diagnostic-type information that they needed and then they are to go out… into the community and help with some of those questions. So it was very much a hands-on collection for the last… several years.

Furthermore Gentry (2010) explains:

> I did a lot of educational awareness, trying to promote diversity in tree species, so we used that collection as it was dying… to kind of show homeowners the difference between the different ash species. How to

> recognize it in your home landscape, how to treat the plants, so it was a collection that we used heavily until it… totally died out. So again, it was for emerald ash borer education and alternatives to ash.

The Garden was also extensively involved in addressing questions and diagnostic work of samples brought in by visitors and by fielding phone calls. Additional initiatives completed outside the Garden included extensive outreach in the form of lectures and presentations to the general public, schools, and various city groups and the collaborative production of print materials, addressing issues such as the movement of firewood (Gentry, 2010).

> Actually… the awareness, all the education, all the people we brought in, all of the walks… it increased our visibility quite a bit… that's the positive portion of it… a lot of people that live in our community, they have no idea what we are, or have never been here. And because we were so much out there with education, I think it helped… put a public face on us… we have some viability… there's something going on there. We were needed to a certain point, education-wise, and people knew where to come. That's a good thing (Gentry, 2010).

Finally, the Garden was very receptive to outside researchers utilizing the grounds and collections for various projects to further the understanding of the exotic pest, treatments, and its ecological impacts (Gentry, 2010).

University of Minnesota Landscape Arboretum

Identified in the state of Minnesota on May 13, 2009 (USDA Forest Service et al., 2010), the University of Minnesota Landscape Arboretum (MLA) resides in one of the states most recently inflicted by the pest. Although yet to be found on the institution's grounds, the Arboretum sits in Chaska, MN approximately 30 miles from the point of the EAB discovery in the state (Moe, 2009). As part of the University of Minnesota, the mission of the Arboretum,

> … is to provide a community and a national resource for horticultural and environmental information, research and public education; to develop and evaluate plants and horticultural practices for cold climates; and to inspire and delight all visitors with quality plants in well designed and maintained displays, collections, model landscapes, and conservation areas (MLA, 2010a).

Founded in 1958, the Arboretum covers over 1,100 acres holding more than 5,000 taxa in its collections and gardens (MLA, 2009a). Through the extensive tree and shrub research of the Woody Landscape Plant Breeding and Genetics program, the institution has been involved in the introduction of 46 cold hardy woody landscape plants, most notably the ‘Lights’ series of azaleas (MLA, 2010b). The institution holds 45 collections including significant taxa of *Malus* (crabapples), *Pinus* (pines), *Acer* (maples), and *Rosa* (roses), as well as 28 unique gardens and 17 landscape display models (MLA, 2009a). In addition to the collections, the Arboretum has been involved in extensive restoration activities in its natural areas including tallgrass prairie, wetlands and bogs, and several hundred acres of native forests (Moe, 2009).

One of the original collections to be established, the institution has a significant number of *Fraxinus* taxa represented as well. Although considered a secondary collection, these holdings include seven species and 26 cultivars represented by 86 specimens, in two identified ash collections. In addition, street tree evaluation plots planted back in the 1970’s in response to the loss of the American elm, contain ash trials that are not included in the figures above. The institution’s woodlands also contain low population densities of black (*F. nigra*) and green (*F. pennsylvanica*) ash (Moe, 2009). Given the Arboretum’s strong woody plant evaluation and introduction program, Peter Moe, Director of Operations, describes the Arboretum’s objectives with ash as follows:

> We were looking for trees that had the best form… specifically for white ash (*F. americana*)… Because… really the Twin Cities are very close to the northern edge of the natural range of white ash. And so most of the white ash that are found in the wild in Wisconsin and Minnesota have yellow fall color, so we were looking for some of the hardiest forms with the purple color. And, just in general, plants that have a nice landscape form, course the cultivars have been typically selected for their form, or for being seedless, and… just kind of long term evaluation for which ones get the male flower gall, or ash plant bug, or anthracnose, or some others (Moe, 2009).

In preparation for EAB, the Arboretum has put in place a basic, seven step Emerald Ash Borer Management Plan that identifies key actions the Arboretum will take. These steps read as follows:

> 1. Inspect ash trees in the ash collection and other locations on the grounds on a regular basis.
>
> 2. Designate most valuable native or planted trees for possible insecticide treatments.
>
> 3. Obtain traps from the Minnesota Dept of Ag to monitor for emerald ash borer adults at the Arboretum.
>
> 4. Notify companies bringing woodchips that they may not bring firewood or unchipped materials here.
>
> 5. Enforce the current ash wood and unchipped brush quarantine at the Arboretum compost site.
>
> 6. Attempt to acquire more Asian ash trees from known sources.
>
> 7. Participate in Ash Seed Collection Program where we collect seed from native ash trees to maintain the genetic diversity in the event that the EAB has been controlled (MLA, 2009b).

Beyond increasing visual inspections (step 1), the Arboretum is contemplating possible chemical means to protect valuable specimens as noted in step 2 of the Plan.

High priority individuals are being selected for possible treatment using various factors including aesthetic value in a given location, uniqueness of the specimen on the grounds, and most importantly whether or not the individual is of documented wild origin. Although chemicals are being considered for use, other variables such as possible environmental effects and the unknown duration of commitment to treatments are also being weighed in the decision (Moe, 2009).

The Arboretum has also setup pheromone traps distributed by the Department of Agriculture. In particular these traps are being setup in the vicinity of the institution's commercial composting site, which is of utmost concern as a point of introduction given that the Arboretum sits on the outside edge of the current quarantine zone. In addition to traps the staff at the institution has been involved in statewide Emerald Ash Borer Task Force meetings to ensure the quarantine is being rigorously enforced (Moe, 2009).

This group brings together a broad spectrum of stakeholders including the USDA, University of Minnesota, Minnesota Department of Agriculture, Minnesota Nursery and Landscape Association, and representatives from municipalities. These entities share information making sure all parties are trained on proper procedures, such as with quarantines, to highlight the strengths that each party brings to the effort, and to disseminate information to the public. The Arboretum brings to the table 50 years of expertise in evaluation for potential resistance and of species suitable as future ash tree replacements in the urban environment. In addition, the institution has taken an active role in EAB public education through newsletters, postings to the Arboretum website, addressing questions from visitors and accepting phone calls on behalf of the University Extension Service, and participating in Q&A sessions over the radio. Furthermore, the Arboretum has employed the expertise of its staff to be involved in the state's Forest Pest First Detector program. This volunteer based initiative trains individuals to be first responders to sites where EAB has potentially been identified (Moe, 2009).

Additional initiatives the institution intends to implement include collection expansion of potentially EAB resistant *Fraxinus* species through collaborative efforts for evaluation, and involvement in native ash seed collection (Moe, 2009).

Phone Interviews: Institutions Affected by Other Biological Invasions

The Arnold Arboretum of Harvard University

In recent years one of The Arnold Arboretum's most treasured and beloved collections, *Tsuga* (hemlocks), and in particular a semi-natural hemlock stand covering 22 acres of the property, known as Hemlock Hill, has come under attack by the exotic insect, hemlock woolly adelgid (HWA; *Adelges tsugae*; Dosmann, 2009). Located in Boston, Massachusetts, The Arnold Arboretum, founded in 1872, is the oldest public arboretum in North America (The Arnold Arboretum, 2010a). The institution's mission reads:

> The Arnold Arboretum of Harvard University discovers and disseminates knowledge of the plant kingdom to foster greater understanding, appreciation, and stewardship of the Earth's botanical diversity and its essential value to humankind (The Arnold Arboretum, 2010b).

The woody trees, shrubs, and vines of worldwide origin that are the foundation of the Arboretum, comprise nearly 15,500 individual specimens representing over 4,000 taxa (The Arnold Arboretum, 2010c). With a focus on North American and Eastern Asian flora hardy to the New England region (The Arnold Arboretum, 2010c), the Arboretum holds six NAPCC collections including the multi-institutional *Acer* (maples) collection, and single-site collections of *Carya* (hickories, pecans), *Fagus* (beeches), *Stewartia* (stewartias), *Syringa* (lilacs), and *Tsuga* (hemlocks; APGA, 2010d).

The institution's *Tsuga* holdings are represented by 59 taxa within 7 species and the beloved Hemlock Hill, a semi-natural stand of Canadian hemlock (*Tsuga canadensis*). In 1938, the Hill received a devastating blow from a hurricane, in which more than 400 individuals, including some of the largest specimens dating back to the late 1700's were lost (Del Tredici, 1994). After the loss, the Hill was replanted with various sources of material, and once again returned to the majestic forest. Although the Hill was of historical, aesthetic, and restorative value to the expansive urban community that it served and an educational remnant representative of the hemlock forests of New England, little emphasis was put on its management, prior to the HWA occurrence in the collections (Dosmann, 2009).

Beginning in 1997, the Hill would once again be challenged with the discovery of HWA (The Arnold Arboretum, 2010d). With the pest decimating hemlock stands throughout the Mid-Atlantic region of the U.S., and dormant oil applications nearly impossible in the dense stand, the Arboretum saw little hope for the cherished Hemlock Hill. An in-depth inventory of the entire stand in the years that followed revealed the Hill was home to nearly 2,000 individuals. This inventory included assigning accession numbers and mapping the location of each specimen (Dosmann, 2009). In 2003, through close observation of the decline, it was expected that over the next two years, over 1,000 specimens would have to be removed (Schulhof, 2007).

With the Hill in mass decline, new hope was found in available chemical treatment options and some much needed relief in the weather. Arboretum Curator, Michael Dosmann (2009) explains:

> We dodged the big bullet when it came to… the potential deaccessioning of that whole hill. We had some pretty nice years… we didn't have huge droughts in the summer, and so the trees were a little healthier than normal, during the early 2000's. If we had normal years, in which those plants would be normally… water stressed during the summer, they would have looked a lot worse and we would have been forced to take them down, all of this before Merit® [Imidacloprid] came on board.

In addition, the winter of 2004 brought the coldest temperatures in several years to the area, and although little was known about the effects of such conditions on HWA, the insect suffered a 90% population reduction that season (Schulhof, 2007).

> And so that was pretty significant… we have been able to use Imidacloprid for the time being to kind of bring that collection back from the brink… to the extent possible, every plant that we can access, we will apply Merit®… and that gives us 3-4 years of control… it's a systemic and we're seeing plants that… had been hit by the insect for 5, or even longer, years… on the brink of death, it's amazing that within a year we were already starting to see them re-grow (Dosmann, 2009).

In addition, the institution saw this new hope as an opportunity to bring the imperiled collection to the forefront of the Arboretum's holdings. Dosmann (2009) explains that the hemlock collection,

> … was really put on the radar. And it was about the same time that hemlock woolly adelgid was coming on the scene… that NAPCC was being created and because we had this very significant, robust *Tsuga* collection and it made logical sense that we would ask if we could get that as one of our NAPCC collections, but it was also a way to recognize and say, "hey look, this is the national collection, it's being challenged by a foreign object, let's see what we can do to… focus our efforts on preserving it."

Although over 500 hemlock trees have been removed on the Hill thus far due to the effects of HWA, the Arboretum has been able to preserve a significant portion of these hemlocks through the process of Adaptive Management (Holling, 1978). As then Deputy Director Richard Schulhof (2007) explains, "Gathering data that monitor changing conditions as well as the effectiveness of management actions is essential, as is the willingness to completely revise strategies based on new results." Dosmann (2009) adds, "… the inventory and the maps, and the information on who's been sprayed, who's been injected… those have all been critically important [pieces of information]."

Although the effects of HWA have been devastating, its occurrence has generated a lot of new opportunities for research, collection development, collaborative partnerships, and teaching (Dosmann, 2009). Dosmann (2009) explains:

> We've always had strong relationships with other sister arboreta and botanical gardens, particularly those NACPEC organizations. We've exchanged a tremendous amount of material, primarily *Tsuga chinensis*, but a few other species as well… so we've had this huge infusion of *Tsuga chinensis* particularly in trading with the Morris

> Arboretum and… [U.S.] National [Arboretum], that's been a strong collaborative relationship that has definitely benefitted the institution.

Utilizing these collections for research opportunities to evaluate the susceptibility of *T. chinensis*, studies demonstrated that *T. chinensis* was unaffected by HWA. Other collaborative research efforts, such as understanding the biology of the insect, the co-evolution of the pest with its native host, and the ecological dynamics of such an invasion, have also been undertaken by researchers within and outside the Arboretum (Dosmann, 2009).

In dealing with the invasion, the institution also saw the need to educate the public about the potential loss of the beloved collection. Dosmann (2009) explains,

> …the public loves… Hemlock Hill, they are going to be outraged if all of a sudden we start taking that down. So there were some opportunities for public education… evening meetings and things like that, so the community would be educated… about the insect, what it was doing, etc… That was very local, basically just to let people know what we potentially would be doing.

As the institution continues to deal with the effects of HWA, the pest has provided a first-hand educational opportunity to educate the community on the destructive impacts of biological invasions in general. Dosmann (2009) comments,

> … we service a couple thousand Boston school kids a year and… one of the components of the curriculum is looking at Hemlock Hill as an ecological site, and so normally we never would have taken them out there, but because of the HWA, we can teach them about introduced organisms and how they can negatively affect the landscape, or a natural system and what happens… And the kids can go there and see.

University of California Botanical Garden

Although sudden oak death (SOD; *Phytophthora ramorum* Werres et al.) has not killed a single tree at the University of California Botanical Garden, the institution's operations, economics, and memberships have been significantly impacted by the pathogen. Located in Berkeley, California the Garden is nestled in Strawberry Canyon covering 37 acres, with the surrounding canyon slopes undeveloped and dominated by coast live oak (*Quercus agrifolia* Née; Carmichael, 2009). Established in 1890 the mission of the institution is:

> To develop and maintain a diverse living collection of plants to support teaching and worldwide research in plant biology, further the conservation of plant diversity, and promote public understanding and appreciation of plants and the natural environment (UCBG, 2010a).

Maintaining one of the largest, in terms of species represented, collections in the U.S., the majority of the institution's holdings are of wild collected material arranged in a series of bio-geographical collections displayed in a habitat orientation (Carmichael, 2009). Such collections include The New World Desert Collection, The Southern African Collection, and The Eastern North American Collection. With a focus primarily on plants of Mediterranean climates, its collections hold nearly 13,000 taxa, with the most substantial holdings representing the families of Cactaceae (cactus family; 1,198 taxa), Asteraceae (sunflower family; 771 taxa), Orchidaceae (orchid family; 711 taxa), Liliaceae (lily family; 675 taxa), and Ericaceae (heath family; 614 taxa; UCBG, 2010b).

Two species that are most affected by SOD include tanbark-oak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.) and coast live oak, which as previously noted is a significant species in the forest community that surrounds the

Garden. Associate Director of Collections and Horticulture, Chris Carmichael (2009), explains the occurrence of these species on the grounds:

> Now tanbark is not native to this canyon and it's not a significant part of the collection though we have a number of them here. The coast live oak is the native tree in the canyon, so we have thirty-seven acres [at the Garden], of that total, roughly thirty acres are developed and the additional seven acres are [coast] live oak and bay (*Umbellularia californica* (Hook. & Arn.) Nutt.) woodland and then we have coast live oaks dotting the rest of the collection that we've just left and built around over the years. And they also form a core within our Californian collection, which is our largest single collection… in terms of our numbers and our geographic area. So, live oaks are a big deal and the threat to them by sudden oak death is one that we would take seriously.

The disease causes mortality in several other oak species as well. Beyond coast live oak, the institution has an additional 70 oak taxa represented in its collections. Furthermore, many other plant groups can be carriers of the pathogen with little effect on the health of the plant. In particular, ericaceous plants including heathers, azaleas, rhododendrons, and also California bay laurel (*Umbellularia californica*) can serve as a reservoir for the pathogen. Given that California bay is a dominant component in the surrounding natural lands and Ericaceae is one of the top five families represented at the institution, the transfer of the disease from these vector species to the oaks is of significant concern (Carmichael, 2009). Carmichael (2009) speaks to the potential impact:

> And so both within our natural areas and… the surrounding vistas, were sudden oak death to come in and start impacting oaks… it would be a very severe impact. A visual impact, and within our California collection, it would alter how we do our business, because we have a lot of things planted under and around the oaks in terms of oak-woodland communities that would be impacted as well.

> It would change our interpretation of the native Bay area habitat and it would alter the structure of our California collection in particular, which is one of the collections we do a lot of interpretation and, particularly K-12, but also California habitats for UC Berkeley classes, so the removal or the impact of oak loss in those areas would severely impact those objectives.

Phytophthora ramorum was first discovered in California in 1995, and in certain parts of the state where the pathogen has taken hold, the effects on forested land has been devastating. Although the institution has not lost a single tree to the disease, the Garden has experienced significant negative effects such as changes in operations, and lost revenue from the closing of the Garden's annual plant sale and resulting membership losses. These effects were the result of a quarantine put in place for the Bay area. Carmichael (2009) explains,

> … one of the biggest impacts was that it altered our operation. We stopped selling plants to the public, and selling plants is a way that we make money to support our operations, and until we had a better understanding of what the heck was going on here… the Garden was… as the whole Greater Bay area, was placed in quarantine, there's a large quarantine zone along the California coast, maybe even into Oregon, and what that means is that plants are not supposed to move in and out of the quarantine zone without being certified by various state and local agencies.
>
> For the one-year period… when we stopped plant sales, we probably lost $30-40,000.

In addition given that the Garden's plant sale also acts as a source for new memberships, Carmichael (2009) indicates, "… our membership took a big hit in that period as well." Although the plant sale has resumed given that the quarantine zone has significantly expanded, the Garden has completely stopped selling certain plant groups, such as *Rhododendron*, as a result. Furthermore, intense monitoring of existing collection plants and testing of incoming nursery stock have also impacted operations at the institution.

> And the way that sudden oak death played out for us, it was as much of a disaster as a wildfire would have been or could have been as much of a disaster in terms of impact on our operations, the loss of collections. Knock on wood it didn't turn out to be that way, but it was certainly a sobering experience… when we thought we had it here and we altered our operations and we shut down our plant sales… which impacted our membership (Carmichael, 2009).

Although not found on the grounds yet, the institution continues to alter collections development and management procedures to help prevent the possible introduction of the pathogen.

> I would say that the vast majority of plants coming into our collection are seed grown and I don't think there's ever been an issue with seed… and the transmission of this disease. And then when we bring plants in from native habitat for our Californian collection, we're very thoughtful about where we collect. We do not bring in and introduce things from defined sites of sudden oak death (Carmichael, 2009).

If plant materials, particularly ericaceous, are brought in from other institutions or in limited cases from nurseries, the Garden does so only if they can be assured that appropriate monitoring and testing for SOD has taking place at those facilities, and that the materials are clean of the disease. In any case, material is never brought in from a known SOD outbreak location (Carmichael, 2009).

Management efforts to remove or prune back the naturally occurring California bay laurel where natural areas adjoin the collections and could potentially transfer the disease have also been taken. In addition, regular testing and monitoring of the collections and plant sale stock is performed by local and state government agencies, in concert with trained staff continuously making observations at the

Garden. Furthermore, a phosphonate compound used as a prophylactic treatment has been shown to be effective in protecting trees against *Phytophthora ramorum*, and is an option the institution is exploring as part of its Integrated Pest Management (IPM) program. These management strategies are informed by information sharing through collaborative relationships with Berkeley researchers as well as researchers from other universities in the area. Information is also disseminated to fellow gardens via partnerships such as the Bay Area Garden Network, which meets twice a year to discuss current issues (Carmichael, 2009).

The Garden is also involved in additional initiatives, playing an educational role and supporting the research community. Carmichael (2009) explains:

> We have provided plant material for a series of studies on campus, looking at susceptibility to *Phytophthora ramorum*, we have a very broad collection, so we've provided the lab on campus with material for several studies, including an interesting study done by some Australian researchers… who were interested in looking at susceptibility in Australian species. And since we have a large number of them here, they sampled and worked with a whole lot of them from our collection. So one thing that we do is support research on the topic wherever we can.

Additionally, educating the public about SOD, through lectures, interpretive signage, and leading tours, "has become part of the ongoing dialogue with the public" (Carmichael, 2009).

Montgomery Botanical Center

For a little more than a decade the Montgomery Botanical Center's prized cycad collection, and in particular the genus *Cycas*, has been continuously menaced by the introduced Asian cycad scale (ACS; *Aulacaspis yasumatsui* Takagi; Griffith, 2009). Located in Coral Gables, Florida, the Montgomery Botanical Center (MBC) holds one of the finest collections of palms and cycads in the world.

> The mission of MBC is to advance science, education, conservation, and horticultural knowledge of tropical plants, emphasizing palms and cycads, and to exemplify excellent botanical garden design. Through this mission, MBC endeavors to make the Montgomery name known and respected throughout the world in the field of plant science (MBC, 2010a).

To meet this mission the Center focuses on building its holdings through the collection of documented wild origin seed resulting in scientific, population-based collections. MBC's grounds host 1,040 taxa represented by nearly 11,000 individual living plants. Focusing on palms and cycads, the institution maintains 356 (272 wild origin) taxa represented by 5,222 (3,838 wild origin) individuals of palm and 227 taxa (202 wild origin) represented by 3,191 (2,682 wild origin) individuals of cycad (MBC, 2010b).

Specifically the genus *Cycas*, one of eleven genera recognized in the Cycadales group, is represented at the Center by 64 taxa (RBGE, 1997), including one taxon very rare in collections and no longer extant in the wild, and two that are critically endangered in their native range as a result of ACS (Griffith, 2009). The entire genus *Cycas* occurs natively in Australia, Asia, and South Pacific and Indian Ocean Islands, but does not have representative taxa in the Americas. The institution's objective with the genus, as with many of its holdings, is to develop as broad a collection including all species, with good population and geographic representation. The Center's Executive Director, Dr. Patrick Griffith (2009) comments, "… because of the importance of those collections, we put a lot of time and money into making sure that they stay alive."

Introduced to Florida in the mid-1990's, ACS was first discovered in the U.S. on the Center's property, in a nursery run by the Fairchild Tropical Botanic Garden, and thus as Griffith (2009) explains "both institutions have culpability" for the introduction of the pest. It is thought that the pest was brought on to the institution's grounds via living plants collected from Thailand, the country that is the native range of ACS and where the scale is kept in control by natural pressures of its native ecosystem. Given that the genus *Cycas* is predominately native to Asia, the introduction of the pest to the U.S. has significantly affected living collections at botanical institutions and cultivated landscapes, but does not have a known susceptible host to affect in native ecosystems of the Americas. *Cycas revoluta* Thunb. (sago palm), once very commonly used for residential plantings, no longer graces the neighborhoods of South Florida. And although the pest has put a tremendous maintenance burden on MBC and its *Cycas* collection, the Center has not lost a single specimen due to ACS. Since its introduction, the pest has spread to other parts of the New World including South Texas and many Caribbean islands. Although native populations are not affected in the U.S., the pest has also been imported to other Asian nations, such as Guam and Taiwan, where ACS has pushed some *Cycas* species to the brink of extinction in the wild (Griffith, 2009).

Although the institution does not have a formal readiness plan in place for biological invasions per se, given its tropical location the Center has developed and implemented a protocol for responding to natural disaster, particularly hurricanes, as well as over-arching management principles that help to safeguard its valuable germplasm. Beyond the emergency response to a disaster in the hours that follow laid out in the protocol, Griffith (2009) describes, "… the plan is to share collections and to get them out to other places so that whatever the problem is, they are backed-up elsewhere." Griffith (2009) continues:

> … if the pest is a problem and it really is going to be a disaster, our best bet is to make sure that the species, or the population with those collections exist elsewhere so that they don't go extinct, and the lineage lives on. So we share them locally with places like Fairchild, or the USDA, or the Kampong, but we also try to share them with other places that grow cycads such as, Huntington out in California or UC Berkeley.

Beyond the storage of collections in other locations, MBC has had to go through continuous maintenance efforts to assure the survival of their *Cycas* collection. Given that the insect feeds on the surface of the leaves, the first line of defense is mechanical removal using high-pressure water, physically removing the insect from the plant. Additional management efforts include removal of heavily infested leaves, application of horticultural oil, and of last resort chemical applications of Distance® (Pyriproxifen) or Safari™ (Dinotefuran). Furthermore, the Center is investigating anecdotal evidence that the use of coffee grounds as a mulch around susceptible plantings may help to control the insect. MBC would like to develop scientific trials to measure the efficacy of such treatment, if funding becomes available. Collaborative research efforts with the USDA looking at possible biological controls for the pest, have also utilized the institution's collections (Griffith, 2009).

In addition to research in collections management and control, the organization strives to aid in the preservation of the imperiled *Cycas* species in the wild, through rescue efforts of critical populations.

> In areas where… the scale has escaped into the wild, we're very interested in going to those places to try to rescue those plants before they go extinct in the wild… we have a commitment to try to collect as much as possible from Micronesia and other Pacific island systems where *Cycas* is known (Griffith, 2009).

By storing this material, the Center hopes that it can be used for reintroduction efforts, which they have done with other plant groups in the past, as control measures are found in those regions. The Center has also participated in collaborative on-the-ground research efforts regarding ACS in Guam and Rota in recent years, but Griffith (2009) explains "our best efforts are probably focused on keeping the plants alive here."

The Center has also been involved in local advocacy and global planning efforts as part of the IUCN World Conservation Union Cycad Specialist Group, dedicated to the conservation of Cycads. As part of this effort MBC developed a webpage on their website with management information pertaining to ACS, which is now hosted by the Group's website. More local efforts have also been made, including recommending to commercial growers that nursery materials be inspected before being transported and to grow alternative genera not affected by the pest (Griffith, 2009).

Phone Interviews: Professionals Involved in Collaborative Initiatives

North Central Regional Plant Introduction Station

Dr. Mark Widrlechner, Horticulturist at the North Central Regional Plant Introduction Station (NCRPIS) for the past 26 years, has been fighting to preserve ash germplasm through the collection and storage of seed with a national coordinated effort of government agencies, private landowners, and public gardens. The NCRPIS is part of the U.S. National Plant Germplasm System (NPGS) of the U.S. Department of Agriculture (USDA) - Agricultural Research Service (ARS; Widrlechner, 2009). The mission of the NCRPIS,

> … is to conserve genetically-diverse crop germplasm and associated information, conduct germplasm-related research, and encourage the use of germplasm and associated information for research, crop improvement and product development (NCRPIS, 2010).

To preserve this plant biodiversity the Station stores germplasm, mostly in the form of seed, in repositories. Although the focus of the NCRPIS efforts are on field and horticultural crops, Widrlechner's work has been focused on the collection, curation, and research of ornamental, medicinal, and aromatic plants. Additionally, he coordinates what is known as the NC-7 Trials, a regional effort to evaluate germplasm collections of trees and shrubs for use in the U.S. midwestern region. One of many woody ornamental plant species that Widrlechner curates, ash was of relatively low priority, "… until a few years ago when we had to look seriously at emerald ash borer and how to respond to this pest, that I really got more involved with the preservation of ash" (Widrlechner, 2009).

Prior to the EAB introduction, the initiatives that the NCRPIS were involved in regarding *Fraxinus* were fairly minor, but the genus has become a top priority since the invasion. Widrlechner (2009) explains that the *Fraxinus* objectives prior,

> … were to preserve any *Fraxinus* that happened to be collected for or donated to the National Plant Germplasm System… also I was interested in ash to a certain extent as to find new ash species and populations that might do well in the midwest, so there were ash collections that were going into the NC-7 Trials, primarily from China,

> but also from Ukraine. I've [also] worked with a number of people… on trying to breed cold-hardy *Fraxinus ornus*. Flowering ash is a really beautiful street tree, but we can't use it in the midwest… it's just not hardy enough… and we've been doing… a long-term recurrent selection program to try to improve flowering ash. But… it's also susceptible to EAB, so I don't know where that's going to go in the future.

These objectives have changed with the EAB threat. Susceptible species are no longer sent to trial sites, and the status of past research objectives, such as with *F. ornus* L., are in question. Although, some initiatives have been sidelined, other *Fraxinus* related missions certainly have become of top priority (Widrlechner, 2009).

Although the NCRPIS was not the first USDA agency to start major seed collection of native ash in the face of EAB, it has taken on an increasingly vital role in these germplasm preservation efforts.

> It jumped from… a minor component of the many genera that I'm responsible for, to one of the top ones. And we set up specific goals for collecting, both Eastern North American ash, and trying to acquire more ash from Northeastern Asia. And so, our objectives really got focused on seed collection of *Fraxinus*, shifting my activity in that whole woody curation area much more heavily to *Fraxinus* and my technician, spends a pretty good chunk of his time now just working on this *Fraxinus* seed project.
>
> There's… a pressing issue that's reducing the diversity in nature, and ash is an economically important species, both to horticulture and to forestry (Widrlechner, 2009).

Although, NCRPIS has focused on collection of wild germplasm for economically important plant groups in the past, the ash mission brings a greater emphasis on potential for restoration efforts of native populations, for which few examples within NCRPIS exist from the past (Widrlechner, 2009).

The seed collection efforts both in North America and Asia have brought together many parties, including government agencies, private landowners, and public gardens. Although only approximately six gardens have been involved in these efforts in a serious way, the resource contributions, local knowledge of ash populations in the region the institution resides, and contacts provided, particularly aiding in collection of Asian germplasm, have played an important role in meeting these objectives. Communications regarding seed collection have been made through established relationships with gardens participating in NC-7 Trials, individual contacts, and efforts by the APGA, to identify potential gardens that may be interested in involvement. Furthermore, the established partnerships of the NACPEC and of individuals, such as Kris Bachtell of The Morton Arboretum with Chinese gardens, have yielded a source of Asian germplasm via connections that would have been difficult for Widrlechner to make on his own accord (Widrlechner, 2009).

Although gardens have been involved, the number of participating institutions has been fairly limited. Widrlechner (2009) reports:

> I was hoping that our network of [NC-7] Trial site cooperators might want to get more involved in seed collection and documenting ash in their areas, but to be honest… only a very few of those cooperators seemed to have great interest in helping with this.

Institutions already stretched for resources, may have a hard time justifying the allocation of resources and time to contribute to these efforts (Widrlechner, 2009).

Although NC-7 germplasm distribution of North American ash species has stopped and the effort to establish Asian *Fraxinus* species for evaluation is fairly limited at this point, as more material is generated from Asia, these efforts will be of increasing interest. Widrlechner (2009) reports, "… the Dawes [Arboretum] has been very interested in assisting with the development of resistant ash. They're a very good example of one of our NC-7 cooperators that have stepped up to the plate." The Arboretum has been provided with a significant amount of Asian material through this program for propagation and evaluation efforts (Widrlechner, 2009).

Although many mechanisms are in place to communicate with stakeholders, in particular inter-governmental agencies involved in similar efforts, it has been challenging to develop a coordinated and unified force. Widrlechner (2009) reports:

> And that's been an interesting challenge because they (National Resources Conservation Service and U.S. Forest Service) have different approaches to this [seed] collection effort than I do, and although we've sat down together to talk, we still don't really have a single, unified voice. There isn't a single protocol to follow, and that's been a challenge to me. I don't know how much to invest in having that unified voice, and how much to invest in just making sure that we have good collections in… I wish we were all really on the same page, but I'm not really sure that we are.

North American Plant Collections Consortium

The mission of the North American Plant Collections Consortium (NAPCC) of the American Public Gardens Association (APGA) is two fold; it "… is a network of botanical gardens and arboreta working to coordinate a continent-wide approach to plant germplasm preservation, and to promote high standards of plant collections management" (APGA, 2010a). With the Association recognizing a need, particularly for curatorial standards back in the late 1980's, a formal cooperative agreement was established in 1995 between the APGA and USDA–ARS, to form the partnership of the NAPCC. The USDA-ARS established the NPGS program in 1990, with a focus on safeguarding germplasm of agriculturally important plant species. The NAPCC partnership brought to the table a way to preserve ornamental plant germplasm, utilizing existing collections, resources, and the expertise held among public gardens (Allenstein, 2009).

Participation in the Program provides for tremendous institutional benefits, as well as greater overall direction in the preservation of identified plant groups. Program acceptance acknowledges an institution's commitment to curatorial excellence, and dedication to collections preservation. Through the NAPCC program, the collaborative relationships with partnering collection holders allows for the sharing of information, comparison of holdings between institutions to identify duplication and gaps in collections to inform future acquisition efforts, and utilizes the collective strengths of individual institutions making efficient use of available resources (APGA, 2010a).

Today, the NAPCC has grown to 48 participating institutions throughout the U.S. and Canada, representing 35 woody and herbaceous plant groups, mostly at the genera level, but a few family collections and a single geographic collection. Only two of the NAPCC collections are formally multi-site at this time, including *Acer* (maples) with 11 participating institutions, and *Quercus* (oaks) with 17 institutions (APGA, 2010d). The remaining plant groups are represented at a single institution or multiple institutions without a formal link presently. It was the intention of the Program from the start that no sole institution would be the holder of an entire collection, and thus efforts are being made to establish coordinated groups when multiple single institutions represent the same plant group (Allenstein, 2009).

Prior to EAB, *Fraxinus* was of lower priority for establishing a NAPCC collection, largely in part because of the lacking number of institutions identified as curating generic level *Fraxinus* collections. The idea was revisited in the years that followed the pest's introduction, as the Program tried to figure out its role in addressing the invasion. Pam Allenstein (2009), NAPCC Manager, explains:

> Certainly as the news continued with… how devastating it was, we revisited… the idea of a *Fraxinus* multi-site collection, but our multi-site collections so far have been based on existing robust collections, and there were very few [*Fraxinus*] collections in the states that had been identified. And one of them, at the University of Michigan, had been wiped out…
>
> We've tried to figure out what would be our role. Start with the fact that it wasn't on our priority list and we didn't have any NAPCC *Fraxinus* collections… we next looked at, OK, well but then if we're supposed to be facilitating germplasm preservation… should we be looking at fast tracking… actually going after existing collections, trying to bring them into the program, and that was kind of the approach that we took, and found that there weren't very many… some of the ones that were actually in harm's way, we're… not going to be focused… on filling out an application for NAPCC. We had more immediate concerns.

With lacking *Fraxinus* holdings in place and uncertainty surrounding the collections that did exist, the Program turned its focus to more of an advocacy and awareness role promoting the NCRPIS seed collection initiatives. Allenstein (2009) reports:

> We've been serving as a conduit… having to sort of identify who seemed to be those within the field who were interested…. Just trying to make sure that information got from the government to them, that they were included… when it was formalized that Mark Widrlechner

> was going to serve as the overall coordinator for *Fraxinus*… part of what I would do, would be to try to speak up and lend support… to say… "This is becoming a priority and we need to move on this"…

As Widrlechner (2009) reported, participation from public gardens to these efforts has been fairly limited. Allenstein (2009) adds:

> You can… make the opportunity available, but… that's one of the aspects that I learned. I guess I naively thought that well, if I told them about this seed collecting opportunity and said we're logical players in this, we have the expertise… the manpower, we could even use our own volunteers together with expert leaders, that they'll go out and collect seed... So in retrospect that might have been a little naive to think that that was going to happen just with one or two notices, so I haven't quite figured out necessarily how to motivate for these efforts.

Chapter 5

RESULTS: LESSONS LEARNED AND PREPARING FOR FUTURE BIOLOGICAL INVASIONS

This Chapter presents the lessons learned from EAB and other biological invasions affecting the gardens and arboreta discussed at length in the previous Chapter. These lessons have been extrapolated from the interviews with staff at affected institutions and the additional individuals highlighted through this research. Thirteen overarching themes, some of which contain subthemes, were identified from these interviews and were assigned descriptive titles grouped in three general topic areas. Quotes to support each theme have been selected from all interviews and are presented below.

Institutional Planning

Theme 1: Institutional vulnerability

Need to acknowledge the threat:

> We're damned complacent. And the thing that I take out of it is that anything can go at any point… and that the status quo won't continue, something will interrupt it (Michener, 2009).

> Anytime you have a living organism that you are trying to protect in perpetuity, there are hazards… be they native risks… such as weather… native insects… diseases, but then you add the added threat of outside influences, it just makes it all the worse (Payton, 2009).

> I think one of the lessons is that in this day and age of rapid global economy and trade, that anything at anytime can be a victim (Telewski, 2009).
>
> It's made us aware of our vulnerability (Carmichael, 2009).

<u>Theme 2: Disaster readiness planning</u>

Need for overarching disaster planning:

> I image now it (readiness planning) is probably something we will have to look at, because there are other plants that are at risk out there…with HWA… Asian longhorn beetle… so we are definitely now more aware of the potential for large-scale infestations (O'Dell, 2009).
>
> It wasn't really a direct result of the… EAB outbreak, but as part of a process called the Museum Accreditation Program… I put together… an Emergency Action Plan for the collections... The essence of that plan is that... first of all, you have to identify high-priority taxa… so that they can be represented in more than one location, just in case something happens… I think it was a great opportunity to assess how we deal with, should this kind of emergency situation, like this EAB outbreak, happen to us… we didn't really think about that seriously, but this has prompted us to plan and implement these kind of steps… It is a serious problem and scenario. And it could happen. So we've got to have a plan and a proactive approach to deal with these kinds of problems (Kim, 2009).
>
> Nope, [a emergency readiness plan for collections,] that's not a requirement [for NAPCC] and… there are very few institutions that have that in existence. But in some ways that is kind of an emerging standard… an emergency collections plan is something we'd certainly be promoting… bring into professional development programs through our conference… maybe through the website, just trying to bring some awareness there… Another angle, would be to inform [NAPCC collection] reviewers that this is something that we're wanting to promote and they could include that in their recommendations. (Allenstein, 2009).

Development of action plans that address specific foreseen threats:

> I mean, the first thing is being prepared, having a plan on how to deal with it when it comes and then knowing when it comes… we had a strategy for our monitoring… we also knew what we were going to do in terms of triage, what trees we're going to treat… we knew we had to complete our inventory… and then making sure that we had a commitment for the resources from the administration… then you better be sure… that you've purchased the equipment beforehand, and that you have the personnel trained (Telewski, 2009).

> I think in anticipation… putting that plan together. Obviously… emerald ash borer is something that's on our radar… it's going to probably hit us, we don't know when. It's something we are conscious of, and thinking about how we can respond… so we can basically take the template that we've used elsewhere, kind of this collections prioritization response that we've used for other things and just apply it to *Fraxinus*… (Dosmann, 2009).

Collections and Natural Areas Stewardship

Theme 3: Importance of documentation and mapping

Importance of internal record keeping:

> The best way to be prepared for any collections management is really… to have as accurate as possible a database and map, so that you know what you've got (Telewski, 2009).

> You've got to know what you've got! We didn't have an inventory [of Hemlock Hill], so that spurred that on… "let's inventory these pronto" (Dosmann, 2009).

> [For our natural areas] (1) We need a much better, more complete species list and (2) an overall assessment of health… so what we'll have up this summer, at least for a lot of our areas, is just that spread sheet for the moment… of what's present in any of our twenty-some management zones… But, we also need it way more accurate in certain

areas. And this gets back to what I mentioned… about prioritizing the areas, so rather than doing this across the board… what are the really important areas to map well, and what are other areas where just knowing presence or absence is all we have until someone does a research project (Michener, 2009).

Need for multi-institutional externally accessible databases:

That isolation, I think is a real stumbling block, and any efforts that we can make to help overcome that, so that we're working more in tandem with our efforts [is key] (Allenstein, 2009).

And as we're looking for a unified way to go forward, we have to have the information available and it needs to be web-accessible. Somebody has to be able to pull it up real fast (Michener, 2009).

It's called the PlantCollections™ database as a means to investigate all these accessions held by many botanical gardens and… to understand the scientific quality of those accessions, and then plan [future acquisitions] accordingly. So this is a very timely thing to do (Kim, 2009).

The other thing that ties into that is having a good database and there are a lot of initiatives now… PlantCollections™ database, that's one… just so people know what other people have. Is it a value to collect?.. Zoos work very much like that. They have these extensive databases because of breeding lines, they want to make sure they're not getting too close of a line… so it's pretty sophisticated. So I think we're probably not there yet (Bachtell, 2009).

Furthering the documentation of your collections:

And something else that's not commonly thought of, but gardens such as ourselves, especially when you're part of NAPCC… they encourage vouchering… and how genetics are progressing… you can extract DNA from an herbarium voucher, so in the future perhaps, through vouchering of your collections you could be a source for some sort of genetic reintroduction of a plant (Payton, 2009).

> Even if there doesn't appear to be an immediate need for any particular area of the data, it's amazing… how data like that can be looked at later on. For instance, with the climate change research, who would have thought that we'd be looking at historic photographs to see when the bloom time has changed (Allenstein, 2009).

> In our protocol, we do ask that they do voucher materials… to be honest about it, I haven't seen a lot of vouchers from the people that have made collections outside of our system… We're supposed to be vouchering… I'll give you an example of some place where I've really learned something. I was down in southern Illinois in habitats of pumpkin ash… all the experts that looked at these vouchers told me, no way these are green ash. And then when we looked at the seeds that we actually collected from those trees later, sure enough they were green ash… So I'm really glad that we vouchered that material. And I'll continue to do that (Widrlechner, 2009).

<u>Theme 4: Prioritizing collections</u>

Prioritizing at the collection level:

> Really critically thinking, for us, about which plants, whether groups or areas, are important… we have to identify what I'll call an elite group within it, that really has the focus of our attention for long-term stewardship. And we can only move another group into it as we endow the first one (Michener, 2009).

> So we're starting with the peonies. And we're very much aware that we could get blasted at any point and lose one of the country's most critically important, and not well-known historic cultivar collections. And that would be a major loss of cultural capital for us… now it's part of our cultural heritage, it's what's called a legacy collection and we're very protective of them as an institution… (Michener, 2009).

> I think you really have to go through carefully and assess the content of your collections… Every institution has its own priority collections, primary, secondary, and tertiary… and then you have to have a plan how you can manage those. I am involved with that in some of the core collections, for example… oak, maple, elms, and lindens, those are the primary or high-priority collections (Kim, 2009).

Prioritizing individual accessions within collections:

We were spending a tremendous amount of resources on maintaining either redundant material… stuff that was replicated ten other times, clones… or material… that was unknown from a nursery… it was like wow! Why should we be spending our resources on that?.. And so if you don't have any concept of what you have in your collection, your entire collection, and the relative priority of those, then you're not very efficient at doling out the resources that you have… So, you've got to prioritize, and at times thin the flock, so to speak, of low priority, low collections value material (Dosmann, 2009).

Within the collections, I'm a triage person, I always have been. You know, critically important, draws, or stuff you'll live with, and things you have to push one way or another. And so that's where we're coming up with this mindset of what's the very small percentage that are cultural, intellectual capital, which we will defend against all comers… whatever it is (Michener, 2009).

So we've got this disease that we don't really understand… We want to minimize our chemical usage… so we're looking at the plants in our collection that are most susceptible to this new pathogen, and it looks like *Rhododendrons…* And we're identifying within the *Rhododendron* collection the rare and endangered species that we want to target now for extra use of chemicals. We don't want to use chemicals, but where do we need to use them most focally in order to preserve the rarest and most crucial germplasm (Carmichael, 2009).

Importance of providing adequate resources:

We're in the process of very much doing that. And also, on paper, articulating… how they fit the mission long term, such that they are ranked as being so important, and then we're keeping that number fairly restricted, because part of it has been endowing the care of the collection. And that we figure is one of the ways that we will really identify and prioritize what's important (Michener, 2009).

Are you willing to let any of the trees go? If not, then you have to work out your budget… make sure you have the money available, the resources available to do the treatments, the labor… and the equipment, and make sure it is ready, on site, and ready to go planning-wise. Otherwise, you can have all the plans in the world, but if you don't have the personnel and the money to buy the chemical, it's not going to do any good… I'd love to save every tree in the natural areas; it's not feasible financially or resource-wise (Telewski, 2009).

I think one thing that this has shown is that we don't have infinite resources, and for a variety of reasons, whether it's for disaster planning or responding to disasters, or it's just everyday collections management decision making, you've got to be able to prioritize and make decisions based on sound information. And so I think that that's been extremely important (Dosmann, 2009).

Prioritizing with the use of objective criteria:

We just had hosted… the BGCI… red-listing group. It's called the global tree specialist group… the three-day workshop was to actually redlist a certain group of plants… There are three categories, critically endangered, endangered, and vulnerable. And based on the information we obtained from field surveys, we will assign one of those categories, and that… in itself is very important for any conservation organization, because they will use that as a guide in the collections. So we have… *Ulmus gaussenii* that is critically endangered. And it is the highest priority in terms of conservation. We have over 80 different taxa in the Arboretum collections that are variously categorized as endangered or threatened (Kim, 2009).

That's part of the whole thing we're figuring out, both with ourselves locally, and with NAPCC, is to come up with a strategy of ranking them for rarity or significance, with the registrar of both the American and Canadian peony societies, I mean if something's common in the trade, even if it's historical and classic… it's basically protected from that point. But… we have 46 different introducers represented in our peony cultivar collection, a lot of them look like each other, so how do we assess the importance and the significance, and that's something we have to figure out, the logic of that one. (Michener, 2009).

Theme 5: Backing-up of collections

General importance:

> As far as with the collections, to safeguard them, to back them up, and to think about how they are backed-up, how are they most vulnerable? And do you have them at a different location on your site, do you have them at a different location in the country?.. can you back them up through seed, either a seedbank that you hold or that you work with others who do have that capacity. I think that's important (Allenstein, 2009).

Value of on-site duplication:

> I think it is a requirement for any institution, I mean depending on the size of it… But, for us, it is… mandatory that we have representative locations… so that's part of my job on an ongoing basis… *Fraxinus americana* in taxonomy collection is also represented in… the midwest and northern Illinois collections… that way if we lose it in the taxonomy collections, we still have it in the geographic collections (Kim, 2009).

> We're still maintaining several hundred different kinds of lilacs… four hundred individuals, but many of those are duplicated twice (Dosmann, 2009).

> And we still have to figure out what I'll call "the algorithm" or ranking mechanism, because of the over 2,000 cultivars in the time period of interest, we can only hold 300 some in our site because the design duplicates itself (Michener, 2009).

Need for duplication at alternative locations:

> We have 260-some [cultivars] 700-some plants [in the peony collection]. Well obviously, it's a sitting duck for the next epidemic… Duplicating them there to here is not going to work. So we're working with NAPCC, we've already had the site review, and part of it is how to have an epidemic resistant strategy of how do you have a

dispersed… documented collection that won't just disappear in the next epidemic (Michener, 2009)?

In North America, for example, we have the NAPCC program, it is not only important to maintain [specimens] here at the Arboretum, but also share… them… just in case something happens here. The fact that we do have duplications elsewhere, I think that is very important (Kim, 2009).

I would say that one of the main things is back-up collections at other sites. We're big advocates of that now. That used to not be something that we're that into. In fact it used to be we'd take pride if we had something and nobody else had it. But the way we feel now is it's not something we'd be proud of if you had it and nobody else does, then you've got some work to do (Griffith, 2009).

Seed and other forms of repository storage:

It's something that all botanic gardens and arboreta could do a better job at across the board. It's a challenge when you're working with long-lived woody perennials… they take up a lot of space… one of the things that I think is most challenging and we need to figure out… [is] to really deal with this issue of back-ups, as seed… And botanic gardens and arboreta don't do a very good job at maintaining seed, at all. And so that's a big missing link, and I think that that's something we collectively need to get our heads around… we might not be able to maintain the seeds [ourselves], but what other partners are out there (Dosmann, 2009)?

I imagine that important collections at botanical gardens could be backed-up in Fort Collins as dormant buds. That hasn't happened yet, but I think that that could happen over the next couple of years. And I wish that we had had something like that in place for Matthaei and the University of Michigan, because it sounds like they lost a very important collection of ash hybrids (Widrlechner, 2009).

Part of what we're seeing that could be emerging is that private collectors could be backing-up public collections. And in fact the Matthaei peony collection, they are looking at a network of back-up collection holders, between public and private entities to be able to do just that (Allenstein, 2009).

Theme 6: Value of consortium involvement

Partnership for germplasm sharing and backup:

[The benefits are] 1) you'll actually have the stuff alive somewhere else. 2) It'll give the time to figure out is there another host institution. Because in our case, we can't bring these plants back, the pathogens are still out there. So… we're not a good site for elms, ashes, or larches. And so somebody else is going to have to take it on. And if there were a consortium, at least we'd be able to know that they were somewhere protected… (Michener, 2009).

Oaks, you know, you think "well, back-up." They take up a lot of space, and so that's why NAPCC was born, and that's why they're primarily our woody collections… the multi-site program within NAPCC is good because it presents a greater chance that you can share/distribute… duplicative material (Dosmann, 2009).

The main one is just that genetic back-up… We've gotten collections back as a result of having them backed-up elsewhere, so we really believe in that here… I'll tell you we split some collecting work with some folks from Hawaii, a few years back, and we lost the plants here because of the *Zamia* borer, and then we were able to get some of those accessions back in. So it's certainly useful (Griffith, 2009).

Building more extensive collections:

And another reason I say it's important is because the *ex situ* conservation, representing the genetic diversity is very challenging [at one institution], just because you have a certain species collected in the wild, it doesn't mean that you have fulfilled the *ex situ* conservation [mission]… I think that is the value of the collaboration, with organizations like NACPEC and the NAPCC, [you can spread out the germplasm between institutions]… you cannot act alone, you have to really work with other groups to effectively achieve your goal in planning, acquiring, managing, conserving the germplasm. It is almost mandatory now (Kim, 2009).

Particularly with the multi-institution collections, one of the goals is to preserve germplasm, to share germplasm… we're only part of one NAPCC collection now, we're part of the multi-institution oak collection, and our strength is in Mexican and Central American oaks, that's what we bring to the table for that consortium (Carmichael, 2009).

Mechanism for information sharing:

Information sharing, would be a benefit of course, if you are experiencing a problem, that may go beyond your immediate area, you can learn of that information through the interactions… I think that would be a real benefit (O'Dell, 2009).

The other is, just to have a good network of people that you can talk to who might know someone who can help you out when you're faced with a problem (Griffith, 2009).

NAPCC can potentially play an important role in linking institutions and sharing information and bringing a focus on core collections. So there's a lot of potential there. I don't think we've realized it yet, but I think we've got gardens talking… and collaborating… and instances like emerald ash borer, where finding ways to preserve the germplasm become really crucial (Carmichael, 2009).

Theme 7: Monitoring of collections and natural areas

General need for increased monitoring:

One thing we have learned is to not take things for granted, and to pay more attention to the natural areas. The country as a whole has seen more large devastation of plant populations, in a shorter time span… and I think one of the lessons with EAB is to pay more attention to what is going on in the natural areas, and not just take for granted, "well this is just typical insect damage." [We need to] do a more hands-on monitoring and just try to be more aware of what is going on out there (O'Dell, 2009).

It's just monitoring, being aware of it… keeping up on the literature. Knowing what things have been introduced into the country, what things are in your area, how close they are. And then if you can get pheromone traps or sticky traps, or trap trees, or whatever the technology… exists to be able to monitor the population to find out if it's actually in your arboretum, or in your collection (Telewski, 2009).

Maybe don't end up with such a narrow focus with what's happening in… your own collection. While that's very important… to look for what's unusual in your own collection, because you might be the first detector of something. But also, make sure that your feelers are out for knowing what's happening so… you can pick up on something before it's going to be on the national news. That's very valuable too (Allenstein, 2009).

Importance of knowing proper contacts:

We pay closer attention to what's going on, and if we know that this pest is out there, then we're looking for the pest, but we're also just looking for different problems and I'll give you another example of a pest. We have this thing and it's… unidentified, but it causes a little black smudge on some of our palms here. And as soon as we saw that, we knew who to contact and she's been out here and they're working on trying to identify it. So it's again, just knowing the people to contact on these things (Griffith, 2009).

It's made us aware of the need for vigilant monitoring and good communication with the state and county agencies involved… we started dialoguing with the county ag people who would ultimately be monitoring it (brown apple moth) and when it finally hit here, I think we were all decently on the same page for response (Carmichael, 2009).

I think that the more connected that public gardens can be with APHIS on communicating new hazards that are coming in, new invasions, the better… they are the point people on this and the more that they can do to communicate with botanical gardens, the better (Widrlechner, 2009).

Theme 8: Collections and natural areas management

Reducing the risk to collections:

> We are very conscious about how we maintain/develop the collections and manage in a way that it minimizes that kind of susceptibility… We have a *Malus* collection as part of Rosaceae, they are all located in the same place, in close proximity… This is an on going problem… one of the diseases that we experience every year is called fireblight… And we try to proactively manage it by… removing any specimens that are heavily infested, but if it's a minor [infestation]… we try to prune out infected branches and then discard them in a proper manner… (Kim, 2009).
>
> So one of our NAPCC collections, *Syringa*, and we've got… phytoplasmas throughout… we keep the plants as healthy as possible, we try to remove those plants that are the most affected… The other thing that's changed is that we're doing our best to maintain them (*Syringa* collection) in a better situation. You know, they are all growing on slope and they're going to get subjected to drought and things like that, so they're all challenged. In order to keep them happy, we went ahead and installed irrigation systems in there, we started mulching to a better extent, we're just trying to keep those plants healthier and happier so that they're able to ward off the phytoplasma on their own… there's no treatment for it… it's a virus-like organism. So we figured… keeping those plants as healthy as possible is going to be our best defense (Dosmann, 2009).
>
> So we've got this disease that we don't really understand… so we're looking at the plants in our collection that are most susceptible to this new pathogen, and it looks like *Rhododendrons…* we're looking at what we can do culturally in terms of reduction of water use and keeping things drier in order to… create conditions that are not favorable to disease production (Carmichael, 2009).

Greater stewardship of natural areas:

> In terms of the natural areas, we can probably learn something similar that if we see a natural area that is going in the direction of decreasing diversity, and increasing in one particular species, that we may expect

that at some point that we may have a dramatic change, or its more likely that the balance could get thrown off more dramatically. Even if it is a native species that we are seeing in abundance, all it takes is one pest, to build up a big population, and it can really knock things loose in a bad way… consider being watchful of even native populations that become extremely dominate in one species… (Plakke, 2009).

We took out 8 acres of oak [due to *Armillaria mellea* root disease]… It was a cultural issue that caused that. The whole issue that none-management causes, you know, sets us up for this… we had… 2'-3' diameter trees on 6' centers (Mason, 2009).

One of the things I was thinking about was… looking at our natural resources, perhaps, and taking some of that for granted… from a natural resources point of view, or even from just a biodiversity point of view, looking at making sure that we are shoring up our germplasm of what's here at home… first… And so maybe that's something that botanic gardens should be taking a look at… what is our role in conserving natural populations, indigenous natural populations? Where do we fit in? And even those that aren't identified as endangered at this point (Allenstein, 2009).

Theme 9: Collections development

Need for diversity:

And so… what we're trying to do is really up the diversity, get away from monocultures, get away from clusters of collections, other than where they're historically needed… but we know we're not going to put single-genus stands back. It's just too vulnerable. So what do we do that keeps the sense of design..? That's something that we're really looking at and this whole epidemic problem is driving it… But we're not going to do it based on generic collections, and what I will call the "gallery of genera"… it's got to be much more sustainably presented and in terms of ecological diversity (Michener, 2009).

You've got these legacy [taxonomic] collections and… it's hard, like an ocean liner, trying to change the direction… in some ways it's just kind of archaic… just by their nature, you're grouping plants that are very closely related… you're just setting yourself up for something that's much more difficult. So, by that, in the new age of either geographic-based collections… or you have thematic collections… it's probably more valid than taxonomic collections… I think we'd probably take a broader approach, when we look at collections now. [For example] we have an oak collection… but if that collection were dispersed throughout the grounds, you might be less vulnerable to a significant gypsy moth outbreak (Bachtell, 2009).

There seems to be a pest, of some sort that's appropriate for almost every particular genus… monocultures of course are totally not desirable for that reason, so from a forestry standpoint… diversify our plantings, but we are not learning that, very quickly, because you still see, the problem with ash seems to be a new problem that we had before with elm (Larson, 2009).

Representing the genetic variation within a taxon:

I don't think it's directly resulting from… EAB, but one thing that we're doing now, that is different than what was done before, is we're trying to collect multiple genetic populations… we want to introduce different genetics. I mean in years past, we got plants that were from "Bob's Nursery" and who knows where it was gathered from? I don't think it has any influence when it comes to something that is as devastating as emerald ash borer, but with other diseases and with other insects, I think there is a big advantage (Ecker, 2009).

We are really striving to get local genotypes… if you can stick with the existing genetic material its more true to this area and your less likely to introduce some outside pest… and more adapted to the site… what is local, what is native is becoming more of an issue, a concern for us and it does influence our discussions and the way we look at our collections now, especially with our… restoration work (O'Dell, 2009).

I think that there are many other ways that we can learn from these kind of instances. Like, in planning the development of new collections and particularly for conservation, how we do go out… implementing/ enhancing the botanic garden institutions' ability to do a better job of fulfilling the *ex situ* conservation [role]… [We need to] look at it very carefully, the quality and the content of collections and then plan more strategically, how you can enhance the quality of the collections. In other words, just because you have an ash collection, collected in the wild, that doesn't mean that it is going to serve the *ex situ* conservation [role] as effectively as it should…. particular species may have a large population in the world, then we have to collect more to represent that diversity. So that is kind of a more strategic planning in the future and working with others, either sister institutions, or other organizations like NACPEC… you have to look at what they have collected so far. Which of them are surviving now?.. Or which of the species… have never been collected?.. You have to understand that, and based on that, you have to develop a future plan… (Kim, 2009).

Need for collaboration:

This is a plan of what is happening now with the new display gardens, which are very focused on Michigan natives… one of the staff is building a state-wide collaborative with volunteers with different plant societies… I'm trying to work with some of the tribal groups, in terms of with seeds from their properties, engage with them, working with us or interacting with us. I've been around the state last year trying to build some of the rapport with some of the local land conservancies… (Michener, 2009).

NACPEC has been an extremely important mechanism for us to obtain a lot of these species. When you combine the expertise together and plan together and conduct a plant exploration together, there is a lot of advantage in that. And we also [have] been collaborating with the Chinese institutions. That is even more important. So, really, in a way, we are complying with the spirit of the CBD, Convention on Biological Diversity, that requires us to work with the native countries, in this case China… ensuring the profit and the knowledge, training the professionals from that country in the management of the germplasm… And I think NACPEC is playing a very important role in that regards (Kim, 2009).

Collaborative Efforts by the Public Garden Community and Beyond

Theme 10: Power of collaborative efforts

General importance:

> But even within an institution, when you get an institution of this size, it has to be collaboration. Unfortunately some institutions you can actually have two people right next to each other and they don't even know what each other is doing. So, I think that the first thing that's really important is within your own organization… that you're collaborating/coordinating with your people (Telewski, 2009).

> I mean within the limits of time, money, and space… we are quite willing and it's really great when we can get a natural fit like the providing of plant material to researchers studying disease (Carmichael, 2009).

> I think that finding the time to just stay connected is key. I mean it's really easy for us to sort of go off and do our own things, but the time that I have been able to invest in staying in touch with the collaborators that have been involved in this project has paid off (Widrlechner, 2009).

Benefits of collaboration:

> I think it adds to our mission, in the sense that… we're not doing the research, but we're providing the materials and the area that allows them to do the research (Ecker, 2009). Right, I mean our deed of trust and our primary mission isn't a research mission. But to assist researchers… I think it's providing that aspect. It's given us some exposure in the scientific world with work that's done… quotations and references to us… (Payton, 2009). A little credibility (Ecker, 2009). Yeah credibility, it's also added to the wild collected plants we're getting, having the opportunity to get good choice material like the NACPEC seed, because we're doing this sort of work, it lends some credibility to those acquisitions (Payton, 2009).

Oh they've been extremely helpful, I'd say particularly with the USDA… tremendous intellectual capital, and knowledge, expertise, that we can't really have on-site, because of our focus and resource limitations, but… they have expert entomologists and bio-control researchers. So the fact that they wanted to do that research here with us was extremely helpful. And even if it knocked the pests down 10%, that's wonderful (Griffith, 2009).

You know we're a scientific institution, so we're always willing to collaborate with the different agencies when they want to do this. As they do their study, we stay in good communication with them about, "OK, are you finding it? What would be the implications for our collections? What should we do" (Carmichael, 2009)?

Be proactive:

Start early and recognize that each part has their own corporate culture and their own objectives and goals. And I think that the earlier one can start on efforts like this, the better… That's probably the… number one lesson (Widrlechner, 2009).

If you don't have collaborations already established, or if you don't have a process or protocol about how you're going to get there, one of the things that strikes me about what's happened with EAB is it's the classic, "it's a little too late." And… getting the collaborations take time to build. They can be intrinsically complex. And, some of it is relationship building, which isn't something that you can really shortcut… So I think that's one of the real challenges… that can be pointed out, is the need to attempt to be proactive in the first place, understand the mechanisms of collaboration (Allenstein, 2009).

You should at least try to make a connection… with your state plant health director from the USDA-APHIS, to just say… "Here's what we bring to the table, we have 28,000 members, or… we have an ash collection, or oak collection that's second to none."… even if you don't want to get involved in advocacy… This is not going to stop. Emerald ash borer is not the last bug we're going to get (Makra, 2009).

Theme 11: Information sharing

Among public gardens:

> Botanical gardens are very aware of their collections and the more that they have… an awareness of potential new insect and disease threats, the better. Because there are a lot of eyes out there, and if they are thinking that way, that's a really good thing… Frank Telewski coordinates that collections listserv, and I think mechanisms like that could be used to share information among gardens as they see potential problems (Widrlechner, 2009).

> Just being able to talk with other institutions who've dealt with [EAB] like Dave [Michener]… with Deb McCullough and researchers here on campus we've been able to actually apply their research to conserving our own collections (Telewski, 2009).

Receiving information:

> Well, with me it's all been about the regulations, which is something that I think most land managers are very unfamiliar with. You know, what happens? Are they going to cut down our trees..?... what are our regulations? What are we required to do? What does the quarantine mean?.. that's really been crucial and so I think that's probably true for other public gardens, is to really understand, it's kind of incumbent upon them… so they should probably know that (Makra, 2009).

> You know as that [treatment information] continually changes we continually update our policy for treatment (Telewski, 2009).

> Keep themselves educated to stay on top of opportunities to learn… the latest about some of the changing conditions and emerging pests and pathogens as well as other technologies that are available to them, so that they can do… their jobs more efficiently (Allenstein, 2009).

Disseminating information:

> We have a huge responsibility. Not only conducting research, but also disseminating information through the proper channels… (Kim, 2009).

> I would say… it's good to get the word out as soon as something like this happens, and also to get the word out to partners, particularly like those at the USDA. Because they may have some research opportunities that can help you out (Griffith, 2009).

> The other one (lesson learned) that I still need to work on is getting a better web presence, and I'm actually working on that right now… I have a lot of different projects that I need to work on, but I'm definitely devoting more time to trying to get a web presence up (Widrlechner, 2009).

Lacking information:

> I would say if we knew just more about this bug and more about what kinds of predators retard it… just basic research. And the basic research for this pest is probably not as robust as it could be, but then again it's not economically important and it's really not native to the United States, so I think maybe it's one reason why [research is lacking] (Griffith, 2009).

> I'd probably say I think the most crucial information that was needed was the regulatory type information. That was very confusing in the beginning, the quarantines… I got many, many calls about that… where can I move my wood, can I cut down my tree, can I burn it? You know those regulatory type questions were really hard to answer in the beginning (Gentry, 2010).

> There's very limited information about the resistance of Asian ash species (Kim, 2009).

Theme 12: Importance of advocacy and education

Importance of promoting diversity to the public:

> I'm pushing diversity so that everybody doesn't use *Viburnum dentatum*, why are we always using *Viburnums*? Let's just diversify… if we do want to have *Viburnums*, let's start pushing the diversity… Otherwise, we'd all end up with the same palette (Michener, 2009).

I think that… our biggest tool we can use is diversity… so arboreta need to constantly be working on new species, hybrids… and that's where its going to come from, I mean a lot of universities aren't going to work too much in there, that's dropped off… we are no different than the people in the pharmaceutical industry trying to come up with a vaccine to combat a new strain of flu, we've got to stay ahead of the curve, and we're not… and it takes much, much longer with trees than it does with developing… a new corn variety, because the nature of the plant, how long it takes to get some results, so I think that's going to be key… (Miller, 2009).

You know, so that's still our mantra… diversity. And trying to change people's ideas about what that is can be difficult especially on street trees, because they have a certain way that they think is aesthetically pleasing (Gentry, 2010).

Advocacy and education through collaboration:

What we're doing instead… for all mission critical groups, or projects… is we're finding a collaborator who does it. And the collaborator is then encouraged to use our facilities and for us to learn from them. So this is Mary Grove College, with two of the midwest's best teacher educators, this is their third weeklong workshop. It's regionally recognized as one of the best programs. We don't have the staff to do this, so this is not officially being done by us, but as far as outreach, look at all the teachers we're able to reach, they'll bring their classes back here. They're from all over this part of Michigan and Ontario. They are using our facility, they are getting what we want… primary education. And reaching the teachers that way (Michener, 2009).

If there's an advocacy interest or function… I think you can accomplish a lot with that… If you're not, I still think, thinking beyond, "here's what trees you can plant that would be great substitutes for that." I think you could still get involved in facilitating and leading… even if you just host a seminar or a conference… at least as a public garden, put yourself out there and say, "What can we do to help?"… and if that is "we have 28,000 members we can get information out to them", but to try to get to the table and say "here's what we bring" (Makra, 2009).

Institutional benefits of communication with the public:

> Actually… the awareness, all the education, all the people we brought in, all of the walks… it increased our visibility quite a bit… that's the positive portion of it… a lot of people that live in our community, they have no idea what we are, or have never been here. And because we were so much out there with education, I think it helped… put a public face on us… we have some viability… there's something going on there. We were needed to a certain point, education-wise, and people knew where to come. That's a good thing (Gentry, 2010).

<u>Theme 13: Regulation and inspection advocacy</u>

Need for greater entry inspection and regulation:

> So what have we learned? Wood palettes, they have to be heat treated or chemically treated, certified as that… all the wood that comes in, so finally maybe with EAB and Asian longhorn beetle, now maybe… but you can imagine these box cars of these crates… So that's the lesson learned. You have to be extra-extra careful (Bachtell, 2009).

> It's one of the sad lessons learned from many of these things is that, I think if we had had the resources to deal with this problem to begin with and the discipline… we might have… caught the problem. But by the time we knew what we were up against… [it was too late] (Telewski, 2009).

> I wish they pumped all the money they've pumped into post-quarantine as opposed to pre-quarantine. We could have had bigger eyes out there saying this stuff can't be un-inspected. As opposed to, well when it gets here we'll take care of it. It never works (Ecker, 2009).

Public gardens' role:

> If you're going to… be doing active collections development work, and you're aware of a pest, then talk to your USDA people, or whoever it is and say "hey, this is what we're doing, what do you suggest?" In terms of coming back, and what they helped us out with, was they said if

you're working in areas of red palm mite, take all of your field clothes, before you come back, and put them in a garbage sack and put that immediately into the washing machine when you get back… just getting protocols like that from people. And the other thing is just following all of the regulations on phytosanitary import (Griffith, 2009).

I think the major lesson is… in the way of protecting our shores. That's not something we're involved in, but… we could perhaps be an advocate for increased inspection (Payton, 2009). And I don't know if it's taken place at this point, but maybe joining, with other like-minded organizations, the forestry associations, the agriculture associations, and forming that lobbyist group… to help tighten border securities… obviously… the voice isn't out there at this point in time, in mass enough, to make that change come about (Mason, 2009).

I think another lesson that we could learn that is valuable… is responding to this trend that we're seeing… more and more pests… because of the ease of traffic of all sorts of commerce, because we know that some of these pathogens… are coming through, not directly from plant imports, but palette material or something… that we may need to be a part of the detection process. That we have… a need to more formalize our role as a… public garden field in helping detect and recognize the next new pest, or whatever's not looking quite right and be real clear on a process of what to do with that information… try to figure out how we can assist them in that process… otherwise… with the change in importation regulations, and some of the changes that are coming forward… we may end up not having had our views or perspectives be recognized, and the borders being closed, so some of the traditional roles that botanical gardens have been playing will be that much more difficult to continue. And to have more informed laws… we need to be at the table, and when asked, we need to be responding… rather than waiting until after the fact (Allenstein, 2009).

Impact on germplasm acquisition efforts:

I mean there ought to be a mechanism available for getting around this problem of importation that we have… you know this research we are doing for EAB is very important… and they're discarding material… and we got emerald ash borer like an elephant coming through…

they’re following they’re protocol, and they’re going to follow it to the letter of the law. But there should be some provision for allowing this material to come through for research, post quarantine (Larson, 2009).

I don’t think you need to advocate for greater need, I think you can actually ask for some reasonableness, because we had a heck of a time… We lost a third of our ash seed to the inspectors in 2008. And the challenge is some of it… the samara, that sits out there all year long, you get these saprophytic fungi that get on it and… if they can’t identify the fungi, that means they don’t have any treatment protocol, so it’s gone… so, it just makes it very, very difficult (Bachtell, 2009).

Chapter 6

RESULTS: PRELIMINARY USER GROUP SURVEY AND SURVEY OF *FRAXINUS* COLLECTIONS

The results from two online surveys that evaluated the current state of global *Fraxinus* holdings are presented in this Chapter. The first survey, referred to as the "User Group Survey," identified specific information about individual plant specimens that is needed by various professionals, in order for the specimen to be of value to their objectives. Identified information from this survey was then collected from institutions reporting *Fraxinus* holdings, in the second survey, the "Survey of *Fraxinus* Collections."

User Group Survey

For 30 days over the months of April and May of 2009, 32 responses were recorded from 60 email invitations, representing a 53.3% response rate. Respondents were engaged in a variety of objectives in their current positions, with "conservation," "breeding/selection," and "collections" most often noted (Table 6.1).

Table 6.1 Primary objectives involving plants as reported by respondents regarding their current professional positions.

Primary Objectives	Number of Responses	Percentage
Research	26	81.3%
Conservation	14	43.8%
Breeding/Selection	13	40.6%
Collections	13	40.6%
Production	8	25.0%
Entomology	6	18.8%
Other	6	18.8%
Pathology	2	6.3%
Forest Products	1	3.1%

"Other" responses:

- Teaching (2 responses)
- Evaluation, characterization, molecular markers
- Germplasm collection
- Informal education, historical landscape studies, cultivar preservation, wild-species demonstration, habitat restoration
- Champion trees

Listed in Table 6.2 are plant materials that are utilized by survey respondents, with "cultivated living plants" most commonly identified.

Table 6.2 Types of plant material(s) that is(are) of value to the professional objectives of respondents.

Response Categories	Response	Percentage
Cultivated Living Plants	28	87.5%
Seed	23	71.9%
Clonal Material	23	71.9%
Herbarium Specimens	17	53.1%
Other	13	40.6%

"Other" responses:

- Wild collected material/germplasm (5 responses)
- Digital herbarium/library (2 responses)
- Wild plants
- Mature trees
- Native & exotic plants; plant materials - e.g. fiber, gums, etc.
- Samples for DNA extraction and anatomical/palynological study
- Silica gel collected material
- Preserved material for molecular analyses

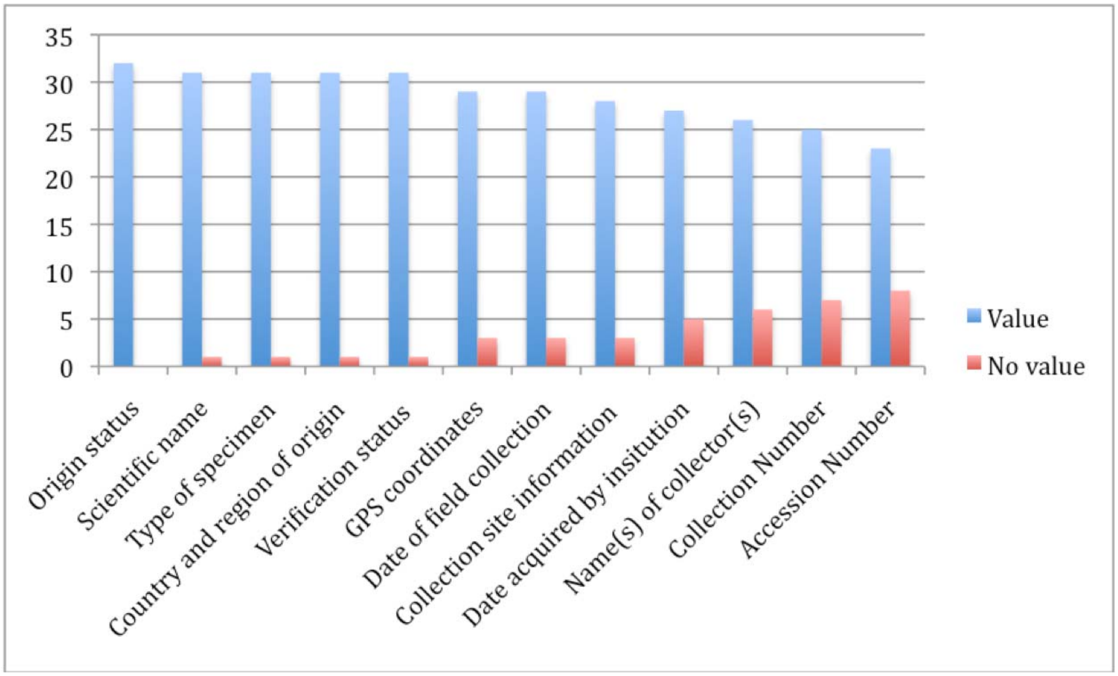
Table 6.3 represents respondents' rankings of 12 specific plant specimen information fields for a specimen to be of value to their professional objectives; "scientific name" and "type of specimen" were most commonly noted as being "necessary."

Table 6.3 Plant specimen information that respondents ranked based on level of necessity for a specimen to be of value to their professional objectives.

Response Categories	Necessary for specimen to be of value	Not necessary, but increases value of specimen	Not at all necessary	Number of respondents (n)
Scientific name of specimen	28	3	1	32
Type of specimen (cultivated living plant, seed, or herbarium specimen)	28	3	1	32
Country and region of origin if wild collected	22	9	1	32
Origin status (wild collected vs. cultivated source)	21	11	0	32
Verification status (whether the specimen has been determined to be identified correctly)	15	16	1	32
Date of field collection	12	17	3	32
Accession Number (assigned by institution holding specimen)	9	14	8	31
GPS coordinates if wild collected	8	21	3	32
Collection Number (assigned by collectors)	7	18	7	32
Date acquired by institution holding specimen	7	20	5	32
Name(s) of collector(s)	6	20	6	32
Specific information about the collection site if wild collected (e.g. soil type)	5	23	3	31

To gain a clearer comparison of the value of different information fields, data from "necessary for specimen to be of value" and "not necessary, but increases value of specimen" in Table 6.3, were combined in Figure 6.1 and reported as "value." This combined response was compared to "not at all necessary" from Table 6.3, which is reported as "no value" in Figure 6.1. Response category, "specific information about the collection site" in Table 6.3 is reported as "collection site information" in Figure 6.1.

Figure 6.1 Plant specimen information that respondents ranked based on level of necessity for a specimen to be of value to their professional objectives.



As in Figure 6.1, information fields of reported lesser "value" included "collection number" and "accession number." However, these categories still received a majority of respondents indicating that these information fields have value in their professional objectives (25 (78.1%) and 23 (71.9%), respectively). Origin status (32 (100%)), scientific name (31 (96.9%)), type of specimen (31 (96.9%)), country and region of origin (31 (96.9%)), and verification status (31 (96.9%)) were all reported overwhelmingly as has having value to respondents' professional objectives. Furthermore, specific information was collected regarding the information field “collection site information.” Respondents were asked what site information, in particular, is of value. These results, as well as additional information fields that respondents reported as having value to their objectives, are found in Appendix I.

Given these results, all information fields identified in Table 6.3 were asked to be submitted by institutions in the succeeding “Survey of *Fraxinus* Collections,” with the exception of “collection site information.” This information field received the least responses, reporting it to be “necessary for a specimen to be of value” to respondents’ work (Table 6.3). Additionally, the volume and range of information that this data field could represent, was another reason it was not collected.

Finally, this survey sought to capture respondents’ opinion on the value of a global *ex situ* collections inventory of a particular plant group, with which the respondent is currently working. Table 6.4 shows responses on a scale of “value” regarding three identified types of collection holdings.

Table 6.4 Value of a global *ex situ* plant collections inventory for completion of respondents' professional objectives regarding a plant group with which they are currently working.

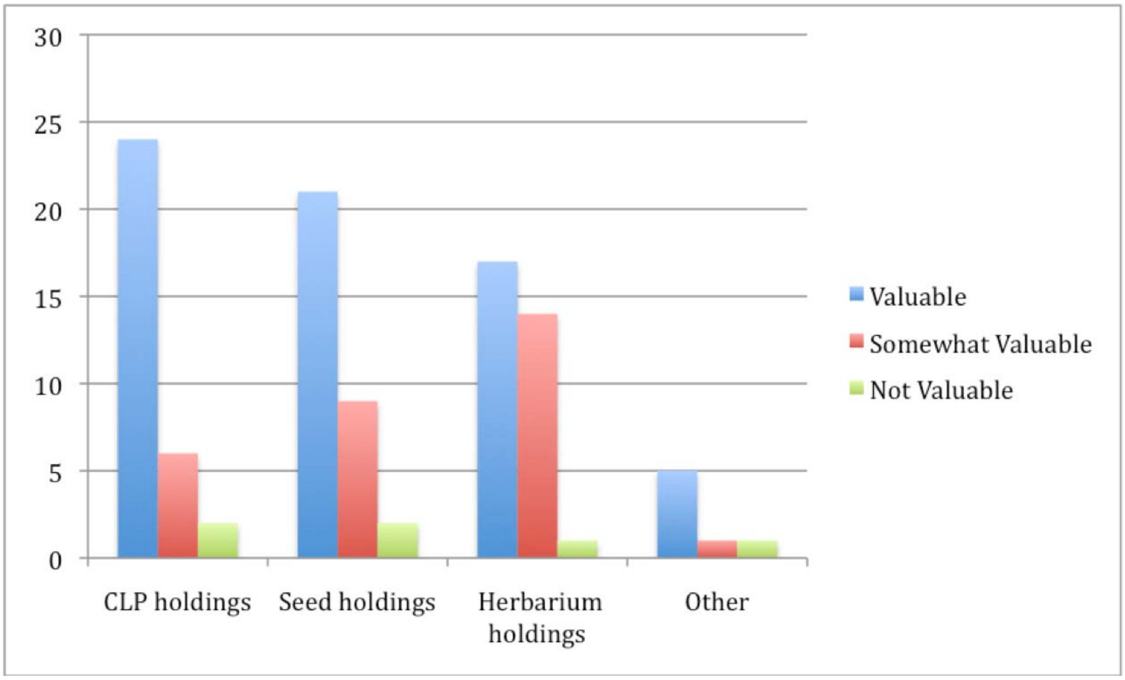
Response Categories	Extremely Valuable	Very Valuable	Somewhat Valuable	Slightly Valuable	Not at all Valuable
Cultivated Living plant holdings	12	12	6	0	2
Seed holdings	11	10	6	3	2
Herbarium holdings	3	14	10	4	1
Other	4	1	0	1	1

"Other" responses:

- Wild locations/accessibility of species (2)
- Wild germplasm holdings (2)
- Authenticated digital photos
- DNA samples

For clearer comparison, data from Table 6.4 has been consolidated and presented in Figure 6.2 as follows: data representing "extremely valuable" and "very valuable" have been combined and reported as "valuable;" data representing "somewhat valuable" and "slightly valuable" have been combined and reported as "somewhat valuable;" and data for "not at all valuable" is reported as "not valuable."

Figure 6.2 Value of a global *ex situ* plant collections inventory for completion of respondents' professional objectives regarding a plant group with which they are currently working (CLP= cultivated living plants).



For all three holding types, respondents reported overwhelming value in a global *ex situ* plant collections inventory (Figure 6.2). Cultivated living plants (CLP) received 24 (75%), seed holdings 21 (65.6%), and herbarium holdings 17 (53.1%) respondents indicating that an inventory would be "valuable" to their professional objectives. Only 2 (6.3%) respondents for CLP and seed holdings, and 1 (3.1%) for herbarium holdings indicated that such inventories would have no value ("not valuable") to their professional objectives. Given that over 90% of all respondents saw at least some value in a global *ex situ* collections inventory for the three identified holding types, the succeeding “Survey of *Fraxinus* Collections” would seek to capture information on all three.

<u>**Survey of *Fraxinus* Collections**</u>

The “Survey of *Fraxinus* Collections” remained open for a three-month period from May through August 2009. Of the 151 institutions invited to participate, 59 survey responses were included in the analysis (39.1% response rate). In all, 72 surveys were submitted, but 13 were removed due to duplicate responses from one institution and/or little or no information reported.

All (100%) institutions completing the on-line survey (Appendix J and K) reported having *Fraxinus* holdings (cultivated living plants, seed, and/or herbarium specimens). Furthermore, respondents were asked to identify the origins of their holdings from options that included: direct wild origin (specimens collected directly from plants in wild), indirect wild origin (specimens collected from cultivated plants of known wild origin), and finally horticultural or unknown origin (Table 6.5). Twenty-one (35.6%) institutions reported holding all three origin types.

Table 6.5 Origin type(s) of *Fraxinus* accessions represented at respondents' institutions (DW = direct wild, IW = indirect wild, H/U = horticultural/unknown origin).

Response Categories	Response	Percentage
DW, IW, and H/U	21	35.6%
DW and H/U	18	30.5%
H/U	12	20.3%
DW	7	11.9%
IW and H/U	1	1.7%
DW and IW	0	0.0%
IW	0	0.0%

Given that the focus of this study was to inventory wild origin *Fraxinus* holdings, the 12 institutions that reported only holdings of horticultural/unknown origin (Table 6.5) were not asked for additional information about their accessions. All 12 expressed a willingness to be involved in future *Fraxinus* inventory research and are listed in Appendix J.

The remaining 47 institutions that reported wild origin *Fraxinus* holdings were asked to further identify the collection type(s) maintained at the institution (Table 6.6). Institutions maintaining CLP were most represented in this study with 41 (87.2%) reporting such holdings (Table 6.6).

Table 6.6 Collection type(s) of *Fraxinus* accessions represented at respondents' institutions of direct and indirect wild origin (CLP = cultivated living plants, Herb = herbarium specimens).

Response Categories	Response	Percentage
CLP	17	36.17%
CLP and Herb	12	25.53%
CLP, Herb, and Seed	9	19.15%
CLP and Seed	3	6.38%
Seed and Herb	3	6.38%
Seed	2	4.26%
Herb	1	2.13%

Additional information pertaining to the number of accessions, specimens, species, and taxa was also collected. Some of these responses were removed from the data set due to unreasonable reported values; for example, a respondent reporting 5 accessions representing 100 taxa. Of the 41 institutions reporting cultivated living plant accessions, 38 (92.7%) provided additional information. The number of CLP direct wild origin accessions averaged 16.2 (n=37, Std. Dev.=17.5) compared to 3.1 (n=37, Std. Dev.=6.4) for indirect wild origin. Similarly, institutions reported 58.4 (n=38, Std. Dev.=125.3) direct versus 16.1 (n=38, Std. Dev.=47.9) indirect specimens, 7.9 (n=37, Std. Dev.=7.6) direct versus 1.8 (n=37, Std. Dev.=3.2) indirect species, and 10.8 (n=37, Std. Dev.=12.3) direct versus 2.2 (n=37, Std. Dev.=4.4) indirect taxa.

For herbarium holdings, 16 (64.0%) of the 25 respondents provided additional information. As for CLP, herbarium holding represented greater numbers of direct wild origin specimens as compared those of indirect wild origin. On average, institutions held 30.3 (n=15, Std. Dev.=51.4) direct wild origin versus 1.4 (n=15, Std. Dev.=3.0) indirect wild origin accessions, 169.8 (n=16, Std. Dev.=339.0) direct versus 4.4 (n=16, Std. Dev.=12.6) indirect specimens, 11.7 (n=16, Std. Dev.=16.4) direct versus 1.0 (n=16, Std. Dev.=2.4) indirect species, and 13.1 (n=16, Std. Dev.=17.3) direct versus 1.1 (n=16, Std. Dev.=2.5) indirect taxa.

Finally for seed, 11 (64.7%) of the 17 institutions reporting holdings supplied additional information. No indirect wild origin seed holdings were reported by institutions. On average, institutions held 29.1 (Std. Dev.=56.5) direct wild origin accessions, 11.8 (Std. Dev.=14.0) direct species, and 13.2 (Std. Dev.=15.1) direct taxa.

Institutions were also asked about their use of specimen verification systems to ensure correct identity; 33 (70.2%) institutions reported having accession verification systems in place, as well as their methodologies (Table 6.7). Respondents were presented with three options as outlined by Gates (Hohn, 2008), including the “phenotypic approach:” “comparing morphological traits with previously authenticated herbarium specimens and scientific literature”, the “molecular approach:” “comparing DNA and other relevant chemotaxonomic material with other authenticated samples,” and the “digital imagery” approach: images “of exterior features taken during peak bloom periods that are then compared with known specimens or with literature.” All 33 (100.0%) respondents utilized a phenotypic approach, some in conjunction with other methods (Table 6.7).

Table 6.7 Accession verification method(s) used by respondents reporting a verification system for accessions at their institution (PA = phenotypic approach, MA = molecular approach, DA = digital imagery approach).

Response Categories	Response	Percentage
PA	22	66.7%
PA and DA	7	21.2%
PA and Other	3	9.1%
PA, MA, DA, and Other	1	3.0%
DA	0	0.0%
MA	0	0.0%
Other	0	0.0%

<u>"Other" responses</u>:

- In-house staff and visiting experts (2)
- Visiting specialists of a particular plant group

Finally, institutions were asked to submit a complete inventory of their direct and indirect wild origin *Fraxinus* cultivated living plant, herbarium, and seed accessions. As mentioned in the "User Group Survey" results section, all information fields identified in Table 6.3, except specific information about the collection site, were requested for each reported accession. In addition to these information fields, the number of specimens within the accession was also requested. Of the 47 institutions that reported having wild origin *Fraxinus* holdings, 37 (78.7%) submitted the requested inventory (identified in Appendix K as "**bolded"** text).

Two spreadsheets were created from the compilation of the institutional inventory submissions. The first contains information pertaining to the reported wild origin *Fraxinus* accessions that are held at these institutions (Appendix L); the second (Appendix M), contains data regarding unsolicited information surrounding accessions of “natural” origin (naturally occurring accessioned specimens at the institution), "unknown" origin (origin unknown by institution), or "not reported" (origin not provided to researcher). In a limited number of cases, information regarding an institution’s horticultural origin accessions was submitted, but has not been included in the results of this study.

Each institution was assigned a unique identifier based on BGCI’s Institution Codes (BGCI, 2010b). Institutions lacking a BGCI Institution Code were assigned an identifier by the researcher. Within the compiled inventories, these identifiers accompany each accession number, allowing the inventory to be sorted by different information fields, while still being able to identify the institution holding each accession.

The information reported in Appendix L regarding wild origin *Fraxinus* holdings includes cultivated living plant accession information from 33 institutions (567 total accessions), 9 institutions providing herbarium specimen information (68 total accessions), and 6 institutions providing information regarding seed holdings (213 total accessions).

Institutions submitting inventories reported a total of 60 species (combined total from Appendix L and M) that are indentified in Table 6.8 under the column “species name.” Of these, 32 (53.3%) are reported as unique species in

Wallander (2008), a revised infrageneric classification of the genus *Fraxinus* (Table 6.8; see “name recognized” column). An additional 26 intraspecific taxa were reported and are indentified in the “reported intraspecific taxa” column of Table 6.8. As indentified by an asterisk, “*”, in Table 6.8, 14 taxa occurred only in Appendix M, and therefore may not represent wild origin accessions. Although some cultivars are reported in both Appendix L and M, cultivars are not included in the intraspecific taxa summary represented in Table 6.8, or in the total taxa counts highlighted above.

Table 6.8 Summary of taxa reported by institutions submitting *Fraxinus* inventories; compiled in Appendices L and M. The column labeled "species name" represents species reported at least once in either of these lists. The "reported intraspecific taxa" column represents intraspecific taxa under the associated "species name" that are reported at least once in either Appendix (L, M).

Species Name	Name Recognized**	Reported Intraspecific Taxa
F. americana L.	x	f. *iodocarpa* var. *biltmoreana* (Beadle) Wright var. *juglandifolia* (Lam.) Rehd.*
F. angustifolia Vahl	x	ssp. *oxycarpa* (Bieb.) Afonso ssp. *pannonica* Soó & Simon ssp. *syriaca* (Boiss.) Yaltrik ssp. *angustifolia* var. *australis* var. *lentiscifolia**
F. anomala Torr. ex S. Watson	x	
F. apertisquamifera Hara	x	
F. bungeana De Candolle	x	
F. biltmoreana Beadle*	*F. americana* L.	
F. caroliniana Mill.	x	
F. caucasicus		
F. chiisanensis Nakai	x	
F. chinensis Roxb.	x	ssp. [var.] *rhynchophylla* (Hance) E. Murray ssp. *chinensis* var. *acuminata* Lingelsh.
F. cuspidata Torr.	x	
F. densata Nakai	*F. rhynchophylla* Hance var. *densata* (Nakai) Y.N. Lee[1]	
F. dipetala Hook. & Arn.	x	
*F. elonza**		

F. excelsior L.	x	f. *crispa* Willd.* f. *pendula**
F. floribunda Wall.	x	
F. formosana Hayata	*F. griffithii* C.B. Clarke	
*F. glabra**		
F. greggii A. Gray	x	
F. griffithii C. B. Clarke	x	
F. holotricha Koehne	*F. pallisiae* Willmott ex Pallis[3]	
F. inopinata	*F. platypoda* Oliv.[2]	
F. insularis Hemsl.	*F. floribunda* Wall.	
F. japonica Blume ex K. Koch	*F. chinensis* Roxb.	
F. lanuginosa Koidz.	x	f. *serrata* (Nakai) Murata
F. latifolia Benth.	x	
F. longicuspis Sieb. & Zucc.	x	var. *sieboldiana*
F. lowelli	*F. anomala* Torr. ex S. Watson	
F. malacophylla Hemsl.	x	var. *septentrionlis*
F. mandshurica Rupr.	x	var. *japonica*
F. nigra Marsh.	x	
*F. numidica**		
F. oregona Nutt.	*F. latifolia* Benth.	
F. ornus L.	x	ssp. *cilicica*
F. oxycarpa	*F. angustifolia* Vahl	
F. pallisiae Willmott ex Pallis	*F. angustifolia* Vahl	
F. paxiana Lingelsh.	x	

F. pennsylvanica Marsh.	x	var. *subintegerrima* (Vahl) Fern. var. *lanceolata* var. *austinii**
F. platypoda Oliv.	x	
F. potamophila Herder	*F. angustifolia* Vahl	
F. profunda (Bush) Bush	x	
*F. pubinervis**		
F. quadrangulata Michx.	x	
F. raibocarpa Regel	x	
*F. reichardii**		
F. retusa	*F. floribunda* Wall.	
F. rhynchophylla Hance	*F. chinensis* Roxb.	
F. rotundifolia	*Fraxinus angustifolia* Vahl subsp. *syriaca* (Boiss.) Yalt.[3]	
F. sieboldiana Blume	x	
F. sikkimensis (Lingelsh.) Hand.-Mazz.	*F. paxiana* Lingelsh.	
F. sogdiana Bunge	*F. angustifolia* Vahl	
F. stylosa	*F. floribunda* Wall.[3]	
F. suaveolens W.W. Smith	*F. paxiana* Lingelsh.	
F. syriaca Boiss.	*F. angustifolia* Vahl	
F. texensis (A.Gray) Sarg.	x	
F. tomentosa Michaux f.	*F. profunda* (Bush) Bush	
F. trifoliata (Torr.) Lewis & Epling	*F. dipetala* Hook. & Arn.	
F. uhdei (Wenzig) Lingelsh.	x	
F. velutina Torr.	x	var. *coriacea*

		var. *glabra** var. *toumeyi**
F. xanthoxyloides (G. Don) DC.	x	var. *dimorpha**

*Denotes that the taxon name only occurred in Appendix M, and therefore may not represent wild origin accessions. Potential synonyms were not investigated for these species names.

**An "x" in this column indicates that the species is represented as a unique species in Wallander's (2008) revised infrageneric classification of *Fraxinus*. If a species name appears in this column, the corresponding name in the "species name" column is a synonym of this name according to Wallander (2008), unless otherwise noted. If this column remains blank, the species name did not appear in the Wallander (2008) classification.

[1]Cited as possible synonym by: The International Plant Names Index (2010)
[2]Cited as possible synonym by: eFloras (2010)
[3]Cited as possible synonym by: USDA-ARS, National Genetic Resources Program (2010)

The number of accessions at each institution for taxa reported in Appendix L (wild origin accessions) is summarized in Appendix N. Additionally, Appendix O presents the species in Appendix L by their geographic distributions. Furthermore, Appendix P identifies 11 species (5 Asian and 6 North American) reported as unique species in Wallander (2008), but that were not reported as being held at institutions participating in this study and thus do not appear in either Appendix L or M (non-wild origin accessions).

Chapter 7

DISCUSSION AND RECOMMENDATIONS

The findings from this research have led to the development of 13 critically important recommendations under three general topic areas: Institutional Planning, Collections and Natural Areas Stewardship, and Collaborative Efforts by the Public Garden Community and Beyond. These recommendations will help public gardens and arboreta prepare for and manage future biological invasions. Discussion of the preliminary account of *Fraxinus* collections globally follows these recommendations.

Preparing for Future Invasions

Institutional Planning

Recommendation 1: Institutional vulnerability

> **Summary:** *Institutions need to acknowledge that their collections and natural areas are at risk; and to ensure the long-term survival of priority holdings, actions must be taken to mitigate the potential impacts. Additionally, effects extend beyond the loss of individual plants, having significant ecological and institutional consequences that should be recognized.*

The impact of biological invasions on plant collections and natural areas has been devastating, but effects from invasions extend beyond the loss of individual plants, having had severe implications on many facets of an institution and the surrounding environment. Unlike other disasters, such as fire or tornados, biological invasions present a continuous assault on plant specimens, requiring immense management efforts until sustainable control measures are found. Beyond the decimation of collection and natural area specimens, and the resulting effects on aesthetics, reported negative impacts included changes to collection development, extensive secondary ecological implications, shifts in resource allocation, operational changes, impacts on public programming relevance, unrealized financial gains, stress on donor relations, and effects on visitor morale and experience. If public horticulture institutions are to ensure the long-term survival of their core collections from such threats, the vulnerability of these holdings, and the institution in general, must be recognized and actions taken to protect these valuable resources.

Biological invasions and other disasters have caused and will continue to cause tremendous loss of valuable collections and natural area specimens. In situations where threatened specimens provide shade for other accessions the loss of those structural specimens would have secondary collection implications as well (Carmichael, 2009). Furthermore, with biological epidemics, "… unlike a fire or other 'normal' disaster, after which the site can be re-used… it will be years before resistance ashes are available even for our non-research… needs" (Michener, 2008). Cases noting the destruction of accessions from other disasters, such as hurricanes, also warn of the vulnerability of living collections (Maunder, 2007; Evans, 2003).

In addition, biological invasions can have implications on collection development, changing the institution's acquisition focus. Michener (2009) comments, "one of the things we're trying to do is have at least representatives of all the major genera and plus the key species of our bio-region… and so it's a real loss… something's missing." Carmichael (2009) adds, "when we bring plants in from native habitat… we're very thoughtful about where we collect. We do not bring in and introduce things from defined sites of sudden oak death."

Managed natural areas are also at risk, evidenced by the incredible loss of key canopy species to biological invasions that institutions, such as the Matthaei Botanical Gardens and Nichols Arboretum (MBGNA), have seen over many years. Beyond the loss of individual trees, institutions report a number of secondary ecological impacts to natural areas, including increased occurrence of invasive plant species, rising water tables and increased sun exposure changing environmental conditions, erosion issues, rising creek temperatures, and detrimental effects on other native flora and fauna. It is reported, "… species shifts due to exotic pests and pathogens may be the dominant force driving changes in ecosystem processes over the next few decades, perhaps even overwhelming other environmental changes occurring simultaneously" (Lovett et al., 2006).

The destruction has also had an impact on landscape aesthetics and relevance of planned public programming. Carmichael (2009) reports the potential impacts of the loss of a key species:

> It would change our interpretation of the native Bay area habitat and it would alter the structure of our California collection in particular, which is one of the collections we do a lot of interpretation and, particularly K-12, but also… for UC Berkeley classes, so… the impact of oak loss in those areas would severely impact those objectives.

Furthermore, institutions experienced significant operational, financial, and detrimental effects on visitor experience and morale.

> From a property management perspective… look at all of the resources that have to be diverted, like all gardens, we don't have nearly enough people to run the programs… probably in the six figures at this point over the years, to have trees dropped just so people can walk on the path (Michener, 2009).

Effects on visitors are also apparent; "It's hard to measure, but… there were a lot of people that were really upset and frustrated… it was really shocking to see their favorite areas changing, dying so dramatically" (Plakke, 2009).

From the death of specimens to the loss of critically important sources of funding, the threats to an institution and the integrity of its collections from biological invasions are immense. Public gardens need to acknowledge the threats (biological invasion or other) to their institution and its holdings and take steps to mitigate the potential impacts. Similarly, speaking to the increased intensity and frequency of tropical storms Maunder (2007) states, "We need to prepare our institutions and collections for change…"

Recommendation 2: Disaster readiness planning

> **Summary:** *Planning is the key to preparedness. Institutions should work to identify risks that pose a threat to their collections, and develop an overarching Disaster Readiness Plan to mitigate potential impacts. A plan should include proactive and reactive steps that will be taken. Additionally, Action Plans that address specific foreseen threats should be developed as threats are identified, and should be continuously informed and modified based on newly emerging information from the research community.*

"We don't have a disaster plan that addresses biological organisms and we're aware of that and our goal is to add that in" (Carmichael, 2009). Of the nine gardens and arboreta participating in interviews for this study, only one indicated that the institution had a formal Disaster Readiness Plan that contained information pertaining to its plant collections (Griffith, 2009). The disaster planning process helps an institution identify potential risks to collections, outlines proactive steps that can help safeguard priority holdings and other aspects of the institution, and creates reactive steps to reduce impacts during and after an event. As is stated by the American Association of Museums (AAM, 2007):

> Museums care for their resources in trust for the public. It is incumbent upon them to ensure the safety of their staff, visitors, and neighbors, maintain their buildings and grounds, and minimize risk to the collections that they preserve for future generations. Conscious, proactive identification of the risks that face people and collections, and appropriate allocation of resources to reduce these risks is a vital part of museum management.

Public gardens have a responsibility to take steps to mitigate the potential impacts of identifiable disastrous events, and thus a Disaster Readiness Plan should be a key component of an institutions' collection policy. When threats are identified development of a specific Action Plan that speaks to management steps to be implemented for the impending threat should be drafted.

Of the eight gardens not having disaster readiness plans in place, six clearly expressed the need for or have already begun the process of developing such a plan. The Morton Arboretum, for example, is currently seeking accreditation through the AAM Museum Accreditation Program, which requires the development of an emergency/disaster preparedness plan (Kim, 2009). The need for a disaster plan is as well a key recommendation by Bergquist (2009); "Simply put, the process of disaster planning helps to ensure the safety of plant collections, and the true relevancy of a botanical institution." A "Natural Disaster Planning Template for use in Plant

Collections Management" is a result of Bergquist's (2009) research. Additionally, Evans (2003) advocates for "A Clear Plan" stating, "Since practical preventative measures are so limited, a garden's most practical line of defense for its collections is a clear plan for managing the storm's aftermath."

In the case of biological invasions, the planning process needs to go beyond preparing for reactive responses. If core collections are vital to an institutions mission and the preservation of those holdings for cultural, historical, or conservation means is of utmost importance, greater preventative planning is paramount. Actions discussed previously and in succeeding recommendations, such as prioritizing holdings, backing-up of core collections, focusing resources on the health of key specimens, and ensuring comprehensive documentation and mapping is in place, are all tools that can be used to reduce the impact of an invasion, and should be highlighted as part of any readiness plan. Allenstein (2009) comments that the North American Plant Collections Consortium (NAPCC) of the American Public Gardens Association (APGA), should probably have a greater role in advocating the planning process for such proactive approaches with its collection holders; "… we probably should be thinking about that and how as a Program (NAPCC) we… can respond programmatically… Trying to raise the level of concern about the vulnerability of our living collections…" (Allenstein, 2009).

A disaster plan can be a particularly valuable tool when an institution is faced with a disaster in time of leadership turnover, especially when full time staff is already very limited. Gentry (2010) explains that in the midst of the EAB epidemic, "We did not have a director… or a manager for the garden… we did not have a lot of direction… I just picked out some plants… to treat with the money that I had.” “I wish we could have done more… before all the plants were gone… we just did not have a plan on how to manage a collection that was going to be gone in a few years” (Gentry, 2010).

Beyond a Disaster Readiness Plan, Action Plans that outline specific steps a garden intends to take in the management of a particular foreseen pest were commonly reported as being developed by institutions (Kim, 2009; Dosmann, 2009; Moe, 2009). Action Plans may be used to present specific information, such as the collections that will be impacted, staff utilized, and monetary resources needed to implement monitoring and management strategies. It can be used to inform upper-management or other institutional stakeholders and staff for general awareness of the plan of action. It can also address additional initiatives such as public awareness and education, collection expansion, research opportunities, or plans for involvement in collaborative initiatives pertaining to the impending threat. For example, The Morton Arboretum’s EAB Action Plan outlined specific steps to monitor for the insect, propagate priority accessions, determine control options, chemically treat identified specimens, participate in collaborative research, and to be involved in public awareness and statewide readiness planning (Kim, 2007).

Collections and Natural Areas Stewardship

Recommendation 3: Importance of documentation and mapping

Summary: *Institutions, for at the very least their priority specimens, need to understand the relative value and location of their holdings, through thorough documentation and mapping. Without these*

> *fundamental components of collections stewardship, reacting to disasters in a timely and resource efficient way is nearly impossible. An integrated database system linking multiple institutions together would further collection development and other research initiatives in the face of impending crises.*

"All of our plants are accessioned… we have… the core ability to respond [to disasters] with a good understanding of the plants in our collection and their distribution" (Carmichael, 2009). Documentation is a fundamental component of any collections policy and should be an internal part of general curatorial practices for every garden (Hohn, 2008). Lacking documentation and mapping in the face of a disaster makes it very difficult to make informed estimations of potential impacts, for budgeting and acquisition of funding for the associated cost of management, and to allocate the appropriate resources to specific areas of concern. The need to perform reactionary documentation of collections in the face of a disaster utilizes valuable time and energy, and is completely avoidable. Beyond internally isolated documentation, there is a great need for the development of integrated databases linking collection inventories of various institutions into a single, multi-user system.

In the face of the impending threat of EAB, Telewski (2009) reported that a complete inventory of the institution's holdings had not yet been completed, and the Garden reactively aimed to inventory its ash resource. In the aftermath, Telewski (2009) states, "… the best way to be prepared… is to have as accurate as possible a database and map, so that you know what you've got." Dosmann (2009) reported a similar situation with Hemlock Hill, as it had to be reactively surveyed as it was being threatened by hemlock woolly adelgid (HWA). "If you have a high-priority collection, you've better have high-priority records and documentation attached to it" (Dosmann, 2009).

This finding is also clearly evident in resources speaking to other natural disasters. Evans (2003) reports, "The most helpful tool in this process was the Garden's up-to-date plant records, including detailed plot maps showing precise locations of all plants." This allowed staff to locate high-priority specimens that were buried under debris. Furthermore, "These meticulous records also proved invaluable to the host of researchers who descended on the Garden to take advantage of the many specimens available for scientific study and assay" (Evans, 2003). Bergquist (2009) similarly reported, "Plant collections documentation is critical in disaster management practices." "At a minimum, documentation of the highest priority plants should be updated annually" (Bergquist, 2009).

Given the limited staffing resources of his institution, Michener (2009) highlights the proactive, but selective documentation strategy the Garden will use for its natural areas in the aftermath of EAB:

> 1) We need a much better, more complete species list and 2) an overall assessment of health… so what we'll have… is just that spread sheet for the moment… of what's present in… our twenty-some management zones… But, we also need it way more accurate in certain areas… So what are the really important areas to map well, and what are other areas where just knowing presence or absence is all we have…

The importance of documentation for an institution's natural areas is as well highlighted by Hohn (2008); "… each garden should conduct and maintain a plant inventory of its reserves."

The collaboration of institutions to make internal databases unified and externally accessible is also a key area for improvement in the public garden realm. Allenstein (2009) reports, “That isolation… is a real stumbling block, and any efforts that we can make to help overcome that, so that we’re working more in tandem with our efforts [is key].” Having the ability to make informed decisions about acquisition efforts based on the scientific quality of the current collective holdings is vital (Kim, 2009). “Existing germplasm collections and their associated documentation could be invaluable to the planning of plant-collecting missions” (Hohn, 2008). Furthermore, the ability to identify holdings available for breeding and other research, in a timely and efficient fashion will make collections more useful resources in the face of biological invasions and other disasters. “… online information is a good way to alert researchers to the resources available to them at various gardens” (Hohn, 2008).

Proper preparation for and management of biological invasions and other natural disasters starts with knowing what the institution is holding. With thorough records, including locations of specimens on the grounds, priority can be assigned, and management strategies implemented in a timely fashion.

Recommendation 4: Prioritizing collections

Summary: *Public gardens need to perform an in-depth evaluation of their collections, identifying those of core significance to the institution, based on clearly identified and informed criteria. Furthermore, prioritized holdings should be allocated adequate resources to support their long-term survival.*

After proper documentation is in place, identification of core collections based on an institution’s mission and values, as well as the elite group of specimens within those collections that deserve the long-term insurance of survival, is paramount. Institutions spend valuable resources stewarding redundant or low value accessions that drain limited assets (Dosmann, 2009). Through prioritization, resources can be focused on the health and stewardship of key holdings. Evaluation of specimens should be based on sound decisions, informed through established criteria that reflect the goals of the organization, aided by external resources. Furthermore, assigning priority can be done using a multiple-tiered approach of significance. The prioritization process will allow for clear justification of further preparatory actions focused on specific plants before a disaster hits and will be a valuable reactionary tool for the immediate allocation of resources when an event does occur.

Prioritization is a key-step in not only preparing for biological invasion, but disasters that affect collections in general. Additionally, the process represents an in-depth knowledge of an institution’s accessions and the relative value of those holdings to its mission. Michener (2009) explains his institution’s initiative:

> So we’re starting with the peonies. And we’re very much aware that we could get blasted at any point and lose one of the country’s most critically important… historic cultivar collections. And that would be a major loss… now it’s part of our cultural heritage… we’re very protective of them as an institution…

Beyond identifying overarching collections of priority, the prioritization process should further evaluate individual accessions within a collection. “From a curatorial side… we need to start prioritizing, and having an understanding of what’s the relative values of certain accessions, so that if a pest comes in, we can… say let’s target these first…” (Dosmann, 2009). Similarly, in the aftermath of Hurricane Andrew, one of the initial steps in the recovery process for Fairchild Tropical Botanical Garden (FTBG) was to “triage” the collections, identifying priority specimens to determine which plants were most critical to rescue in terms of institutional value (Evans, 2003).

In the prioritization process, accessions can be assigned different levels of priority based on a tiered approach of significance. Telewski (2009) explains this process with the impending threat of EAB as “… a triage approach… which trees do we definitely want to save, which trees can we not save, and which trees can we allow to go over a period of time, if we don’t have a biological control that becomes available…” In this case, the institution had time to evaluate its accessions, but when an institution is located near the epicenter of the pest’s introduction and plants are infested before the institution is aware of the problem (Michener, 2009; Gentry, 2010), prioritizing before a crisis will allow for more timely reaction and focusing of resources. “If a collection is prioritized before a disaster, post-disaster recovery steps can be taken immediately, focusing on plants that were deemed of highest importance before the damage” (Bergquist, 2009).

Prioritization decisions should be based on clear criteria supporting the mission, values, and collection goals of the institution, aided by the use of external resources. Kim (2009) reported that priority in the case of *Fraxinus* at The Morton Arboretum was based on a number of criteria including known wild provenance, species representation in the collections, taxonomic importance, and the aesthetic value in the landscape. Michener (2009) adds core collections criteria at MBGNA include, among others, uniqueness of the collection to the institution, its cultural, natural, or historical significance, and its educational value for teaching of conservation stewardship. Furthermore, criteria based on external resources allows for clearer justification of decisions. The Morton Arboretum's involvement in Botanic Gardens Conservation International's Red-listing Group, helps it assess the conservation status and levels of endangerment of its holdings. The Morton has used this information to guide prioritization decisions (Kim, 2009). "Botanical gardens… are facing escalating labor and materials costs. Curators… must have information from which they can make sound management and preservation decisions" (Hohn, 2008).

Along with the prioritization of collections, comes the need to provide adequate resources for the stewardship of those holdings. "We don't have infinite resources, and… whether it's for disaster planning… or it's just everyday collections management… you've got to be able to prioritize and make decisions based on sound information" (Dosmann 2009).

The importance of prioritizing collections based on clear criteria cannot be overstated. It allows for clear direction and allocation of resources prior to an invasion and is an invaluable reactionary asset when crises do occur.

Recommendation 5: Backing-up of collections

> **Summary:** *Institutions need to seek out collaborative means of backing-up core collections through on-site (local) and remote (beyond immediate region) duplication. Beyond cultivated collections, other forms of repository storage, such as seed and dormant bud should be investigated. Collaborative partnerships are fundamental to such initiatives.*

"There are not enough lifeboats for everything if we hit the iceberg… we have to assign seats in advance, or else we're all going down" (Michener, 2009). If germplasm for which a specimen represents is of utmost value to the organization, ensuring its long-term survival through duplication is of vital importance. On-site (local) duplication may serve as a valuable tool when localized and brief disturbances occur. But with regional and potentially continent-wide epidemics with persisting effects, local back-up is not sufficient. If the epicenter of a pest's introduction is located near an institution, providing little or no reaction time, backing-up specimens at facilities beyond an institution's immediate region, will at least allow for time to respond. Given the space that living plant collections, particularly tree species require, duplication alternatives including seed and dormant bud storage may provide valuable refuge for core collections. No matter the means, ensuring the survival of valuable germplasm through duplication is reliant on collaborative efforts.

On-site duplication provides some protection for high-priority germplasm from local, isolated events, such as lighting-storms or vandalism. Institutions have taken the initiative in the planning process of collections to ensure space for duplication of core accessions on-site (Kim, 2009; Dosmann, 2009; Michener, 2009). These initiatives do have their limitations. As Michener (2008) points out, the backing-up of living collections through on-site duplicates or at nearby locations, is an irrelevant approach with disasters, such as the invasion of EAB, that are not restricted to a single event or location. "Key collections should be replicated in another region that is suitable but geographically isolated from yours, and/or germplasm storage needs to be explored" (Michener, 2008). Griffith (2009) highlights the significance of this lesson stating that as an institution "… we'd take pride if we had something and nobody else had it. But… now… it's not something we'd be proud of. If you have it and nobody else does, then you've got some work to do." Even if an outbreak, such as

EAB, eventually spreads throughout the U.S., locating back-ups in different regions provides for valuable time to react.

Other forms of storage, such as seed and dormant bud, and even the use of appropriate private collections should also be considered as means to back-up accessions. Dosmann (2009) points out, "… botanic gardens and arboreta don't do a very good job at maintaining seed, at all. And so that's a big missing link, and… something we collectively need to get our heads around…" Dormant bud storage is yet another potential tool that could be utilized, especially for collections, where a clone of the parent plant would be ideal (Widrlechner, 2009). Finally, as space and resources are limited, private collections could be another asset for backing-up material (Allenstein, 2009).

Similarly, Bergquist (2009) reported in the face of disasters, "institutions suggested that back-up plant stock and seed should be dispersed to sister institutions… to maintain sources of replacement plants." No matter the means taken to safeguard vitally important germplasm, collaborative partnerships are the fundamental key to the success of such initiatives.

Recommendation 6: Value of consortium involvement

Summary: *Core collections and natural lands should be part of a network of like-minded organizations on a regional, national, or international scale, working towards the conservation of that particular assemblage of plants. Through these established partnerships, sharing of plant material can be a means to safeguard high-priority accessions. Furthermore, such consortiums provide a mechanism for disseminating information, sharing expertise, resources, and objectives.*

"You cannot act alone, you have to really work with other groups to effectively achieve your goal in planning, acquiring, managing, and conserving the germplasm" (Kim, 2009). Institutions need to critically evaluate and prioritize their collections to identify, which are worthy of inclusion in larger regional, national, or even international initiatives, advancing the preservation and significance of those holdings. Consortiums, such as the NAPCC provide an unparalleled opportunity for gardens to work together to meet common goals. They provide gardens with means to share germplasm, back-up core collections, disseminate valuable information, share expertise and resources, and build more extensive and genetically diverse plant collections. Furthermore, involvement in collaborations such as the NAPCC, reconfirms the value of those priority holdings to institutional stakeholders, as well as recognizes a commitment to a high level of collections stewardship. Seeking to join partnerships in the management of natural areas is equally a valuable tool.

Plant consortiums provide the opportunity to share germplasm, back-up core collections, and become part of a greater initiative bringing the strengths of your institution to the partnership. "We've gotten collections back as a result of having them backed-up elsewhere, so we really believe in that here… it's certainly useful" (Griffith, 2009). Carmichael (2009) comments:

> Particularly with the multi-institutional collections, one of the goals is to preserve… share germplasm… we're part of the multi-institution [NAPCC] oak collection, and our strength is in Mexican and Central American oaks, that's what we bring to the table for that consortium.

"All of the [NAPCC oak collection] institutions are committed to germplasm conservation and recognize the effectiveness of working collectively rather than independently" (Collins, 2008). The MBGNA also reported seeking out such partnerships in the preservation of its natural lands (Michener, 2009). The value of partnerships in the management and development of natural areas is as well highlighted by Hohn (2008).

Such consortiums also provide opportunity to build more extensive, genetically representative collections, particularly with larger tree species, that take up large amounts of space (Dosmann, 2009). Kim (2009) explains that to adequately represent the genetic diversity of a certain taxon for *ex situ* conservation purposes, it requires more than holding a single specimen from the wild population. The value of efforts such as the NAPCC, is that you can work with multiple institutions to meet the groups genetic representation goals (Kim, 2009). "Multiple institutions… contribute to… distributed holdings… where no single institution is capable of forming a comprehensive collection due to climatic and physical space limitations" (APGA, 2010e). Furthermore, as is pointed out by Collins (2008), "… members of the [NAPCC oak] group now recognize the advantages of sharing resources and coordinating future efforts to acquire new [wild-collected] plant material."

Sharing information is another crucial benefit of such partnerships, as Griffith (2009) explains, "… just to have a good network of people that you can talk to who might know someone who can help you out when you're faced with a problem." Carmichael (2009) adds the, "NAPCC can potentially play an important role in linking institutions and sharing information and bringing a focus on core collections… I don't think we've realized it yet, but I think we've got gardens talking…"

“To protect our vital plant heritage, we need to think about what criteria would induce us to collaborate with other gardens as part of a national collection such as NAPCC” (Michener, 2008). From the backing-up of collections and sharing of information to increased institutional exposure and recognition, the potential benefits of working along side other gardens are profound.

Recommendation 7: Monitoring of collections and natural areas

> **Summary:** *Collection monitoring programs, particularly for priority specimens should be robust. Gardens need to regularly inspect collections and investigate changes from the norm, while keeping abreast of new information and potential threats. Building relationships proactively with government agencies and other gardens, will allow for a quick and unified response when a crisis does occur.*

“I think that the whole experience with sudden oak death has made us aware of the need to be vigilant about disease problems. To take it seriously…” (Carmichael, 2009). If a collection is of institutional priority, monitoring the health of those plants to identify potential problems early should be a fundamental component of a regular management régime. Keeping up-to-date information regarding the spread of regional and national epidemics as well as new pest arrivals that could potentially impact your holdings is of utmost importance. Furthermore, given the range of species diversity and extent of professional expertise that an institution represents, public gardens should play a key role in early detection of new invaders. Knowing your local and state government agency contacts and working to build a network of relationships with such entities before a problem arises, will allow these informational and regulatory stakeholders to be readily contacted when needed.

Monitoring the health of collections is a key component of collection stewardship allowing for a quick response to issues before a situation becomes unmanageable. Dosmann (2009) comments:

> I mean it's one thing if it's a box of rocks… where yeah OK, we've pulled the door open twenty years ago, we go back there, the rocks are still in the drawer… in these [living] collections… you've got to have [frequent inventories]… to see what you've got in the collections, and the conditions… I think that is going to best protect us.

Furthermore, beyond the need for regular monitoring, institutions reported increased monitoring efforts when impending threats were known. Using increased visual inspections of specific threatened taxa, pheromone traps, and trap trees, institutions used monitoring as a tool to inform the timing of various management actions. Additionally, Telewski (2009) reported that ultimately the discovery of EAB on the grounds of Michigan State University was through visual inspection found in the center of campus before perimeter traps detected any presence of the pest; thus monitoring programs should be robust, and include many different approaches to detect an infestation.

Finally, public gardens also need to work collaboratively with one another as well as with their local and state agencies to stay informed of new information and threats, and in responding as a unified force in management efforts. Establishment of relationships prior to invasions is key, especially given that quarantines may effect institutional operations. Carmichael (2009) reports, "It's (sudden oak death) made us aware of our vulnerability. It's [presence] made us aware of the need for vigilant monitoring and good communication with the state and county agencies involved…" Allenstein (2009) confirms:

> It's… keeping up with the local extension agent and knowing… who the government service people are… setting up… a networking process that… you can have in place even if there isn't a crisis, so that in the event that there was… you'd be able to activate that.

Collaboration is essential to the effective monitoring and response to potential threats.

Recommendation 8: Collections and natural areas management

> **Summary:** *No matter the pest, management decisions should be based on sound information from the research community and updated as new information becomes available. Treatment effectiveness should also be evaluated through continuous institutional observations. The utmost concern should be placed on human safety, and the potential for larger environmental impacts. Before threats emerge identified priority holdings should be maintained at the highest horticultural standards as part of regular maintenance programs.*

Institutions reported many different approaches to management both preventative and reactive for collections and natural areas in dealing with biological invasions. Management strategies and the extent to which they were implemented depended on a number of factors such as the pest in question, institutional resources available, knowledge of the threat before the pest was found on the grounds, and known effective treatments. No matter the management techniques implemented, treatment decisions should be based on sound information gathered from the research community and updated as new information becomes available. Effectiveness of treatments should be evaluated on a regular basis and adjustments made if warranted. First and foremost, human safety and the larger environmental implications of selected treatments should be of utmost importance. Through the prioritization of an institution's collections, identified specimens that are of greater institutional value, should be allocated sufficient resources to maintain those collections at the highest horticultural standards before threats emerge.

Management techniques utilized by institutions included preventative and reactionary chemical treatments, mechanical removal of infected plant material (sanitation), testing biological and non-chemical controls, cultural practices, and the preemptive or after death removal of specimens. Management decisions should be based on emerging information from the research community, and updated continuously as new information becomes available. Furthermore, institutions should be evaluating effectiveness of their own treatments, ensuring that precious resources are being utilized efficiently and effectively, and adjusting management techniques accordingly. Telewski (2009) explains:

> Have a good monitoring program so that you're evaluating, keeping track of your injection program, so you know what trees have been injected, how much, when, with what treatment? And then go back on an annual basis and evaluate that tree… otherwise you don't know how effective your program is.

Schulhof (2007) highlights this Adaptive Management (Holling, 1978) strategy stating, "Gathering data that monitor changing conditions as well the effectiveness of management actions is essential, as is a willingness to completely revise strategies based on new results."

Management strategies should first and foremost aim to reduce risks to human safety and the larger environment. Although many institutions reported leaving dead and declining natural area trees in place as wildlife habitat, tree removals in such areas were reported in all cases as being done with a "public risk management approach" (Michener, 2009). Anything that could pose a hazard to visitor safety, such as trees along the trails, is removed. Furthermore, institutions only used chemical applications in cases that do not pose immediate risk of water contamination or other negative environmental impacts. Schulhof (2007) notes:

> Finding a balance among stewardship, education, and public service goals, we protect hemlocks that are of sufficient vigor to recover and that grow in conditions that are favorable for treatment and do not present risk of water contamination.

“The control of weeds, insect pests, and pathogens uses a large percentage of our… resources and impacts the garden and local environment as well as garden visitors” (Hohn, 2008). Actions should be taken to reduce potential for such negative impacts.

As trees are lost to infestations and removals do occur, finding value in the destruction can provide hope in the midst of despair. Wood utilization programs were common among gardens that have lost specimens (Gentry, 2010; Michener, 2009; Swartz, 2009). Similarly, Evans (2003) reported that having the “vision” to find value in the wreckage is an important component of disaster recovery. Utilizing wood, in some cases from extremely valuable species, raised FTBG $40,000 in the aftermath Hurricane Andrew. Permanent and temporary art displays were developed, and the newly opened space due to losses, provided an opportunity for landscape improvements including restoring overgrown vistas and clearing space for more botanically significant specimens (Evans, 2003).

Keeping collections, especially those of institutional priority, at the highest level of horticultural standards before threats are present and being aware of techniques to minimize spread of an infestation, is also vitally important. Although some pests, like EAB, attack even the healthiest of specimens, institutions reported that sound practices and healthy plants can aid in the management of many other biological threats (Carmichael, 2009; Dosmann, 2009; Kim, 2009; O'Dell, 2009). Bergquist (2009) similarly reported that by developing healthy root systems and performing proper pruning to thin a trees canopy, institutions noted that specimens are better adapted to withstand hurricane force winds.

Recommendation 9: Collections development

> **Summary:** *Institutions should consider more sustainable means of collections development in place of taxonomically grouped holdings in a confined location. The genetic diversity represented within a particular taxon, in both displays and formal collections should be evaluated and measures taken to ensure diversity in future acquisitions. In the development of displays that utilize native species, locally sourced genetically diverse material is preferred for its adaptation to local environmental conditions.*

"I always say, 'nature abhors monocultures.'… your little corn borer doesn't have to travel far in a cornfield to find its next host…" (Payton, 2009). Although living collections are exposed to environmental threats all the time, taxonomic collections, in which you have a single group of related taxa located in a confined location, will present even greater issues of sustainability. Institutions preach to the value of diversity in community landscapes, but fail to acknowledge the lack of diversity that lies in their own collections. Public gardens should seek to develop collections in a more sustainable fashion, spreading taxonomically related holdings throughout the grounds of an institution. Alternative collection themes, such as geographic (e.g. plants of China) or thematic (e.g. shade trees) should be explored in the development of new collections. That being said, taxonomic collections do have significant value for comparison purposes in educational and research activities (Kim, 2009). Beyond the overarching theme of a collection, efforts should be taken to expand the genetic diversity represented for a number of important reasons.

Collections based on taxonomic groupings may present an increased risk of exposure to disease and insect pest outbreaks, and institutions should consider alternative means of representing desired taxonomically related taxa. Taxonomic collections should still continue to be developed, but with a broader, institutional-wide view for their development.

> You've got these legacy [taxonomic] collections and… it's hard, like an ocean liner, trying to change the direction… in some ways it's just kind of archaic… just by their nature, you're grouping plants that are very closely related… you're just setting yourself up for something that's much more difficult. So, by that, in the new age of either geographic-based collections… or you have thematic collections… it's probably more valid than taxonomic collections… I think we'd probably take a broader approach, when we look at collections now. [For example] we have an oak collection… but if that collection were dispersed throughout the grounds, you might be less vulnerable to a significant gypsy moth outbreak (Bachtell, 2009).

In the face of biological invasions, representing the genetic diversity of a specific taxon is important for a number of reasons. Although with a pest as deadly as EAB, genetic diversity among accessions of the same taxon would probably be of little effect, with other less severe pathogens, however, specimens of the same taxon possessing genetic differences (non-clones) could be more or less susceptible.

> … one thing that we're doing now… is we're trying to collect multiple genetic populations… to introduce different genetics. I mean in the years past, we got plants that were from "Bob's Nursery" and who knows where it was gathered from? I don't think it has any influence

> when it comes to something that is as devastating as emerald ash borer, but with other[s]… I think there is a big advantage (Ecker, 2009).

Ecker (2009) also points out that, in the past, to expand the number of taxa at an institution, gardens would simply exchange clonal material and thusly, specific taxa were represented by limited generic diversity in collections. Hohn (2008), as well points out "the recirculation of a limited, often unrepresentative, gene pool," as an issue with such material exchange. Limited genetic variation represented in collections reduces the diversity in germplasm available for research, such as breeding, when material is needed (Larson, 2009). Concurrently, researchers with the USDA Forest Service and the Ohio State University suggest that a current barrier to successful hybridization of EAB-resistant ash is a lack of known species with EAB resistance, as well as a limited, genetically diverse sampling of those species for use as parents in breeding programs (Koch et al., 2007). Today, Ecker (2009) notes that greater efforts are made to obtain seed directly from wild collected sources. Additionally, with natively local species, obtaining genetically diverse, locally sourced material that is more adapted to local conditions may increase the health of those plants and their ability to defend themselves against pests (O'Dell, 2009).

Furthermore, for collections to be of conservation value in the face of such threats, holdings need to represent more than the genetics of an individual plant from the wild population. Working with other institutions to accomplish this goal is a must. Being able to collectively identify gaps in collections, to better inform rationale for future acquisition, reduces redundancies in efforts, and leads to greater conservation of the targeted taxa as a whole (Kim, 2009).

<u>Collaborative Efforts by the Public Garden Community and Beyond</u>

Recommendation 10: Power of collaborative efforts

Summary: *Institutions need to seek out and participate in collaborative relationships and initiatives in all aspects of dealings with the challenges presented by the threat of biological invasions. Working to establish such partnerships on a proactive basis will ensure timelier, more informed, and unified efforts when crises do arise.*

"I'm a partnership person… I am a firm believer in collaborative relationships" (Makra, 2009). Although elements of collaboration are stressed in almost all preceding and succeeding recommendations, it is such a resounding element of need, that it warrants additional and explicit acknowledgement. In the cases of biological invasions, institutions need to seek out and actively participate in collaborative initiatives, bringing together intellectual capital and other resources. These efforts result in more timely, informed, and unified actions utilizing the strengths of each partner and avoiding redundancy in activities. With limited resources smaller institutions, in particular, have a tremendous opportunity to gain credibility by peers and increased public exposure. Such partnerships should be proactively developed before disasters occur.

Institutions reported participation in a variety of collaborative activities including national and international germplasm rescue and exploration, resistance breeding and evaluation work, feeding preference research, public education and outreach, and statewide and international planning efforts. Institutions need to seek out collaborative partnerships externally but also within their own organizations. "Unfortunately… you can actually have two people right next to each other and they don't even know what each other is doing. So… the first thing that's really important is that you're collaborating/coordinating with your people" (Telewski, 2009). Institutions reported the generation of valuable information simply by working with people within their garden or individuals affiliated with the institution (e.g. under same university; Carmichael, 2009; Bachtell, 2009; Telewski, 2009, Dosmann, 2009).

Depending on a variety of factors, including available resources, staff, and time, some public gardens took a leading role in these efforts, others filled a particular niche, or played a supporting role by simply allowing access to their grounds for research. Recognizing the need, The Morton Arboretum took on the function as the lead organization in the development of the Illinois Emerald Ash Borer Readiness Plan for the entire state. Filling a valuable niche, The Dawes Arboretum with knowledge of the local forest communities of the county in which the institution resides, has made the effort to be involved in native seed collection as part of a larger effort and continues to identify valuable locations for future collections. Furthermore, getting involved by simply opening your doors can be of immense value; "… one thing that we do is support research on the topic wherever we can" (Carmichael, 2009). Ecker (2009) adds, "… we're not doing the research, but we're providing the materials and the area." Utilizing collections for "research is a fundamental part" of and "principal justification" for collections (Hohn, 2008). "Gardens, particularly smaller gardens and those with restrictive research budgets should cultivate ties with… [other institutions]" (Hohn, 2008).

Many institutional benefits are obtained from such collaborative efforts including: collections expansion, mission fulfillment, intellectual capital, increased credibility among peers, direction for management, and increased institutional awareness and appreciation by the public. For smaller institutions with limited staff and resources finding a collaborative niche is of paramount importance. “I just don’t have those resources to deal with. So, being able to network with people who have those resources is the best way I can become effective” (Telewski, 2009).

Be proactive. No matter the effort, relationship building takes valuable time and energy that should be approached proactively before a crisis hits. Allenstein (2009) explains:

> If you don’t have collaborations already established, or if you don’t have a process or protocol about how you’re going to get there, one of the things that strikes me about what’s happened with EAB is it’s the classic, “it’s a little too late.” And… getting the collaborations take time to build. They can be intrinsically complex. And, some of it is relationship building, which isn’t something that you can really shortcut… So I think that’s one of the real challenges… the need to attempt to be proactive in the first place, understand the mechanisms of collaboration.

Recommendation 11: Information sharing

> **Summary:** *Gardens need to proactively communicate with other gardens, the research community, and appropriate government agencies regarding threats. Sharing and seeking out information regarding pests’ spread, impact, management, and the potential operational implications that mandated regulations and quarantines may have, is of great value. Advocating for increased research funding where information is lacking is also of importance.*

It is critical that public gardens disseminate and seek out biological invasion information in concert with other gardens, the larger research community, and appropriate government agencies, in a timely and efficient fashion. Communicating potential problems, impacts and rate of spread, detection and treatment methods, potential regulations and quarantines, available funding, and opportunities for involvement in collaborative activities are all highly valuable to share. Established partnerships with other gardens, such as through the NAPCC, allows for the exchange of information among institutions focused on related taxa. Other mechanisms, such as establishing email lists and websites, are valuable tools for disseminating updates.

"Just being able to talk with other institutions who've dealt with [EAB] like Dave [Michener]… and researchers… we've been able to… apply their research to conserving our own collections" (Telewski, 2009). Michener's (2008) Public Garden publication informed the greater public garden community of the potential impact and lessons learned from the EAB epidemic. Established collaborations through consortiums such as the NAPCC provide an ideal mechanism for disseminating information pertaining to specific taxa. "If a pest shows up at one of the gardens… they will be able to notify the other ones quickly" (Moe, 2009). Furthermore, established email lists and on-line forums provide mechanisms to reach large audiences instantly. Telewski (2009) utilized the "AABGACOL Listserv," (an international email listing of botanical gardens and arboreta) in the attempt to establish a network of gardens to assist in a *Fraxinus* genetic preservation program through wild seed collection.

Beyond sharing knowledge specifically among public gardens, websites have been very useful in larger efforts. Griffith (2009) reported the Montgomery Botanical Center, as part of efforts for the IUCN World Conservation Union Cycad Specialist Group, developed a webpage with management information pertaining to

Asian cycad scale, which is now hosted by the Cycad Specialist Group's website. The EAB website, www.emeraldashborer.info, developed by a number of universities and government agencies, provides the latest information, including regional and state maps showing the beetle's spread and resulting quarantine zones.

Understanding regulations, quarantine zones, and the impacts on institutional operations can be particularly challenging. Carmichael (2009) reported the loss of nearly $40,000 in unrealized revenue from the sudden oak death quarantine that completely shut down the institution's plant sale. Gentry (2010) commented, "I'd probably say I think the most crucial information that was needed was the regulatory type... quarantines… I got many, many calls about that… where can I move my wood, can I cut down my tree, can I burn it?" Working to proactively establish relationships with state and county agencies before threats arise, allows for easier communication regarding these issues when invasions do occur.

Institutions reported many areas of information that were crucial to their work as well as areas where information was lacking. Institutions also have taking steps through research to contribute to available information themselves.
"Maintenance of the funding base that supports this research capacity in federal and state agencies, academia, and the private sector is a crucial challenge." "Providing the necessary knowledge will require expanded and integrated research and improved communication between scientists and policymakers" (Lovett et al., 2006). Gardens should seek to increasingly advocate for the importance of research related to biological invasions.

Recommendation 12: Importance of advocacy and education

Summary: *As stewards of the plant world and larger environment, public gardens need to be involved in communicating with the public and communities the grave need for diversity in our planted landscapes, the impacts of invasive species on our ecosystems, and what they can do to help. When crises do arise, providing timely information and educational opportunities for the public is a vital necessity and can be of tremendous institutional benefit.*

As history has shown monoculture landscapes are absolutely unsustainable. As a society, lessons from past invasions, in particular DED, largely went unnoticed, and ash replaced elm as a dominant species in the cultivated landscape (Miller, 2009). Public gardens need to reaffirm their commitment to promoting the importance of diversity in our landscapes to the public and communities alike. As the palette of plants suitable for the ever-expanding urban environment is lost, the public gardens' role in plant improvement research and cultivar introduction is of increasing importance. When biological invasions do threaten the integrity of our cultivated and natural landscapes, gardens can help to limit the human-aided spread of the pest, and provide valuable identification and management information to the public. Working with other organizations and agencies to spread a unified message is key. Although the destruction caused by invaders can be overwhelming, institutional benefits of public outreach opportunities can be salvaged and rewarding.

Promoting species diversity in our cultivated landscapes through educational initiatives, as well as in the development of our own institutional collections and displays is essential for reducing impacts of future invasions. Kim (2009) expresses, "we really need to do a better job… [of] promoting and educating the public about how they should landscape in the urban… or even home landscape."

Furthermore, Gentry (2010) describes the need to represent diversity in our own institutions' displays; "… somewhat is a result of [EAB]… in response to what happened with the ash collection… I would like a new collection… that has a lot of different intermediate to large shade trees, that speaks diversity."

As public gardens promote species diversity in the cultivated landscape, they need to play an increasingly important role in the development of new plant introductions adapted for survival in urban conditions. Miller (2009) comments:

> I think that… our biggest tool we can use is diversity… so arboreta need to constantly be working on new species, hybrids… lot of universities aren't going to work too much in there, that's dropped off… we've got to stay ahead of the curve, and we're not… so I think that's going to be key…

As is pointed out by Hohn (2008), "Plant introductions are one of the primary ways in which botanical gardens can make their plant collections… accessible to the public."

As new pests do pose a threat, gardens can do invaluable public education and outreach for the benefit of controlling the spread of the pest, management information, and making the losses into a teaching opportunity. Bringing the resources your institution can provide to a larger collaborative effort strengthens the advocacy mission as a whole. Makra (2009) stresses, "If there's an advocacy interest… put yourself out there and say, "What can we do to help?.. we have 28,000 members we can get information out to them", but to try to get to the table and say here's what we bring." The Arnold Arboretum has used the loss of 30% of its historic Hemlock Hill to HWA as a teaching opportunity to build public awareness of the impact of exotic pests. Through school group studies, visitor tours, community presentations, and use of media outlets, the Arboretum shares with the public the resulting disturbance to native ecosystems and management challenges that such invasions cause (Schulhof, 2007).

The benefits of gardens' advocacy efforts extend beyond reducing the potential impact of invasion. Reported benefits include management of potential public resentment due to the death and removal of specimens (Dosmann 2009; O'Dell, 2009), and greater public awareness and appreciation for the institution (Gentry, 2010).

> The awareness, all the education, all the people we brought in… it increased our visibility quite a bit… a lot of people that live in our community, they have no idea what we are, or have ever been here. And because we were so much out there with education, I think it… put a public face on us… we have some viability… "there's something going on there." We were needed to a certain point, education-wise, and people knew where to come. That's a good thing (Gentry, 2010).

Similarly, in publicizing the loss of collections due to Hurricane Andrew, FTBG reported tremendous donations of volunteer labor for clean up efforts, financial and material gifts, and emotional support as well (Evans, 2003).

Recommendation 13: Regulation and inspection advocacy

> **Summary:** *If public gardens are to have a real impact on reducing the onslaught of biological invasions, precautions to eliminate the risks that our own activities pose, must be of paramount importance. The public garden community needs to take a proactive approach to advocating for greater port inspections to appropriate agencies, while stressing the importance of the research that is performed at our institutions.*

Although through exploration and introduction efforts, gardens have contributed to the spread of exotic plants (Reichard and White, 2001), and with that the potential spread of related pests (Havill and Montgomery, 2008; Schulhof, 2007), the public garden community now needs to turn-the-page advocating for actions to reduce the threat. With globalization fueling a steady parade of new invaders (Barnard and Waage, 2004), gardens need to come together, bringing a unified, proactive voice to address the overarching issues in the fight to slow the pace of destruction. We need to learn from the past, and take every measure possible to eliminate the risks that our own exploration activities and exotic plant collection efforts pose. If we fail to take-on the responsibility to proactively advocate for increased regulation and inspection on trade to government agencies, our reactive "Don't move firewood" like messages, are futile efforts in the greater picture. If public garden professionals fail to participate in crafting and relaying the importance of our research results related to plant conservation, resistance breeding, and other research we must accept the fact that increased restrictions on international transport of plant material will continue to limit our success in such initiatives.

First and foremost, public gardens have a grave responsibility to eliminate the threats that our own activities have had on fueling the invasives fire. Griffith (2009) states, "If you're going to… be doing active collections development work… then talk to your USDA people… and say "… this is what we're doing, what do you suggest?"… And… just following all of the regulations on phytosanitary import." "Botanical gardens in particular should exemplify a lawful and ethical approach to plant collecting… [they] must seek out and follow all state and federally mandated quarantine regulations" (Hohn, 2008).

Secondly, the public garden community needs to advance beyond reactive promotion of issues that challenge our collections, environment, and society. As is reported by Schulhof (2007), a 2002 study by the National Academy of Sciences (NAS) indicated that the USDA only inspects 2% of the cargo coming into the U.S. and yet still encounters 53,000 exotic organisms annually. The NAS report suggests that between the years of 2000 and 2020, low estimations predict that 115 new exotic insects and five plant pathogens will become established in the U.S. If we are to have a true impact on reducing these numbers our opinions and concerns must be actively voiced (Schulhof, 2007). Mason and Payton comment:

> I think the major lesson is… in the way of protecting our shores. That's not something we're involved in, but… we could perhaps be an advocate for increased inspection (Payton, 2009)… maybe joining with other like-minded organizations… forming that lobbyist group… obviously… the voice isn't out there at this point in time, in mass enough, to make that change come about (Mason, 2009).

Similarly, Schulhof (2007) says, "The USDA, among other domestic and international agencies, must strengthen efforts to prevent unintended introductions as well as accelerate research programs to better inform management efforts." "Agencies charged with inspecting imports and detecting new introductions must be cognizant of the importance of the task and have the resources necessary to accomplish it…" (Lovett et al., 2006).

With the onslaught of recent invasions, stricter regulations have affected traditional plant exploration and research practices, such as resistance breeding, performed at public gardens in the face of such threats. Allenstein (2009) suggests,

> … with the change in importation regulations, and some of the changes that are coming forward… we may end up not having had our views or perspectives be recognized, and the borders being closed, so some of the traditional roles that botanical gardens have been playing will be that much more difficult to continue. And to have more informed laws… we need to be at the table, and when asked, we need to be responding… rather than waiting until after the fact.

Unless we actively promote the importance of international exchange and collection of plant material for conservation, research, urban plant breeding and development, education, and other mission critical initiatives, public gardens should be prepared for these roles to change.

Preliminary Account of *Fraxinus* Collections Globally

User Group Survey

As an initial step in inventorying the documented wild origin *Fraxinus* collections held globally, the "User Group Survey" first sought to identify the specific information regarding a plant specimen that is valuable to plant professionals in various fields. This information could then be collected through the "Survey of *Fraxinus* Collections." In the ranking of 12 specified plant information fields on a "necessity" scale, respondents reported all fields to have value (Table 6.3). Even for the lowest ranked field, "accession number" (number assigned by institution holding specimen), 71.9% of respondents indicated that it would have some level of value in their objectives (Figure 6.1). Participants suggested a number of additional information fields as well (Appendix I). One respondent commented:

> I would prefer that every sample come with all of this passport information. It would lead to MUCH better plant breeding. In the ornamental plant breeding world we have used poorly documented

> plant material in breeding for so long, we don't expect any better. So much of the wild germplasm utilized in breeding has no associated passport information, we have no idea how close we have come to seeing or utilizing the potential in these genetic resources!

Several respondents noted, "The plant resources needed for different endeavors varies greatly."

Furthermore, participants were asked how valuable a global *ex situ* collections inventory would be for a particular plant group with which they are working. Over 90% of all respondents saw at least some value in global collections inventories of living plant, herbarium, and seed holdings (Figure 6.2); with one respondent noting, "online databases of living and herbarium specimens can save a lot of data entry time, and can be very helpful in locating resources." As stated in the "Importance of documentation and mapping" recommendation in this Chapter's previous section, gardens should seek to maintain well-documented collections, increasing the usability of those holdings for research and other activities. Furthermore, gardens should continue to explore ways to unify multiple institutions' databases into a single accessible system, making such inventories more immediately available when needed.

<u>**Survey of *Fraxinus* Collections**</u>

The "Survey of *Fraxinus* Collections" yielded a response rate, to the on-line survey portion of the study, of 39.1% (59 institutions). Of respondents reporting wild origin *Fraxinus* holdings, on average it was reported that institutions held greater numbers of direct wild origin (specimens collected directly from plants in wild) versus indirect wild origin (specimens collected from cultivated plants of known wild origin), of cultivated living plants and herbarium specimens. Seed was only reported as being held of direct wild origin. Although, the majority of specimens held were reportedly of direct wild origin, the survey did not take into account whether specimens were from unique collections. For example, if an institution collects seed from a tree in the wild and disperses portions of the seed lot to 50 other institutions through their Index Seminum, all 50 institutions would report the holdings to be of direct wild origin; but in actuality, all the specimens would represent a very narrow range of or no genetic diversity. One "User Group Survey" respondent brings up the issue of relatedness in botanical garden holdings:

> One thing I have run into is that through sharing materials, the same individual, or individuals derived from the same seed lot, may be represented in different botanical gardens. Since each garden has its own accession number assigned, we have collected duplicate… and closely related individuals and not realized it until after considerable effort was made to arrange transfer and propagate the material. A system of tracking the relatedness or common identity of collections in different gardens should be incorporated into any inventory project.

As is stressed in the "Collection development" recommendation in this Chapter's previous section, institutions need to seek greater genetic diversity among their holdings (Kim, 2009; Ecker, 2009), more completely representing the genetics of a given population, to be of value in *ex situ* conservation efforts and research initiatives when needed.

Ultimately survey participants were requested to submit an inventory of their *Fraxinus* holdings. In all, 37 institutions followed through, providing information regarding their documented wild origin *Fraxinus* holdings. Thirty-three institutions provided cultivated living plant accession information (567 total accessions), 9 institutions provided herbarium specimen information (68 total accessions), and 6 institutions provided information regarding seed holdings (213 total accessions; Appendix L). Appendix M contains unsolicited information surrounding many more accessions of origins including: specimens naturally occurring at the institution, unknown origin, or in cases where the origin was not provided to researcher. Although it should be noted that this study does not endorse the use of any one *Fraxinus* classification system, in all, 60 species were reported, of which only 32 (53.3%) are classified as unique species in Wallander (2008), a revised infrageneric classification of the genus *Fraxinus* (Table 6.8). Of the six species that were only found in Appendix M, Wallander (2008) reports none as unique species and only one has an associated synonym.

In all, the Wallander (2008) classification indentifies 43 unique species. This leaves 11 species (5 Asian and 6 North American; listed in Appendix P) that were not represented in the institutional inventories obtained through this research. All 6 North American species have southern geographic distributions on the continent (Wallander, 2008), and thus the lack of representation may reflect the limited number of institutional inventories received from southern regions. Similarly, no inventories were obtained from Asian institutions and may reflect the lacking 5 Asian species not recorded by this study. Additionally, many taxa that were reported by institutions are collectively represented by a limited number of accessions. In particular, as is reported in Appendix N, *F. apertisquamifera* Hara, *F. chiisanensis* Nakai, *F. greggii* A. Gray, *F. malacophylla* Hemsl., and *F. raibocarpa* Regel are represented by only a single accession. These species are all reported as unique species by Wallander (2008), and only *F. malacophylla* Hemsl. has a single reported synonym (*F. retusifoliolata* Feng ex P.Y. Bai) in the Wallander (2008) classification, also not represented in the compiled inventory. Further investigation into the *ex situ Fraxinus* collections held globally, and in particular in the regions mentioned above, should be preformed to obtain an accurate assessment of the current state of *Fraxinus* holdings.

Furthermore, although 70.2% of the on-line survey respondents reported having a formal accessions verification system at their institution, in the submission of the actual inventories it is conservatively estimated that only 17.7% of submitted wild origin accessions were noted as being verified by the submitting participants. Gardens need to take steps to ensure the validity of the collections for which they oversee. As one “User Group Survey” respondent noted, the value of global *ex situ* collection inventories would be “extremely important, if I could trust the veracity of the *ex situ* collections.” “Gardens striving to develop comprehensive and credible living collections have an active and ongoing verification program” (Hohn, 2008).

A few challenges should be noted in the completion of this inventory. First, the majority of institutions contacted for participation in the survey were based on institutions reporting *Fraxinus* accessions to the © Copyright BGCI Garden Database. It was indicated by BGCI that data quality issues, such as being outdated, are associated with the institutional contact information provided to the researcher (BGCI, 2009b) and thus could have had an impact on response rate. Additionally, many more institutions may hold *Fraxinus* collections, but simply do not report these accessions to BGCI’s database, and thus were not included in the study unless added to the survey recipient list individually by the researcher. Furthermore, language barriers may have played a role in reducing the number of responses received from institutions residing in countries in which English is not the primary language. Finally, in a few cases institutions simply reported that inventory information was already available on-line or the information is confidential.

Ultimately it is the intention that this preliminary account of *Fraxinus* holdings will aid in future *Fraxinus* inventory efforts, identify plant material available for breeding work and other research, better focus future exploration efforts targeting *Fraxinus* species, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

Appendices

Appendix A

HUMAN SUBJECTS REVIEW BOARD APPROVAL LETTERS

HUMAN SUBJECTS PROTOCOL
University of Delaware

Protocol Title: **Preliminary Survey for Future *Fraxinus* Collections Research**

Principal Investigator
Name: **Andrew Gapinski**
Contact Phone Number: **(302) 690-9978**
Email Address: **atgap@udel.edu**

Advisor (if student PI):
Name: **Dr. Robert Lyons**
Contact Phone Number: **(302) 831-2517**
Email Address: **rlyons@udel.edu**

Other Investigators:

Type of Review:
✓ Exempt   Expedited   Full board

Exemption Category: 1 2 3 4 5 6

Minimal Risk: ✓ yes ______ no

Submission Date: 4/12/09

HSRB Approval Signature	Approval Date
Elizabeth Driggus Peloso	4/13/09
HS Number	**Approval Next Expires**
XMP 402	n/a

Investigator Assurance:
By submitting this protocol, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the HSRB. Should any unanticipated problems involving risk to subjects, including breaches of guaranteed confidentiality occur during this project, I will report such events to the Chair, Human Subjects Review Board immediately.

Signature of Investigator: ______________________________

Date: ______________________________

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

May 5, 2009

Andrew Gapinski
Longwood Program

Re: Global Inventory of Ex Situ Fraxinus (ash) Collections

Dear Andrew,

Thank you for letting us know about your planned research activities. Because you are requesting only factual information about institutional practices and collections, you are not engaging in human subjects research. Consequently, IRB review of the project is not required.

Sincerely,

Elizabeth Duggins Peloso

Elizabeth D. Peloso
IRB Administrator
Director of Compliance
Research Office

HUMAN SUBJECTS PROTOCOL
University of Delaware

Protocol Title: **Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (*Agrilus planipennis* Fairmaire)**

Principal Investigator
Name: **Andrew Gapinski**
Contact Phone Number: **(302) 690-9978**
Email Address: **atgap@udel.edu**

Advisor (if student PI):
Name: **Dr. Robert Lyons**
Contact Phone Number: **(302) 831-2517**
Email Address: **rlyons@udel.edu**

Other Investigators:

Type of Review:
✓ Exempt   Expedited   Full board

Exemption Category: 1 (2) 3 4 5 6

Minimal Risk: ✓ yes ______ no

Submission Date: 4/12/09

HSRB Approval Signature	Approval Date
Elizabeth Duggan Peloso	7/20/09
HS Number	Approval Next Expires
XMP 456	n/a

Investigator Assurance:
By submitting this protocol, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the HSRB. Should any unanticipated problems involving risk to subjects, including breaches of guaranteed confidentiality occur during this project, I will report such events to the Chair, Human Subjects Review Board immediately.

Signature of Investigator: ______________________

Date: ______________________

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	January 5, 2010
TO:	Andrew Gapinski
FROM:	University of Delaware IRB
STUDY TITLE:	[151184-1] Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (Agrilus planipennis Fairmaire)
IRB REFERENCE #:	
SUBMISSION TYPE:	Amendment/Modification
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	January 5, 2010
REVIEW CATEGORY:	Exemption category # 2

Thank you for your submission of Amendment/Modification materials for this research study. The University of Delaware IRB has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will put a copy of this correspondence on file in our office. Please remember to notify us if you make any substantial changes to the project.

If you have any questions, please contact Elizabeth Peloso at 302-831-8619 or epeloso@udel.edu. Please include your study title and reference number in all correspondence with this office.

Appendix B

INFORMED CONSENT FORM

Informed Consent Form for Interviews

The Longwood Graduate Program

Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (Agrilus planipennis Fairmaire*)*

You have been invited to participate in a research study concerning the effects emerald ash borer (EAB) has had on plant collections and natural areas at public horticulture institutions. The purpose of the study is to investigate and document the impact of EAB, articulate and publicize management strategies and lessons learned from the destruction, and discover and report what institutions yet to be affected are doing to prepare for the inevitable spread. This study will also document similar cases of biological invasion that are affecting institutions in other parts of North America. The ultimate goal of this research is to develop recommendations for public horticulture institutions to better prepare for future exotic insect and pathogen introductions.

Please read the information below describing this study and feel free to ask questions about anything you do not understand before deciding to take part. Your participation is voluntary and you are free to refuse to answer any question or withdraw from this study at any time without penalty.

Procedures of the Study

Interviews with public horticulture professionals will be conducted at a number of public gardens throughout North America. Audio recordings of interviews are necessary to ensure proper collection and comprehension of data by the researcher. Audio recordings and notes taken during the interviews will serve as an important component of the research. Audio recordings will be destroyed two years after the study is complete. *Direct quotations, your name, and the name of your organization may be referenced in the final document.* There is no compensation for your voluntary participation in this study.

If you understand that this interview will be audio recorded and you agree to this, please initial here: **______Subject's Initials**

Contact Information

If you have questions about this research, please contact Mr. Andrew Gapinski (e-mail: atgap@udel.edu), Longwood Graduate Fellow, or Dr. Robert Lyons, Longwood Graduate Program Coordinator by phone at (302) 831-1369. If you have any concerns about your rights as a participant, contact the Chair of the University of Delaware Human Subjects Review Board at (302) 831-2136.

If you agree to participate in this research, please print and sign your name below.

____

Name of Subject (Please Print)

____

Signature of Subject **Date**

Appendix C

INTERVIEW PROTOCOL: INSTITUTIONS HAVING LOCATED EAB ON THEIR GROUNDS

Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (*Agrilus planipennis* Fairmaire)

> This research will investigate and document the effects that emerald ash borer (EAB) has had on plant collections and natural areas at public horticulture institutions, articulate and publicize management strategies and lessons learned from the EAB impact, and discover and report what institutions yet to be affected are doing to prepare for the inevitable spread. This study will also document similar cases of biological invasion that are affecting institutions in other parts of North America. The ultimate goal of this research is to develop recommendations for public horticulture institutions to better prepare for future exotic insect and pathogen introductions.

<u>Collection and natural area information</u>

How many cultivated *Fraxinus* accessions/individual specimens did your institution hold before the introduction of EAB? What percentage of specimens have been affected/destroyed? Please describe the effects that EAB has had on your institution's *Fraxinus* specimens.

What is the estimated acreage of your institution's natural areas? What percentage of trees in these areas are/were *Fraxinus*? To what extent has your institution's natural areas been affected/destroyed? Please describe the effects that EAB has had on your institution's natural areas.

How much of your institution's core objectives/mission relied on the success/health of your institution's *Fraxinus* holdings (accessions and natural areas)?

Prior to the introduction of EAB to your institution, what were your institution's primary objectives regarding *Fraxinus*? How has that changed with the introduction of

EAB? Has your institution established any new objectives regarding *Fraxinus* (e.g. resistance breeding, public outreach, etc.)?

Has your institution experienced devastation of other plant groups from past insect or disease invasions? To your knowledge did these events influence/change collections/natural areas management practices at your institution? If so, how do you believe these changes altered the effects that EAB had on your institution?

Has your institution taken steps to report the effects that EAB has had on your institution's collections and natural areas? If so, please describe.

<u>Readiness Planning and Management</u>

Regarding biological invasions, did your institution have a Disaster Readiness Plan for its collections and/or natural areas in place prior to the introduction of EAB at your institution? If so, please describe the plan. Has your institution's plan been modified since the introduction of EAB? If it had not done so prior to the invasion, has your institution implemented a Readiness Plan regarding biological invasions in the aftermath of the EAB destruction?

Regarding its collections and natural areas, what steps is your institution currently taking to manage EAB?

Has your institution established any collaborative relationships with other institutions dealing with or preparing for EAB regarding collections and natural areas? If so, how have these relationships aided your institution?

Outside of your institution what actions has your institution taken to aid in the management of wild *Fraxinus* populations, regarding EAB?

Outside of your institution what actions has your institution taken to aid in the management of urban *Fraxinus* populations (street trees, parks, etc.), regarding EAB?

Has your institution been involved in any community or statewide planning processes regarding EAB? If so, please describe.

Has your institution taken steps to report/share the EAB management strategies utilized by your institution?

Are there activities your institution would like to be involved in regarding EAB, but has been unable to do so thus far? If so, please describe the barriers/obstacles that are preventing involvement in these activities.

Are there activities your institution could be involved in regarding EAB, but has been reluctant to do so thus far? If so, please describe the reasoning behind the reluctance to be involvement in these activities.

Preparing for future exotic pest invasions

What information has been particularly beneficial/crucial to your institution in its EAB preparation, management, and initiatives? What additional information, not available, would advance these efforts?

What lessons has your institution learned, regarding its core collections as a result of the effects that EAB has had on its *Fraxinus* accessions and natural areas?

What steps is your institution taking to prepare/protect other key collections that are vital to your institution's mission, from future insect or disease invasions?

In general, what do you think institutions can do to better protect/prepare their collections from future insect and disease invasions?

What benefits may multi-institutional efforts, such as the North American Plant Collections Consortium (NAPCC), serve to better prepare/protect collections from and in the management of future exotic insect and disease introductions?

Appendix D

INTERVIEW PROTOCOL: INSTITUTIONS LOCATED IN THE IMPENDING RANGE OF EAB

Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (*Agrilus planipennis* Fairmaire)

> This research will investigate and document the effects that emerald ash borer (EAB) has had on plant collections and natural areas at public horticulture institutions, articulate and publicize management strategies and lessons learned from the EAB impact, and discover and report what institutions yet to be affected are doing to prepare for the inevitable spread. This study will also document similar cases of biological invasion that are affecting institutions in other parts of North America. The ultimate goal of this research is to develop recommendations for public horticulture institutions to better prepare for future exotic insect and pathogen introductions.

<u>Collections and natural area information</u>
How many cultivated *Fraxinus* accessions/individual specimens did your institution hold before the introduction of EAB to North America? What percentage of specimens have been removed in preparation for EAB at your institution? Please describe the reasoning behind the removal these specimens.

What is the estimated acreage of your institution's natural areas? What percentage of trees in these areas are *Fraxinus*? What percentage of trees have been removed in preparation for EAB at your institution? Please describe the reasoning behind the removal of these trees.

How much of your institution's core objectives/mission relies on the success/health of your institution's *Fraxinus* holdings (accessions and natural areas)?

Prior to the introduction of EAB to North America, what were your institution's primary objectives regarding *Fraxinus*? How has that changed with the introduction of EAB to North America? Has your institution established any new objectives regarding *Fraxinus* (e.g. resistance breeding, etc.)?

Has your institution experienced devastation of other plant groups from past insect or disease invasions? To your knowledge did these events influence/change collections/natural areas management practices at your institution? If so, how do you believe these changes will alter the effects that EAB has on your institution?

Has your institution taken steps to learn about the effects that EAB has already had on other institutions collections and natural areas? If so, please describe.

<u>Readiness planning and management</u>

Regarding biological invasions, did your institution have a Disaster Readiness Plan for its collections and/or natural areas in place prior to the introduction of EAB to North America? If so, please describe the plan. Has your institution's plan been modified since the introduction of EAB to North America? If it had not done so prior to the invasion, has your institution implemented a Readiness Plan regarding biological invasions in the aftermath of the EAB destruction?

Regarding its collections and natural areas, what steps is your institution currently taking to prepare for the introduction of EAB at your institution?

Has your institution established any collaborative relationships with other institutions dealing with or preparing for EAB regarding collections and natural areas? If so, how have these relationships aided your institution?

Outside of your institution what actions has your institution taken to aid in the management of wild *Fraxinus* populations, regarding EAB?

Outside of your institution what actions has your institution taken to aid in the management of urban *Fraxinus* populations (street trees, parks, etc.), regarding EAB?

Has your institution been involved in any community or statewide planning processes regarding EAB? If so, please describe.

Has your institution taken steps to report/share the EAB preparation strategies utilized by your institution?

Are there activities your institution would like to be involved in regarding EAB, but has been unable to do so thus far? If so, please describe the barriers/obstacles that are preventing involvement in these activities.

Are there activities your institution could be involved in regarding EAB, but has been reluctant to do so thus far? If so, please describe the reasoning behind the reluctance to be involvement in these activities.

Preparing for future exotic pest invasions

What information has been particularly beneficial/crucial to your institution in its EAB preparation, management, and initiatives? What additional information, not available, would advance these efforts?

What lessons has your institution learned regarding its core collections as a result of the effects that EAB has had on collections and natural areas in North American?

What steps is your institution taking to prepare/protect other key collections that are vital to your institution's mission, from future insect or disease invasions?

In general, what do you think institutions can do to better protect/prepare their collections from future insect and disease invasions?

What benefits may multi-institutional efforts, such as the North American Plant Collections Consortium (NAPCC), serve to better prepare/protect collections from and in the management of future exotic insect and disease introductions?

Appendix E

INTERVIEW PROTOCOL: INSTITUTIONS AFFECTED BY OTHER BIOLOGICAL INVASIONS

Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (*Agrilus planipennis* Fairmaire)

> This research will investigate and document the effects that emerald ash borer (EAB) has had on plant collections and natural areas at public horticulture institutions, articulate and publicize management strategies and lessons learned from the EAB impact, and discover and report what institutions yet to be affected are doing to prepare for the inevitable spread. This study will also document similar cases of biological invasion that are affecting institutions in other parts of North America. The ultimate goal of this research is to develop recommendations for public horticulture institutions to better prepare for future exotic insect and pathogen introductions.

<u>Collections and natural area information</u>

What is the most significant invasive insect or disease that is currently or has recently impacted your institution? Which of your collections/plant groups have been affected? How many cultivated accessions/individual specimens of the affected plant group did your institution hold before the introduction of this pest? What percentage of specimens have been affected/destroyed? Please describe the effects that the pest has had on your institution's accessions.

Has this pest had an impact on your institution's natural areas? If so what is the estimated acreage of your institution's natural areas? What is the extent of the population of the affected plant group in these areas? To what extent have those natural populations been affected/destroyed? Please describe the effects that the pest has had on your institution's natural areas.

How much of your institution's core objectives/mission relies/relied on the success/health of the affected plant group (accessions and natural areas)?

Prior to the introduction of the pest to your institution, what were your institution's primary objectives regarding the affected plant group? How has that changed with the introduction of the pest? Has your institution established any new objectives regarding affected plant group (e.g. resistance breeding, etc.)?

Has your institution experienced devastation of other plant groups from past insect or disease invasions? To your knowledge did these events influence/change collections/natural areas management practices at your institution? If so, how do you believe these changes altered the effects that the recent pest has had on your institution?

Readiness Planning and Management

Regarding biological invasions, did your institution have a Disaster Readiness Plan for its collections and/or natural areas in place prior to the introduction of the pest at your institution? If so, please describe the plan. Has your institution's plan been modified since the introduction of the pest? If it had not done so prior to the invasion, has your institution implemented a Readiness Plan regarding biological invasions in the aftermath of the destruction?

Regarding its collections and natural areas, what steps has your institution taken to manage the pest?

Has your institution established any collaborative relationships with other institutions dealing with or preparing for the pest regarding collections and natural areas? If so, how have these relationships aided your institution?

Outside of your institution what actions has your institution taken to aid in the management of wild populations of the affected plant group, regarding the pest?

Outside of your institution what actions has your institution taken to aid in the management of urban populations (street trees, parks, etc.) of the affected plant group, regarding the pest?

Has your institution been involved in any community or statewide planning processes, regarding the pest? If so, please describe.

Has your institution taken steps to report/share the impact that the pest has had and the management strategies utilized by your institution?

Are there activities your institution would like to be involved in regarding the pest, but has been unable to do so thus far? If so, please describe the barriers/obstacles that are preventing involvement in these activities.

Are there activities your institution could be involved in regarding the pest, but has been reluctant to do so thus far? If so, please describe the reasoning behind the reluctance to be involvement in these activities.

Preparing for future exotic pest invasions

What information has been particularly beneficial/crucial to your institution in its preparation, management, and initiatives, regarding the pest? What additional information, not available, would advance these efforts?

What lessons has your institution learned, regarding its core collections as a result of the effects that the pest has had on its accessions and natural areas?

What steps is your institution taking to prepare/protect other key collections that are vital to your institution's mission, from future insect or disease invasions?

In general, what do you think institutions can do to better protect/prepare their collections from future insect and disease invasions?

What benefits may multi-institutional efforts, such as the North American Plant Collections Consortium (NAPCC), serve to better prepare/protect collections from and in the management of future exotic insect and disease introductions?

Appendix F

INTERVIEW PROTOCOL: PROFESSIONALS INVOLVED IN COLLABORATIVE INITIATIVES

Preparing Plant Collections for Biological Invasions: A Case Study of the Effects of Emerald Ash Borer (*Agrilus planipennis* Fairmaire)

> This research will investigate and document the effects that emerald ash borer (EAB) has had on plant collections and natural areas at public horticulture institutions, articulate and publicize management strategies and lessons learned from the EAB impact, and discover and report what institutions yet to be affected are doing to prepare for the inevitable spread. This study will also document similar cases of biological invasion that are affecting institutions in other parts of North America. The ultimate goal of this research is to develop recommendations for public horticulture institutions to better prepare for future exotic insect and pathogen introductions.

<u>Objectives and coordination of efforts</u>
Please describe your current position and general work objectives?
What, if any, were your objectives regarding *Fraxinus* prior to the introduction of EAB? How has the introduction of EAB changed these objectives?

What new objectives regarding the genus *Fraxinus* and/or EAB have you been involved in since the introduction? What is the purpose/goal of these objectives? Was there a strategy for these objectives in place, as part of a Readiness Plan, prior to the invasion? How timely were these objectives instated based on the initial outbreak of the pest?

If a government based program, what agencies at the Federal, State, and local level have been involved? Have public gardens and arboreta been involved in meeting these objectives? How many gardens have been involved? How did these institutions learn of the opportunity to be involved? What other types of institutions have been involved?

Was there a process or set procedure in place for the coordination of efforts within your organization or agency, inter-agency, and/or with external stakeholders such as botanical gardens and arboreta before the invasion?

What were the keys to the successful coordination of efforts between these groups? What were the challenges/roadblocks that you faced in the coordination of these efforts?

Public Gardens' involvement

What roles have institutions, and in particular public gardens, played in meeting these objectives? What resources have these institutions provided?

What impact has the involvement of these institutions had on these objectives? What benefits do institutions gain from their involvement in these objectives?

What information, resources, and/or qualities must an institution have to be of benefit to your objectives? What additional information, resources, and/or qualities increase the value of an institution to your objectives?

Are there qualified institutions that have been reluctant or unable to be involved in your objectives? Do you know why?

Lessons learned and preparing for future biological invasions

In general, what lessons have you learned regarding these objectives and the coordination of parties involved? How have/will these lessons change these objectives and/or future biological invasion initiatives?

Regarding these objectives what lessons having you learned pertaining to the involvement of public gardens and arboreta, in particular? Can you speculate how these lessons may change the involvement of such institutions in future objectives regarding EAB and/or future biological invasions?

What steps can public gardens and arboreta take now to better prepare for involvement in future objectives pertaining to EAB and/or future biological invasions?
In general, what do you think public gardens can do to better protect/prepare their collections and natural areas from future insect and disease invasions?

What benefits may multi-institutional efforts/consortiums provide to better prepare/protect collections and natural areas from future insect and disease invasions? How about in the management of future invasions?

Overall, what are the lessons that can be taken away from our dealings with EAB, in the prevention, preparation, management, and coordination of efforts involving future biological invasions?

Appendix G

USER GROUP SURVEY

First Contact - Invitation to Participate Email

Greetings,

I would like to invite you to participate in a research survey regarding plant specimen information needed by plant professionals. This survey is a component of my M.S. thesis research in the Longwood Graduate Program at the University of Delaware. This research seeks to identify specific, critical information about individual plant specimens that is required by plant professionals engaged in work including breeding, entomological studies, forest products, conservation, and public horticulture, to name a few.

As a participant in the survey, you are free to terminate your participation at any time by simply closing your Web browser before you press the final submission button. Any responses you previously made will not be included in the study.

The survey consists of seven questions and should take less than ***five*** minutes to complete. If you prefer to register a response on a paper survey please contact me to request that a paper copy be mailed to you. Thank you for your consideration and time.

Please click the link below to proceed:
{Survey Link}

Or copy and paste the url below into your internet browser: {Survey URL}

Sincerely,

Andrew Gapinski

Graduate Fellow
Longwood Graduate Program
126 Townsend Hall
University of Delaware
Newark, DE 19716-2106
Tel: 302-831-2517
Fax: 302-831-3651

atgap@udel.edu

www.udel.edu/longwoodgrad/

<u>Reminder Contact - Invitation to Participate Email</u>

Greetings,

This e-mail is a reminder of the opportunity to participate in a research survey regarding plant specimen information needed by plant professionals. This survey is a component of my M.S. thesis research in the Longwood Graduate Program at the University of Delaware. This research seeks to identify specific, critical information about individual plant specimens that is required by plant professionals engaged in work including breeding, entomological studies, forest products, conservation, and public horticulture, to name a few.

As a participant in the survey, you are free to terminate your participation at any time by simply closing your Web browser before you press the final submission button. Any responses you previously made will not be included in the study.

The survey consists of seven questions and should take less than ***five*** minutes to complete. If you prefer to register a response on a paper survey please contact me to request that a paper copy be mailed to you. Thank you for your consideration and time.

Please click the link below to proceed:
{Survey Link}

Or copy and paste the url below into your internet browser: {Survey URL}

Sincerely,

Andrew Gapinski

Graduate Fellow
Longwood Graduate Program
126 Townsend Hall
University of Delaware
Newark, DE 19716-2106
Tel: 302-831-2517
Fax: 302-831-3651

atgap@udel.edu

www.udel.edu/longwoodgrad/

Follow this link to opt out of future emails: {Opt Out Link}

<u>On-line Survey</u>

Specimen Information Needed by Plant Professionals

This survey seeks to identify specific, critical information about individual plant specimens that is needed by plant professionals engaged in work including breeding, entomological studies, forest products, conservation, and public horticulture, to name a few.

This study is being conducted by Andrew Gapinski of the Longwood Graduate Program at the University of Delaware. Survey results will be published as part of a M.S. thesis and will be available upon request.

The survey consists of seven questions and takes approximately five minutes to complete.

Individual responses will be collected on a secure web server and will be confidential and viewed only by the principal investigator. Survey respondents will remain completely anonymous and all data will be destroyed after two years. Your participation is entirely voluntary. To leave the study at any time, simply close the web browser. You may return to the study via the same link.

The electronic survey will be available until Tuesday, May 26, 2009. If you prefer to submit a response using a paper survey or have any questions concerning the study, please contact Andrew Gapinski, atgap@udel.edu. Research results will be available around July, 2010.

Your participation is greatly appreciated! Please press the "next" button to continue.

1. **What position do you currently hold at your institution?**
(No personally identifiable information will be associated with your responses in any reports of this data. Please do not indicate the name of your institution.)

[text box]____________________

2. **In your current position, what are your primary objectives involving plants?**
(Please check all that apply)

___Research
___Breeding/Selection
___Entomology
___Pathology
___Production
___Forest products
___Conservation
___Collections
___Other (specify all additional objectives)

3. **What type(s) of plant material is(are) of value to your professional objectives?**
(Please check all that apply)

___Cultivated living plants
___Seed
___Herbarium specimens
___Clonal material (e.g. cuttings)
___Other (specify all additional types)
[text box]____________________

4. **What information about an individual plant specimen is necessary for the specimen to be of value to your professional objectives?**
For each of the following information fields please indicate whether the information is "necessary for specimen to be of value", "not necessary, but increases value of specimen", or "not at all necessary".

Scientific name of specimen___ ___ ___
Type of specimen (cultivated living plant, seed, or herbarium specimen)___ ___ ___
Origin status (wild collected vs. cultivated source)___ ___ ___
Country and region of origin if wild collected___ ___ ___
GPS coordinates if wild collected___ ___ ___
Specific information about the collection site if wild collected (e.g. soil type); specify all conditions below___ ___ ___

[text box]____________________

Name(s) of collector(s)___ ___ ___
Date of field collection___ ___ ___
Collection Number (assigned by collectors)___ ___ ___
Date acquired by institution holding specimen___ ___ ___
Accession Number (assigned by institution holding specimen)___ ___ ___
Verification status (whether the specimen has been determined to be identified correctly)___ ___ ___

5. **Please indicate any <u>additional</u> information about an individual plant specimen, not described above, that is necessary for the specimen to be of value to your professional objectives.**
Record this additional information as either "necessary for specimen to be of value" or "not necessary, but increases value of specimen" in the corresponding boxes below.

Necessary for specimen to be of value

[text box]____________________

Not necessary, but increases value of specimen

[text box]____________________

6. **Consider a group of plants with which you are currently working.**

How <u>valuable</u> would you consider a global *ex situ* collections inventory, of related plant specimens, in the completion of your professional objectives?
Please note that an *ex situ* collection refers to specimens held in botanic gardens, arboreta and other storage facilities. Indicate the level of <u>value</u> for each type of the collection holding listed. [Extremely Valuable; Very Valuable; Somewhat Valuable; Slightly Valuable; Not at all Valuable]

Inventory of cultivated living plant holdings___ ___ ___ ___ ___
Inventory of seed holdings___ ___ ___ ___ ___
Inventory of herbarium holdings___ ___ ___ ___ ___

Other___ ___ ___ ___ ___
[text box]____________________

7. Please record any additional comments regarding this survey in the space provided below.

Please click the "Next" button to submit your survey.

[End of Survey Message] Thank you for completing the survey. Your professional expertise and insight is critical to the success of this research project. The results of this study will be available around July 2010. If you would like to receive a copy of the results, please contact Andrew Gapinski via e-mail at atgap@udel.edu. To learn more about the Longwood Graduate Program, please visit the Program's Web page at http://www.udel.edu/longwoodgrad.

Appendix H

SURVEY OF *FRAXINUS* COLLECTIONS

First Contact - Invitation to Participate Email

Greetings,

I would like to invite your institution to participate in a global inventory of *ex situ Fraxinus* collections. This survey is a component of my M.S. thesis research in the Longwood Graduate Program at the University of Delaware; Newark, Delaware, USA. This survey seeks to compile information on selected *Fraxinus* collections at approximately 150 institutions globally. This research aims to improve future exploration efforts of *Fraxinus* species, identify *Fraxinus* species that are available for emerald ash borer (EAB) resistance breeding, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

As a participant in the survey, you are free to terminate your participation at any time by simply closing your Web browser before you press the final submission button. Any responses you previously made will not be included in the study.

The survey consists of around ten questions and should take less than ***15*** minutes to complete. If you prefer to register a response on a paper survey please contact me to request that a paper copy be mailed to you.

If you feel a different individual within your institution could better address questions regarding your institution's *Fraxinus* accessions, please feel free to forward this survey to them. Thank you for your time and consideration.

Follow this link to the Survey:
{Survey Link}

Or copy and paste the url below into your internet browser:
{SurveyURL}

Sincerely,

Andrew Gapinski
Graduate Fellow
Longwood Graduate Program
126 Townsend Hall
University of Delaware
Newark, DE 19716-2106
Tel: 302-831-2517
Fax: 302-831-3651
atgap@udel.edu

www.udel.edu/longwoodgrad/

Follow the link to opt out of future emails:{Opt Out Link}

<u>Reminder Contact - Invitation to Participate Email</u>

Greetings,

This e-mail is a reminder of the opportunity for your institution to participate in a global inventory of *ex situ Fraxinus* collections. This survey is a component of my M.S. thesis research in the Longwood Graduate Program at the University of Delaware; Newark, Delaware, USA. This survey seeks to compile information on selected *Fraxinus* collections at approximately 150 institutions globally. This research aims to improve future exploration efforts of *Fraxinus* species, identify *Fraxinus* species that are available for emerald ash borer (EAB) resistance breeding, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

As a participant in the survey, you are free to terminate your participation at any time by simply closing your Web browser before you press the final submission button. Any responses you previously made will not be included in the study.

The survey consists of around ten questions and should take less than ***15*** minutes to complete. If you prefer to register a response on a paper survey please contact me to request that a paper copy be mailed to you.

If you feel a different individual within your institution could better address questions regarding your institution's *Fraxinus* accessions, please feel free to forward this survey to them. Thank you for your time and consideration.

Follow this link to the Survey:
{Survey Link}

Or copy and paste the url below into your internet browser:
{Survey URL}

Sincerely,

Andrew Gapinski

Graduate Fellow
Longwood Graduate Program
126 Townsend Hall
University of Delaware
Newark, DE 19716-2106
Tel: 302-831-2517
Fax: 302-831-3651

atgap@udel.edu

www.udel.edu/longwoodgrad/

Follow the link to opt out of future emails:{Opt Out Link}

Final Contact - Invitation to Participate Email

Greetings,

This e-mail is the **final reminder** of the opportunity for your institution to participate in a global inventory of *ex situ Fraxinus* collections. **This survey will close Friday, August 14, 2009**. This survey is a component of my M.S. thesis research in the Longwood Graduate Program at the University of Delaware; Newark, Delaware, USA. This survey seeks to compile information on selected *Fraxinus* collections at approximately 150 institutions globally. This research aims to improve future exploration efforts of *Fraxinus* species, identify *Fraxinus* species that are available for emerald ash borer (EAB) resistance breeding, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

As a participant in the survey, you are free to terminate your participation at any time by simply closing your Web browser before you press the final submission button. Any responses you previously made will not be included in the study.

The survey consists of around ten questions and should take less than ***15*** minutes to complete. If you prefer to register a response on a paper survey please contact me to request that a paper copy be mailed to you.

If you feel a different individual within your institution could better address questions regarding your institution's *Fraxinus* accessions, please feel free to forward this survey to them. Thank you for your time and consideration.

Follow this link to the Survey:
{Survey Link}

Or copy and paste the url below into your internet browser:
{Survey URL}

Sincerely,

Andrew Gapinski

Graduate Fellow
Longwood Graduate Program
126 Townsend Hall
University of Delaware
Newark, DE 19716-2106
Tel: 302-831-2517
Fax: 302-831-3651

atgap@udel.edu

www.udel.edu/longwoodgrad/

Follow the link to opt out of future emails:{Opt Out Link}
On-line Survey

On-line Survey

Global Inventory of *Ex situ Fraxinus* Collections

This survey seeks to compile information on selected *ex situ Fraxinus* collections at institutions of North America, Europe, China, and Russia, with emphasis on specimens of documented wild origin. Approximately 150 institutions are being asked to participate in this survey. This research aims to improve future exploration efforts of *Fraxinus* species, identify *Fraxinus* species that are available for emerald ash borer (EAB) resistance breeding, and to further the conservation initiatives of the genus *Fraxinus* as a whole.

This study is being conducted by Andrew Gapinski of the Longwood Graduate Program at the University of Delaware; Newark, Delaware, USA. Survey results will be published as part of a M.S. thesis and will be available upon request.

Individual responses will be collected on a secure web server and all personal contact information provided will be confidential and viewed only by the principal investigator. **Institutionally Identifiable information will be associated with reports of these data.** Research results will be available July 2010.

Your participation is entirely voluntary. To leave the study at any time, simply close the web browser. You may return to the study via the same link. **If you feel a different individual within your institution could better address questions regarding your institution's *Fraxinus* accessions, please feel free to forward this survey to them.**

If you prefer to submit a response using a paper survey or have any questions concerning the study, please contact the principle investigator, Andrew Gapinski, atgap@udel.edu.

Your participation is greatly appreciated! Please press the "Next" button to continue.

1. Does your institution have *Fraxinus* accessions (i.e. cultivated living plants, seed, or herbarium) in its collections?

___Yes
___No [skip to "End of Survey Message" if selected]

2. Please indicate the origin type(s) represented by your institutions *Fraxinus* accessions. (please check all that apply)

___ Wild origin - Direct (specimens collected directly from plants in wild) [skip to "Instructional note 1" if selected]
___ Wild origin - Indirect (specimens collected from cultivated plants of known wild origin) [skip to "Instructional note 1" if selected]
___ Horticultural or Unknown origin

3. Thank you for your participation in this survey. As noted in the introduction, the emphasis of this research is on *Fraxinus* accessions of documented wild origin. Information regarding *Fraxinus* accessions of Horticultural or Unknown origin is not being collected at this time, but may be in the future.

Would your institution be willing to participate in a future inventory of Horticultural or Unknown origin *Fraxinus* accessions held in collections?

___Yes
___No [skip to "End of Survey Message" if selected]

4. Please enter your contact information below, to enable the principal investigator to contact you if needed.

Please note that your personal contact information will remain entirely confidential, will not be sold, transferred, or shared with any third parties, and will not be reported in any results of this research. As previously noted, institutionally identifiable information will be associated with the results of this research.

Name____________________
Title/ Position____________________
Institution____________________
Address____________________
Address (line 2) ____________________
City____________________
State/Province____________________
Zip/Postal Code____________________
Country____________________
Phone____________________
Email____________________

[skip to “End of Survey Message”]

[Instructional note 1] Please note the following definitions for the remainder of this survey:

Direct wild origin: refers to specimens collected directly from plants in wild

Indirect wild origin: refers to specimens collected from cultivated plants of known wild origin

5. Please indicate the collection type(s) (i.e. cultivated living plants, seed, herbarium) of direct and indirect wild origin *Fraxinus* accessions your institution holds.
___cultivated living plants only
___seed only
___herbarium only
___cultivated living plants and seed
___cultivated living plants and herbarium
___seed and herbarium
___cultivated living plants, seed, and herbarium

6. Please indicate the number of *Fraxinus* accessions of documented wild origin held at your institution for each of the following collection types.

(# of Direct wild origin accessions vs. # of Indirect wild origin accessions)
cultivated living plants___ ___
seed___ ___
herbarium___ ___

7. Please indicate the total number of accessioned *Fraxinus* specimens (i.e. # of individuals) of documented wild origin held at your institution for the following collection types.

(# of Direct wild origin specimens vs. # of Indirect wild origin specimens)
cultivated living plants___ ___
seed___ ___
herbarium___ ___

8. Please indicate the number of *Fraxinus* species of documented wild origin represented at your institution for the following collection types.

(# of Direct wild origin species vs. # of Indirect wild origin species)
cultivated living plants___ ___
seed___ ___
herbarium___ ___

9. Please indicate the number of *Fraxinus* <u>taxa</u> (i.e. species, varieties, subspecies, and formae) of documented <u>wild origin</u> represented at your institution for the following collection types.

(# of Direct wild origin taxa vs. # of Indirect wild origin taxa)
cultivated living plants___ ___
seed___ ___
herbarium___ ___

10. Does your institution have a verification system for its accessions?

(Verification is referring to the process of determining that a specimen has been identified correctly)

___Yes, we do have a verification system
___No, we do not have a verification system [skip to "Question 12" if selected]

11. Which of the following method(s), outlined by Galen Gates (Hohn, 2008), best describes the verification system at your institution?

(please check all that apply)

___Phenotypic approach: comparing morphological traits with previously authenticated herbarium specimens and scientific literature
___Molecular approach: comparing DNA and other relevant chemotaxonomic material to other authenticated samples
___Digital imagery approach: comparing images of exterior features taken during peak bloom periods that are then compared with known specimens or with literature
___Other (please describe below)
[text box]____________________

Hohn, T.C. 2008. Curatorial practices for botanic gardens. Alta Mira Press. p 116.

12. Thank you for indicating your institution's willingness to participate in the *Fraxinus* inventory. The next portion of the survey involves information regarding submission of your institution's *Fraxinus* inventory. Please enter your contact information below, to enable the principal investigator to contact you if needed.

Please note that your personal contact information will remain entirely confidential, will not be sold, transferred, or shared with any third parties, and will not be reported in any results of this research. As previously noted, institutionally identifiable information will be associated with the results of this research.

Name____________________

Title/ Position____________________

Institution____________________

Address____________________

Address (line 2) ____________________

City____________________

State/Province____________________

Zip/Postal Code____________________

Country____________________

Phone____________________

Email____________________

13. What is your preferred means of submitting your institution's *Fraxinus* inventory information?

___Microsoft Excel spreadsheet or compatible document (.xls, .xlsx, .csv) (preferred by investigator)

___other (please specify below

[text box]____________________

[Instructional note 2] Please submit the <u>primary record (see below)</u> for each of your institution's <u>direct and indirect wild origin</u> *Fraxinus* accessions. If possible, provide separate documents for each collection type (i.e. cultivated living plants, seed, herbarium). **Please submit inventories to Andrew Gapinski through email at:**

<u>atgap@udel.edu</u>

or for large files (larger than 10 MB) visit the University of Delaware's Dropbox Service at:

www.udel.edu/dropbox

Primary Record: please include as many of the following information fields in your report as possible:

Scientific name
Type of collection (cultivated living plant, seed, or herbarium specimen)
Number of individuals in accession
Origin status (Direct vs. Indirect wild origin)
Country and region of origin
GPS coordinates of collection location
Name(s) of collector(s)
Date of field collection
Collection Number (assigned by collectors)
Date acquired by institution holding specimen
Accession Number (assigned by institution holding specimen)
Verification status (whether the specimen has been determined to be identified correctly)

14. Please record any additional comments regarding this survey in the space provided below.

[text box]____________________

[Instructional note 3] If you would like to return to this survey at a later time, simply close your web browser without clicking the "Next" button below. Use the same link provided in your email to return at anytime.

PLEASE CLICK "NEXT" TO SUBMIT YOUR SURVEY

[End of Survey Message] Thank you for completing the survey. Your professional expertise and institutions involvement are critical to the success of this research project. The results of this study will be available around July 2010. If you would like to receive a copy of the results, please contact Andrew Gapinski via e-mail at atgap@udel.edu. To learn more about the Longwood Graduate Program, please visit the Program's Web page at http://www.udel.edu/longwoodgrad.

Appendix I

COLLECTION SITE AND OTHER INFORMATION OF VALUE

Collection Site Information of Value to Respondents

Question
Specific information about the collection site if wild collected (e.g. soil type); specify all conditions below:

Text responses

- “too many possibilities here to list”
- “substrate, habitat, plant description information”
- “soil type, associated flora”
- “soil pH, Cold hardiness, wet or dry soil conditions, salinity level, sun or shade”
- “soil, sun exposure, moisture”
- “soil, slope, aspect, associated species, microtopographic info.”
- “soil, nearby vegetation, distance from a dwelling, age, health, reproductive status”
- “soil, aspect, slope, geology, land form, hydrology, associated taxa, modifying factors, elevation, state, county, locality, habitat, land use”
- “See standard ecological site descriptors by Steiner and Greene (1996)”
- “local abundance at this site”
- “floristics”
- “elevation, habitat, associated plant species”

Additional Information of Value to Respondents

Question
Please indicate any additional information about an individual plant specimen, not described above, that is necessary for the specimen to be of value to your professional objectives. Record this additional information as either "necessary for specimen to be

of value" or "not necessary, but increases value of specimen" in the corresponding boxes below.

<u>Necessary for specimen to be of value</u>

- “Specimen needs locality and an identifier (usually collector and number, but collector and date can be used instead). The herbarium that owns it should mark it - otherwise, loans and images can be hard to associate with their correct institution”
- “For seed: Location of parent trees; whether it is a single-tree, several trees, or a stand collection, collection date.”
- “Your survey is very "research herbarium" specimen oriented (have my own PhD there) - survey ignores issues with authenticating historical / culturally significant plants but I've taken liberty of thinking "wild source" = "originating breeder or first commercial release source"”
- “Source of material!!! Where did it come from (cultivated, wild-collected, nursery grown) and how was it received (seed, cuttings, plant, etc).”
- “Measurements: height, circumference, and crown spread.”
- “population size, sample size, what type of propagule was collected (seeds, cuttings, divisions, whole plants, etc.), habitat parameters, plant community, elevation”
- “Family name”

<u>Not necessary, but increases value of specimen</u>

- “Source used for identification”
- “status of plant in wild population where collected”
- “outstanding ornamental or cultural characteristics that distinguish it from the species type”
- “Data on plant that doesn't show on specimen - height of tree, bark, colour of flowers - which characters are useful/necessary depends on the taxon”
- “Horticultural characteristics, climate adaptation, growing environment”
- “I would prefer that every sample comes with all of this passport information. It would lead to MUCH better plant breeding. IN the ornamental plant breeding world we have used poorly documented plant material in breeding for so long, we don't expect any better. So much of the wild germplasm utilized in breeding has no associated passport information, we have not idea how close we have come to seeing or utilizing the potential in these genetic resources!”
- “Information pertaining to previous collections use for research. For living collections, the environmental conditions of local site. Likewise historical and horticultural management data/information related to living collections studied.

Various other types of data are useful -- but not required. See Dosmann (2006) Research in the Garden. Botanical Review for various other types I value."

- "Is the range of a wild collected species well represented to better capture genetic diversity"
- "For grafted material, the species information for the understock. Gender of the tree (where applicable)."
- "Information (metadata) that places the material in context"
- "cross-referencing to other specimens (e.g. if you have a wild-collected living plant specimen would be nice to know if you also have a corresponding herbarium specimen)"
- "Specific unusual or different traits from the "normal" population"
- "Primary evaluation data; horticultural information on parent plant from which collected."
- "Digital photographs, GPS coordinates."
- "associated taxa"
- "if wild collected, what other plants were in the plant community."

Appendix J

INSTITUTIONS REPORTING *FRAXINUS* ACCESSIONS OF HORTICULTURAL OR UNKNOWN ORIGIN ONLY

Institutional contact information is presented below as it was reported in the on-line portion of the "Survey of *Fraxinus* Collections."

Botanical Garden of the University
28 rue Goethe
STRASBOURG, F-67083
France

Botanischer Garten der Technischen Universitaet
Schnittspahnstrasse 3-5
D-64287 Darmstadt
Germany

Cornell Plantations
One Plantations Road
Ithaca, NY 14850
USA

Fairchild Tropical Botanic Garden
10901 Old Cutler Road
Coral Gables, Florida 33156
USA

Fundación Xochitla, A. C.
Carretera circunvalación S/N,
Colonia Centro, Tepotzotlón, México 54600
México

Kruidtuin Stad Leuven
Kapucijnebvoer 30
Leuven, 3000
Belgium

Paignton Zoo Environmental Park
Totnes road
Devon, TQ4 7Eu
UK

Palmengarten der Stadt Frankfurt am Main
Siesmayerstr. 61
60323 Frankfurt am Main
Germany

Scott Arboretum of Swarthmore College
500 College Ave
Swarthmore, PA 19081
USA

Shenzhen Fairy Lake Botanical Garden
Xianhu Road 160
Liantang, Shenzhen,
Guangdong, 518004
P. R. China

University of Dundee Botanic Garden
Riverside Drive
Dundee, DD2 1QH
Scotland

University of Idaho Arboretum
P.O. Box 442281
Moscow, Idaho 83844-2281
US

Appendix K

INSTITUTIONS REPORTING *FRAXINUS* ACCESSIONS OF WILD ORIGIN

Institutional contact information is presented below as it was reported in the on-line portion of the "Survey of *Fraxinus* Collections." Institutional information appearing as "**bolded"** text indicates that the institution submitted an inventory of its *Fraxinus* accessions, contributing to the compiled inventories found in Appendices L and M. Three institutions indentified by asterisks "*" below, submitted inventories without partaking in the on-line portion of the survey. Institutional identifiers were assigned to institutions submitting inventories. Identifiers are found in parenthesis "( )" following the name of the institution, and are based on BGCI's Institution Codes found by inquiring the Garden Search page on the BGCI website (BGCI, 2010b). Institutional identifiers for Seeds of Success and USDA-ARS North Central Regional Pant Introduction Station were assigned by the researcher.

Arboretum Wespelaar (WESPE)
De Costerstraat 37
Haacht-Wespelaar, B-3150
Belgium

Arnold Arboretum of Harvard University (AAH)
125 Arborway
Boston, MA 2118
USA

Banco de Sementes, Jardim Botanico, MNHN (LISU)
Rua da Escola Politécnica 58
Lisboa, 1250-102
Portugal

Botanical Garden of the University of Osnabrueck (OSN)
Albrechtstrasse 29
Osnabrueck, Lover Saxony, D 49076
Germany

Botanical Gardens Wageningen University
Gen. Foulkesweg 37
Wageningen, 6721 BL
Netherlands

Brooklyn Botanic Garden (BKL)
1000 Washington Avenue
Brooklyn, NY 11225
USA

Cambridge University Botanic Garden (CGG)
1 Brookside
Cambridge, CB2 1JE
UK

Chicago Botanic Garden (CHIC)
1000 Lake-Cook Rd.
Glencoe, IL 60060
USA

Denver Botanic Garden (KHD)
909 York St.
Denver, CO 80206
USA

George Safford Torrey Herbarium (CONN), University of Connecticut
Department of Ecology & Evolutionary Biology
75 N. Eagleville Road
Storrs, CT 6269
USA

Hangzhou Botanical Garden
No 1 Taoyuanling Hangzhou China
Hangzhou, Zhejiang Province, 310013
China

Hebrbario y Jardin Botanico, Benemerita Universidad Autonoma de Puebla (BUAP)
Av. San Claudio s.n
Col. San Manuel
Puebla, Puebla 72590
Mexico

Huntington Botanical Gardens (HNT)
1151 Oxford Rd.
San Marino, CA 91108
USA

Lab of biodiversity conservation
Xi'an Botanical Garden of Shaanxi
No. 17, Cuihua South Road
Xi'an, Shaanxi Province, 712100
China

Longwood Gardens (KEN)
P.O. Box 501
Kennett Square, PA 19348
USA

Los Angeles County Arboretum & Botanic Garden (LASCA)*

LYON Botanical Garden
Mairie de Lyon
LYON, 69205
FRANCE

Main Botanical Garden (MHA)
Botanical st. 4
Moscow 127276
Russia

MNHN -DJBZ (P)
57 rue Cuvier
Paris cedex 05, 75231
France

Morris Arboretum of the University of Pennsylvania (MOAR)
9414 Meadowbrook Ave.
Philadelphia, PA 19118
USA

Musée national d'histoire naturelle - Arboretum Kirchberg (LUX)
25, rue Munster
Luxembourg, L-2160
Luxembourg

National Botanic Garden of Belgium (BR)
Domein van Bouchout
Nieuwelaan 38, Meise 1860
Belgium

National Botanic Garden of Latvia (RIGA)
Miera Street 1
Salaspils, LV-2169
Latvia

National Botanic Garden of Wales
Llanarthne
Carmarthenshire, sa32 8hg
Wales

National Botanic Gardens of Ireland (DBN)*

New York Botanical Garden (NY)
200th & Kazimiroff Blvd.
Bronx, NY 10458-5126
USA

Niagara Parks Botanical Gardens (NFO)
P.O. Box 150
2565 Niagara Parkway North
Niagara Falls, ON L2E 6V5
Canada

Quarryhill Botanical Garden (GELLE)
12841 Sonoma Highway
PO Box 232
Glen Ellen, CA 95442
USA

RBGE (E)
Inverleith Row
Edinburgh, Lothian EH21 6TW
UK

Rogów Arboretum of Warsaw University of Life Sciences (ROGOW)
ul. Lesna 1
Rogow, PL-95-063
Poland

Royal Botanic Gardens Kew
Millennium Seed Bank
Wakehurst Place
Ardingly, West Sussex, RH17 6TN
UK

San Francisco Botanical Garden (CAS)
1199 9th Ave
San Francisco, CA 94122
USA

Seeds of Success (SOS)
Bureau of Land Management
1849 C Street, NW, LSB-204
Washington, DC 20240
USA

Sir Harnold Hillier Gardens (HILL)
Jermyns House
Jermyns Lane, Ampfield
Romsey, Hampshire SO51 0QA
UK

The Arboretum, University of Guelph
Guelph, Ontario N1G 2W1
Canada

The Dawes Arboretum (DAWES)
7770 Jacksontown Rd. SE
Newark, OH 43056
USA

The Holden Arboretum (HOL)
9500 Sperry Road
Kirtland, Ohio 44094
USA

The Morton Arboretum (MOR)
4100 Illinois Route 53
Lisle, IL 60532-1293
USA

The Royal Horticultural Society (WSY)
RHS Garden, Wisley
Woking, Surrey, GU23 6QB
UK

U.S. National Arboretum
3501 New York Ave. N.E.
Washington DC 20002
USA

UBC Botanical Garden
6804 SW Marine Dr
Vancouver, BC V6T 1Z4
Canada

University of Oldenburg, Fac. V: IBU, Botanical Garden (OLD)
Philosophenweg 39
Oldenburg 26121
Germany

Uppsala Linnaean Garden (UPS)
Villavägen 8
Uppsala 75236
Sweden

USDA-ARS North Central Regional Pant Introduction Station (NCRPIS)
Iowa State University
G212 Agronomy Hall
Ames, IA 50011-1170
USA

US Forest Service National Seed Laboratory
1007 N 725 W
W. Lafayette, IN 47906
USA

VanDusen Botanical Garden (VAND)
5251 Oak Street
Vancouver, British Columbia, V6M 4H1
Canada

Vladivostok Botanical Garden, Russian Academy of Sciences (VLA)*

Westonbirt Arboretum (WESB)

Woody Landscape Plant germplasm Repository
10300 Baltimore Ave BLD 010A Rm 233
Beltsville, Maryland 20705
USA

Wuhan Botanical Garden,
Chinese Academy of Sciences
Moshan, Wuchang, Wuhan, Hubei, 430074
China

Appendix L

INVENTORY OF *FRAXINUS* COLLECTIONS – WILD ORIGIN ACCESSIONS

(See enclosed CD on inside of back cover or contact the Longwood Graduate Program for an electronic copy)

Appendix M

INVENTORY OF *FRAXINUS* COLLECTIONS – NON-WILD ORIGIN ACCESSIONS

(See enclosed CD on inside of back cover or contact the Longwood Graduate Program for an electronic copy)

Appendix N

SUMMARY OF WILD ORIGIN *FRAXINUS* ACCESSIONS (APPENDIX L) AT EACH INSTITUTION BY TAXON

Species name	Reported intraspecific taxa	Institutions reporting holdings (# of reported accessions)**	Total # accessions
F. americana L.		AAH(2), BR(3), CGG(1) E(4), HILL(4), HOL(4), KEN(1), LASCA(3), MHA(2) MOR(5), NCRPIS(59), OLD(1), OSN(2), P(3), RIGA(6), ROGOW(3), UPS(3), WESPE(2), WESB(1)	109
	f. *iodocarpa*	HOL(2), MOR(2)	4
	var. *biltmoreana* (Beadle) Wright	AAH(2), CHIC(1), HOL(1), MOAR(2), MOR(1), ROGOW(1) UPS(1), WESB(2)	11
F. angustifolia Vahl		BR(1), HILL(1), LISU(7), MHA(2), P(1) RIGA(1), ROGOW(1), WESPE(2)	16
	ssp. *oxycarpa* (Bieb.) Afonso	AAH(2), E(1), LUX(2), NCRPIS(4), RIGA(1), ROGOW(4), WSY(1) VAND(1)	16
	ssp. [var.] *pannonica* Soó & Simon	HOL(1), MOR(1), UPS(1)	3
	ssp. *syriaca* (Boiss.) Yaltrik	AAH(1), RIGA(1)	2
	ssp. *angustifolia*	E(1), LISU(1), NCRPIS(1)	3
	var. *australis*	MOR(2)	2
F. anomala Torr. ex S. Watson		BR(1), CGG(2), KHD(8), LASCA(1), MOR(1), NCRPIS(4), ROGOW(1) SOS(3)	21
F. apertisquamifera Hara		GELLE(1)	1
F. bungeana De Candolle		AAH(2), BKL(1), MHA(1), MOAR(2)	6

F. caroliniana Mill.		HILL(1), MOR(1), WESB(1)	3
*F. caucasicus**		NY(1)	1
F. chiisanensis Nakai		ROGOW(1)	1
F. chinensis Roxb.		AAH(3), BR(2) E(4), HILL(3), MHA(2), MOAR(1), MOR(1), P(2), ROGOW(3), UPS(1), WESPE(1), WSY(2)	25
	ssp. [var.] *rhynchophylla* (Hance) E. Murray	AAH(5), BR(1), CGG(1), CHIC(3), DAWES(8), E(3), HILL(1), HOL(6), MOAR(3), MOR(5), NCRPIS(5), NY(1), RIGA(2), ROGOW(5), UPS(2), WESB(3), WESPE(2)	56
	ssp. *chinensis*	GELLE(6), NCRPIS(2)	8
	var. *acuminata* Lingelsh.	E(1)	1
F. cuspidata Torr.		HILL(1), KHD(2)	3
F. densata Nakai*		ROGOW(2)	2
F. dipetala Hook and Arn.		CAS(1), CGG(1), LASCA(5), P(1), SOS(2)	10
F. excelsior L.		AAH(3), CGG(1), E(2), GELLE(2), HILL(1), HOL(2), LASCA(1), LUX(3), MOR(6), NCRPIS(10), NY(1), OLD(2), P(1), WSY(1), WESB(5)	41
F. floribunda Wall.		LASCA(1)	1
F. formosana Hayata*		HNT(1), OSN(1)	2
F. greggii A. Gray		CGG(1)	1
F. griffithii C. B. Clarke		GELLE(1), HNT(1),	3

		ROGOW(1)	
F. holotricha Koehne*		MOAR(1)	1
F. inopinata Lingelsh.*		GELLE(2), WESB(1)	3
F. insularis Hemsl.*		DAWES(1), E(1), GELLE(3), KEN(1), MOAR(1), NCRPIS(1)	8
F. japonica Blume ex K. Koch*		E(1)	1
F. lanuginosa Koidz.		AAH(1), CGG(1), E(1), GELLE(4), HOL(1), KEN(1), WSY(2), WESB(3)	14
	f. *serrata* (Nakai) Murata	GELLE(1), E(1)	2
F. latifolia Benth.		AAH(2), CAS(2), E(2), HILL(1), MOR(1), NCRPIS(1), P(2), RIGA(1), SOS(1)	13
F. longicuspis Sieb. & Zucc.		AAH(5), CGG(1), LASCA(1), ROGOW(1)	8
	var. *sieboldiana*	MOR(2)	2
F. lowelli Sarg.*		LASCA(1)	1
F. malacophylla Hemsl.			
	var. *septentrionlis*	HNT(1)	1
F. mandshurica Rupr.		AAH(4), BR(1), CHIC(2), DAWES(4), E(2), GELLE(3), HILL(2), HOL(2), KEN(3), MHA(2), MOAR(3), MOR(4), NCRPIS(6), P(1), RIGA(4), ROGOW(2), UPS(2), WESPE(1), WESB(2)	50
	var. *japonica*	GELLE(3), HILL(1), MOR(1), RIGA(1), UPS(1)	7
F. nigra Marsh.		AAH(1), CGG(1),	31

		DAWES(1), E(1), HOL(3), MOR(2), NCRPIS(7), NFO(1), OSN(1), RIGA(1), ROGOW(4), SOS(1), UPS(2), WESPE(1), WESB(4)	
F. oregona Nutt.*		ROGOW(1)	1
F. ornus L.		AAH(3), E(2), DAWES(1), HILL(2), HOL(1), LUX(4), MHA(2), MOAR(3), MOR(3), NCRPIS(2), NFO(1), OLD(2), P(1), ROGOW(4), UPS(3), WESB(1), WSY(1)	36
	ssp. *cilicica*	WESB(2)	2
F. oxycarpa Willd.*		HOL(1), MOR(2)	3
F. pallisiae Willmott ex Pallis*		AAH(1), CGG(1), HOL(2), MOR(1), ROGOW(1)	6
F. paxiana Lingelsh.		DAWES(3), GELLE(2), HILL(1), KEN(2), MOAR(1), MOR(2), NCRPIS(3), P(1), ROGOW(1), VAND(1), WESPE(5), WESB(1)	23
F. pennsylvanica Marsh.		AAH(4), E(2), HILL(1), HOL(3), LASCA(2), MHA(2), MOR(1), NCRPIS(55), NFO(1), RIGA(1), UPS(1)	73
	var. *subintegerrima* (Vahl) Fern.	AAH(1), MOR(3), RIGA(1)	5
	var. *lanceolata*	P(1)	1
F. platypoda Oliv.		AAH(2), DAWES(2), E(1), UPS(1)	6

F. potamophila Herder*		AAH(1), HOL(1), P(1)	3
F. profunda (Bush) Bush		DAWES(1), E(1), HILL(1), HOL(5), NCRPIS(12), OSN(1), WESB(2)	23
F. quadrangulata Michx.		AAH(2), BR(2), CGG(2), CHIC(2), E(1), HOL(5), KHD(3), LASCA(1), MHA(1), MOR(5), NCRPIS(10), OSN(1), P(2), RIGA(2), ROGOW(2), UPS(3)	44
F. raibocarpa Regel		NCRPIS(1)	1
F. retusa Champ. Ex Benth.*		BKL(1), WESB(1)	2
F. rhynchophylla Hance*		P(2), UPS(1)	3
F. rotundifolia Mill.*		KEN(1)	1
F. sieboldiana Blume		BKL(1), DAWES(2), GELLE(4), HILL(1), HOL(6), KEN(1), AAH(4), BR(1), E(3), MOAR(1), NCRPIS(2), OSN(2), ROGOW(1), UPS(2), VAND(2), WESPE(5), WESB(6)	44
F. sikkimensis (Lingelsh.) Hand.-Mazz.*		E(1), GELLE(2), KHD(1), ROGOW(1) WESB(3)	8
F. sogdiana Bunge*		MOR(1), RIGA(1)	2
F. stylosa Lingelsh.*		DAWES(2), KEN(2), NCRPIS(2)	6
F. suaveolens W.W. Smith*		WSY(3)	3
F. syriaca Boiss.*		P(1)	1
F. texensis (A.Gray) Sarg.		BR(1), MOAR(1), MOR(2), P(1), WESB(3)	8
F. tomentosa Michaux f.*		AAH(3), MOR(3), P(2),	10

		ROGOW(2)	
F. trifoliata (Torr.) Lewis & Epling*		LASCA(1)	1
F. uhdei (Wenz.) Lingelsh.		BUAP(6), LASCA(1)	7
F. velutina Torr.		HILL(2), SOS(1), RIGA(1)	4
	var. *coriacea*	LASCA(3), P(1), WESPE(2)	6
F. xanthoxyloides (G. Don) DC.		BKL(1), E(1), HILL(2), KHD(2), NCRPIS(1), OSN(1), P(2)	10

* Denotes a species that is reported as a synonym of another species by Wallander (2008) or other source. Refer to Table 6.8 or Appendix O for synonym information.
** Refer to Appendix K for full institutional names based on institutional identifiers (e.g. AAH) from this Appendix.

Appendix O

REPORTED SPECIES IN APPENDIX L (WILD ORIGIN ACCESSIONS) BY GEOGRAPHIC DISTRIBUTION

Species by continent(s) (continent grouping based on Wallander's (2008) geographic distributions)	Synonym (Wallander, 2008; unless otherwise noted)	Geographic distribution of species (Wallander, 2008; unless otherwise noted)*
Asia		
F. apertisquamifera Hara		Japan
F. bungeana DC.		China
F. chiisanensis Nakai		Korea
F. chinensis Roxb.		E Asia
F. densata Nakai	*F. rhynchophylla* Hance var. *densata* (Nakai) Y.N. Lee[1]	E Asia
F. floribunda Wall.		Himalaya, E Asia
F. formosana Hayata	*F. griffithii* C.B. Clarke	SE Asia
F. griffithii C. B. Clarke		SE Asia
F. inopinata Lingelsh.	*F. platypoda* Oliv.[2]	China
F. insularis Hemsl.	*F. floribunda* Wall.	Himalaya, E Asia
F. japonica Blume ex K. Koch	*F. chinensis* Roxb.	E Asia
F. lanuginose Koidz.		Japan
F. longicuspis Sieb. & Zucc.		Japan
F. malacophylla Hemsl.		China, Thailand
F. mandshurica Rupr.		China, Japan, Korea, E Russia
F. oregona Nutt.	*F. latifolia* Benth.	W USA
F. paxiana Lingelsh.		Himalaya, China
F. platypoda Oliv.		China
F. raibocarpa Regel		C Asia
F. retusa Champ. Ex Benth.	*F. floribunda* Wall.	Himalaya, E Asia
F. rhynchophylla Hance	*F. chinensis* Roxb.	E Asia
F. sieboldiana Blume		China, Japan, Korea
F. sikkimensis (Lingelsh.) Hand.-Mazz.	*F. paxiana* Lingelsh.	Himalaya, China
F. stylosa Lingelsh.	*F. floribunda* Wall.[3]	Himalaya, E Asia
F. suaveolens W.W. Smith	*F. paxiana* Lingelsh.	Himalaya, China
Asia & Africa		
F. xanthoxyloides (G. Don) DC.		N Africa to China
Europe		
*F. caucasicus***		Republic of Georgia***
F. ornus L.		C and E Mediterranean
Europe & Asia		
F. angustifolia Vahl		S and C Europe to C Asia
F. excelsior L.		N & C Europe to W Russia
F. holotricha Koehne	*F. pallisiae* Willmott ex Pallis[3]	S and C Europe to C Asia
F. oxycarpa Willd.	*F. angustifolia* Vahl	S and C Europe to C Asia
F. pallisiae Willmott ex Pallis	*F. angustifolia* Vahl	S and C Europe to C Asia
F. potamophila Herder	*F. angustifolia* Vahl	S and C Europe to C Asia
F. rotundifolia Mill.	*Fraxinus angustifolia* Vahl subsp. *syriaca*	S and C Europe to C Asia

	(Boiss.) Yalt.[3]	
F. sogdiana Bunge	*F. angustifolia* Vahl	S and C Europe to C Asia
F. syriaca Boiss.	*F. angustifolia* Vahl	S and C Europe to C Asia
North America		
F. americana L.		E USA & E Canada
F. anomala Torr. ex S. Wats.		SW USA
F. caroliniana Mill.		SE USA
F. cuspidata Torr.		SW USA, Mexico
F. dipetala Hook & Arn.		SW USA
F. greggii A. Gray		SW USA, Mexico
F. latifolia Benth.		W USA
F. lowelli Sarg.	*F. anomala* Torr. ex S. Watson	SW USA
F. nigra Marsh.		E USA, E Canada
F. pennsylvanica Marsh.		C & E USA, Canada
F. profunda (Bush) Bush		SE USA
F. quadrangulata Michx.		C & E USA, C Canada
F. texensis (Gray) Sarg.		SW USA (Texas)
F. tomentosa Michaux f.	*F. profunda* (Bush) Bush	SE USA
F. trifoliata (Torr.) Lewis & Epling	*F. dipetala* Hook. & Arn.	SW USA
F. uhdei (Wenzig) Lingelsh.		C America, Hawaii
F. velutina Torr.		SW USA, Mexico

* Geographic distribution of species synonym, if name noted in "Synonym" column
** Not a listed species or synonym of species in Wallander (2008) and synonym could <u>not</u> be found in other source
*** Country of origin reported by institution holding specimen

[1]Cited as possible synonym by: The International Plant Names Index (2010)
[2]Cited as possible synonym by: eFloras (2010)
[3]Cited as possible synonym by: USDA-ARS, National Genetic Resources Program (2010)

Appendix P

SPECIES LISTED IN WALLANDER (2008) - NOT REPRESENTED IN COMPILED *FRAXINUS* INVENTORIES (APPENDIX L OR M)

Species by continent(s) (continent grouping based on Wallander's (2008) geographic distributions)	Synonym(s) (Wallander, 2008)	Geographic distribution (Wallander, 2008)
Asia		
F. baroniana Diels		China
F. hubeiensis S. Z. Qu, C. B. Shang & P. L. Su		China
F. micrantha Lingelsh.		Himalaya
F. spaethiana Lingelsh.		Japan
F. trifoliolata W. W. Smith		China
North America		
F. berlandieriana DC.		SW USA, Mexico
F. dubia (Willd. ex Schult. & Schult. f.) P. S. Green & M. Nee	*F. petenensis* Lundell, *F. schiedeana* Schlecht. & Cham.	Mexico, Guatemala
F. gooddingii Little		SW USA, N Mexico
F. papillosa Lingelsh.		SW USA, Mexico
F. purpusii Brandegee	*F. bicolor* Standley & Steyerm., *F. vallerea* Standley & Steyerm.	Mexico, Guatemala
F. rufescens Lingelsh.		Mexico

REFERENCES

Allenstein, P. 23 November 2009. North American Plant Collections Consortium (NAPCC) Manager, American Public Gardens Association. Personal communication.

Allenstein, P., and K. Conrad. 2004. National Plant Germplasm System and North American Plant Collections Consortium: a decade of collaboration. Public Garden. 19(3):14-16, 37.

American Association of Museums (AAM). 2010a. Accreditation program: annual statistics at-a-glance. The AAM Museum Accreditation Program. Washington, DC. 24 March 2010. <http://www.aam-us.org/museumresources/accred/upload/2010-Accred-Annual-Stats-At-A-Glance.pdf>.

American Association of Museums (AAM). 2010b. Risk management. 24 March 2010. <http://www.aam-us.org/museumresources/ic/frm/rm/index.cfm>.

American Association of Museums (AAM). 2007. AAM standards regarding facilities and risk management. 24 March 2010. <http://www.aam-us.org/aboutmuseums/standards/upload/frmstandards.pdf>.

American Association of Museums (AAM). 2004. The accreditation commission's expectations regarding collections stewardship. The AAM Museum Accreditation Program. Washington, DC. 24 March 2010. < http://www.aam-us.org/museumresources/accred/upload/Collections%20Stewardship%20ACE%20%282005%29.pdf>.

American Public Gardens Association (APGA). 2010a. What is the NAPCC? 12 March 2010. <http://www.publicgardens.org/web/2006/06/napcc_home.aspx>.

American Public Gardens Association (APGA). 2010b. *PlantCollections*™ - a community solution. 12 March 2010. <http://www.publicgardens.org/plantcollections.aspx>.

American Public Gardens Association (APGA). 2010c. Public garden search. 12 March 2010. <http://www.publicgardens.org/Custom/GardenSearch.aspx>.

American Public Gardens Association (APGA). 2010d. NAPCC collections by institution. 12 March 2010. <http://www.publicgardens.org/web/2006/07/napcc_collections_by_institution.aspx>.

American Public Gardens Association (APGA). 2010e. FAQs for NAPCC. 12 March 2010. <http://www.publicgardens.org/web/2006/06/faqs_for_napcc.aspx>.

Anulewicz, A.C., D.G. McCullough, D.L. Cappaert, and T.M. Poland. 2008. Host range of the emerald ash borer (Agrilus planipennis Fairmaire)(Coleoptera: Buprestidae) in North America: results of multiple-choice field experiments. Environ. Entomol. 37(1):230-241.

Bachtell, K.R. 14 August 2009. Vice President of Collections and Facilities, The Morton Arboretum. Personal communication.

Bachtell, K.R. 8 October 2008. Vice President of Collections and Facilities, The Morton Arboretum. Personal communication.

Baranchikov, Y., E. Mozolevskaya, G. Yurchenko, and M. Kenis. 2008. Occurrence of the emerald ash borer, *Agrilus planipennis* in Russia and its potential impact on European forestry. Bulletin OEPP. 38:233-238.

Barnard, P. and J.K. Waage. 2004. Tackling species invasions around the world: regional responses to the invasive alien species threat. Global Invasive Species Programme, Cape Town, South Africa. 12 March 2010. <http://www.gisp.org/publications/reports/FAgisptechbrochure.pdf>.

Barnes, B.V. 28 July 2009. Professor Emeritus of Forestry and Forest Botanist, The University of Michigan Matthaei Botanical Gardens & Nichols Arboretum. Personal communication.

Bentz, S.E., L.G.H. Riedel, M.R. Pooler, and A.M. Townsend. 2002. Hybridization and self-compatibility in controlled pollinations of Eastern North American and Asian hemlock (*Tsuga*) species. Journal of Arboriculture. 28(4):200-205.

Bergquist, J.M. 2009. The development of a natural disaster planning template for use in plant collections management. University of Delaware, Newark, DE. MS Thesis.

Botanic Gardens Conservation International (BGCI). 2010a. Plant search. 12 March 2010. < http://www.bgci.org/plant_search.php>.

Botanic Gardens Conservation International (BGCI). 2010b. Garden search. 12 March 2010. <http://www.bgci.org/garden_search.php>.

Botanic Gardens Conservation International (BGCI). 2009a. Global survey of *ex situ* oak collections. 12 March 2010. <http://www.bgci.org/ourwork/quercussurvey/>.

Botanic Gardens Conservation International (BGCI). 2009b. Personal communication.

Botanic Gardens Conservation International (BGCI). 2008. Global survey of *ex situ* Magnoliaceae collections. 12 March 2010. <http://www.bgci.org/ourwork/2148/>.

Burghardt, J.D. 2000. Natural hazard perceptions, natural disaster experiences & recovery at American public horticulture institutions. University of Delaware, Newark, DE. MS Thesis.

Carmichael, C. 16 October 2009. Associate Director of Collections and Horticulture, University of California Botanical Garden at Berkeley. Personal communication.

Charles, H., and J.S. Dukes. 2007. Impacts of invasive species on ecosystem services. In: W. Nentwig (ed.). Biological invasions. Springer-Verlag Berlin Heidelberg, New York, NY.

Chrystal, R.N. 1916. The forest insect problem in Stanley Park. Proceedings of the Entomological Society of British Columbia. 9:63-66.

Cicuzza, D., A. Newton, and S. Oldfield. 2007. The red list of Magnoliaceae. Fauna & Flora International, Cambridge, UK. 12 March 2010. <http://www.bgci.org/files/Media_Kit/magnolia_red_list_.pdf>.

Collins, D. 2008. Collections on a large scale: the NAPCC multi-institutional *Quercus* collection. Public Garden. 1:27-30.

Creswell, J.W. 2009. Research design: qualitative, quantitative, and mixed methods approaches. 3rd ed. SAGE Publications, Inc., Thousand Oaks, CA.

Del Tredici, P., and A. Kitajima. 2004. Introduction and cultivation of Chinese hemlock (*Tsuga chinensis*) and its resistance to hemlock woolly adelgid (*Adelges tsugae*). Journal of Arboriculture. 30(5):282-287.

Del Tredici, P. 1994. Hemlock hill – the end of an era. Arnoldia (winter 1994-1995). 3 February 2010. <http://arnoldia.arboretum.harvard.edu/pdf/articles/927.pdf>.

Dosmann, M.S. 29 September 2009. Arboretum Curator, The Arnold Arboretum of Harvard University. Personal communication.

Ecker, M. 11 August 2009. Horticulture Department Head, The Dawes Arboretum. Personal communication.

eFloras. 2010. *Fraxinus platypoda*. Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge, MA. 5 July 2010. <http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=210000557>.

Emerald Ash Borer (EAB) Readiness Team. 2006. Illinois emerald ash borer readiness plan. 11 November 2008. <http://www.agr.state.il.us/eab/>.

Evans, D. 2003. Preparing a botanical garden for hurricanes. Public Garden. 18(1):22-25.

Flaster, T. 2004. Survey of medicinal plants in the main US herbaria. Ethnobotany Research & Applications. 2:101-110.

FRAXIGEN. 2005. Ash species in Europe: biological characteristics and practical guidelines for sustainable use. Oxford Forestry Institute, University of Oxford, UK. 128 pp.

Gentry, K. 14 January 2010. Educational Director, Hidden Lake Gardens. Personal communication.

Gouger, R.J. 1971. Control of Adelges tsugae on hemlock in Pennsylvania. Sci. Tree Topics. 3:1-9.

Griffin, G.J., and J.R. Elkins. 1986. Chestnut blight. In: M.K. Roane, G.J. Griffin, and J.R. Elkins. Chestnut blight, other endothia diseases, and the genus *Endothia*. The American Phytopathological Society, St. Paul, MN.

Griffith, P. 19 October 2009. Executive Director, Montgomery Botanical Center. Personal communication.

Havill, N.P., and M.E. Montgomery. 2008. The role of arboreta in studying the evolution of host resistance to the hemlock woolly adelgid. Arnoldia. 65(3):1-9.

Herms, D.A., A.K. Stone, and J.A. Chatfield. 2004. Emerald ash borer: the beginning of the end of ash in North America? Ornamental plants annual reports and research reviews 2003, The Ohio State University. 20 March 2010. <http://ohioline.osu.edu/sc193/index.html>.

Hidden Lake Gardens. 2010a. History. Michigan State University. 11 March 2010. <http://www.hiddenlakegardens.msu.edu/hiddenlakegardens/history>.

Hidden Lake Gardens. 2010b. Mission. Michigan State University. 11 March 2010. <http://www.hiddenlakegardens.msu.edu/hiddenlakegardens/mission>.

Hidden Lake Gardens. 2010c. Education. Michigan State University. 11 March 2010. <http://www.hiddenlakegardens.msu.edu/hiddenlakegardens/education>.

Hohn, T.C. 2008. Curatorial practices for botanical gardens. AltaMira Press, Lanham, MD.

Holling, C.S. (ed.). 1978. Adaptive environmental assessment and management. John Wiley & Sons, Chichester, Great Britain.

Johnson, B. and L. Christensen. 2000. Educational research: quantitative and qualitative approaches. Allyn & Bacon, Needham Heights, MA.

Kim, K. 14 August 2009. Head of Collections and Curator, The Morton Arboretum. Personal communication.

Kim, K. 2007. Emerald ash borer (*Agrilus planipennis*) action plan. The Morton Arboretum, Lisle, IL. Unpublished data.

Koch, J.L., D.W. Carey, and M.E. Mason. 2007. Development of novel ash hybrids to introgress resistance to emerald ash borer into North American ash species. Emerald Ash Borer Research and Technology Development Meeting. Pittsburgh, PA. 36-37 (abstr).

Larson, R.A. 11 August 2009. Nursery Manager, The Dawes Arboretum. Personal communication.

Lovett, G.M., C.D. Canham, M.A. Arthur, K.C. Weathers, and R.D. Fitzhugh. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. BioScience. 56(5):395-405.

Makra, E. 13 August 2009. Community Tree Advocate, The Morton Arboretum. Personal communication.

Mason, T. 11 August 2009. Natural Resources Manager, The Dawes Arboretum. Personal communication.

Matthaei Botanical Gardens and Nichols Arboretum (MBGNA). 2010. Mission statement. University of Michigan. 15 January 2010. <http://www.lsa.umich.edu/mbg/about/mission.asp>.

Maunder, M. 2007. Stormy weather ahead: institutional responses for climate change. Public Garden. 22(4):15-16.

Maunder, M., B. Lyte, J. Dransfield, and W. Baker. 2001. The conservation value of botanic garden palm collections. Biological Conservation. 98:259-271.

Maunder, M., and S. Higgens. 1998. A survey of Bern Conservation plant taxa in European botanic gardens: initial findings and implications. BGCNews. 2(10).

Michener, D.C. 27 July 2009. Associate Curator, The University of Michigan Matthaei Botanical Gardens & Nichols Arboretum. Personal communication.

Michener, D.C. 2008. Lessons from the death of a reference ash (*Fraxinus*) collection. Public Garden. 23(3/4): 39-40.

Miller, F. 14 August 2009. Research Associate, The Morton Arboretum. Personal communication.

Minnesota Landscape Arboretum (MLA). 2010a. About us. University of Minnesota. 3 February 2010. <http://www.arboretum.umn.edu/aboutus.aspx>.

Minnesota Landscape Arboretum (MLA). 2010b. Woody landscape plant breeding and genetics. University of Minnesota. 3 February 2010. <http://www.arboretum.umn.edu/woodylandscape.aspx>.

Minnesota Landscape Arboretum (MLA). 2009a. Minnesota Landscape Arboretum statistical summary. University of Minnesota. 3 February 2010. <http://www.arboretum.umn.edu/UserFiles/File/statisticalsummary09rev.pdf>.

Minnesota Landscape Arboretum (MLA). 2009b. University of Minnesota emerald ash borer management plan. University of Minnesota. Unpublished data.

Mittempergher, L., and A. Santini. 2004. The history of elm breeding. Invest Agrar: Sist Recur For. 13(1):161-177.

Moe, P.C. 12 October 2009. Director of Operations, University of Minnesota Landscape Arboretum. Personal communication.

Montgomery Botanical Center (MBC). 2010a. About Montgomery Botanical Center. 29 January 2010. <http://www.montgomerybotanical.org/Pages/About.htm>.

Montgomery Botanical Center (MBC). 2010b. Montgomery Botanical Center's collections. 29 January 2010. <http://www.montgomerybotanical.org/Pages/Collection.htm>.

Montgomery, M.E., S.E. Bentz, and R.T. Olsen. 2009. Evaluation of hemlock (Tsuga) species and hybrids for resistance to *Adelges tsugae* (Hemiptera: Adelgidae) using artificial infestation. J. Econ. Entomol. 102(3):1247-1254.

National Park Service (NPS). 2008. Great Smoky Mountains National Park: hemlock woolly adelgid. U.S. Department of the Interior. 3 March 2010. <http://www.nps.gov/grsm/naturescience/hemlock-woolly-adelgid.htm>.

Nentwig, W. 2007. Biological invasions: why it matters. In: W. Nentwig (ed.). Biological invasions. Springer-Verlag Berlin Heidelberg, New York, NY.

North Central Regional Plant Introduction Station (NCRPIS). 2010. Home. USDA – Agriculture Research Service (ARS). Ames, IA. 19 February 2010. <http://www.ars.usda.gov/main/site_main.htm?modecode=36-25-12-00>.

O'Dell, T. 27 July 2009. Collections and Natural Areas Specialist, The University of Michigan Matthaei Botanical Gardens & Nichols Arboretum. Personal communication.

Oldfield, S., A. Eastwood. 2007. The red list of oaks. Fauna & Flora International, Cambridge, UK. 12 March 2010. <http://www.bgci.org/files/Worldwide/Publications/the_red_list_of_oaks.pdf>.

Payton, G. 11 August 2009. Plant Records Manager, The Dawes Arboretum. Personal communication.

Pimentel, D., M. Pimentel, and A. Wilson. 2007. Plant, animal, and microbe invasive species in the United States and World. In: W. Nentwig (ed.). Biological invasions. Springer-Verlag Berlin Heidelberg, New York, NY.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. 52:273-288.

Plakke, J. 27 July 2009. Natural Areas Manager, The University of Michigan Matthaei Botanical Gardens & Nichols Arboretum. Personal communication.

Quarryhill Botanical Garden. 2007. Database of Asian Plants in Cultivation. 12 April 2009. <http://www.quarryhillbg.org/asianplantdatabase.html>.

Reichard, S.H. and P. White. 2001. Horticulture as a pathway of invasive plant introductions in the United States. BioScience. 51(2): 103-113.

Reichard, S.H., and C.W. Hamilton. 1997. Predicting invasions of woody plants introduced into North America. Conservation Biology. 11(1):193-203.

Royal Botanic Garden Edinburgh (RBGE). 1997. Multisite searches. 12 March 2010. < http://rbg-web2.rbge.org.uk/multisite/multisite3.php>.

Schreiber, L.R. 1993. An old problem; a new approach. In: M.B. Sticklen, and J.L. Sherald. Dutch elm disease research: cellular and molecular approaches. Springer-Verlag, New York, NY.

Schulhof, R. 2007. Managing biological invasions: introduced pests and pathogens. Public Garden. 22(4): 26-29.

Swartz, J.P. 23 July 2009. Campus Arborist, Michigan State University. Personal communication.

Sydnor, T.D., M. Bumgardner, and A. Todd. 2007. The potential economic impacts of emerald ash borer (*Agrilus planipennis*) on Ohio, U.S., communities. Arboriculture & Urban Forestry. 33(1):48-54.

Taylor, S.M. 27 July 2009. Researcher, University of Michigan. Personal communication.

Telewski, F.W. 23 July 2009. Curator, W.J. Beal Botanical Garden & Campus Arboretum of Michigan State University. Personal communication.

The American Chestnut Foundation (TACF). 2010. History of The American Chestnut Foundation. 20 March 2010. <http://www.acf.org/history.php>.

The Arnold Arboretum of Harvard University. 2010a. About us. 29 January 2010. <http://www.arboretum.harvard.edu/aboutus/aboutus.html>.

The Arnold Arboretum of Harvard University. 2010b. Our mission. 29 January 2010. <http://www.arboretum.harvard.edu/aboutus/mission.html>.

The Arnold Arboretum of Harvard University. 2010c. Inventory. 29 January 2010. <http://www.arboretum.harvard.edu/plants/inventory.html>.

The Arnold Arboretum of Harvard University. 2010d. Hemlock hill management and research. 29 January 2010. <http://arboretum.harvard.edu/research/hemlock_hill.html>.

The Dawes Arboretum. 2010a. History. 24 January 2010. <http://www.dawesarb.org/history.php>.

The Dawes Arboretum. 2010b. Home. 24 January 2010. <http://www.dawesarb.org/index.php>.

The Dawes Arboretum. 2010c. Trees. 24 January 2010. <http://www.dawesarb.org/trees.php>.

The Dawes Arboretum. 2010d. Nature. 24 January 2010. <http://www.dawesarb.org/nature.php>.

The International Plant Names Index. 2010. Plant Name Query: *Fraxinus densata*. 4 July 2010. <http://www.ipni.org:80/ipni/plantnamesearchpage.do>.

The Morton Arboretum. 2009a. About. 18 January 2010. <http://www.mortonarb.org/about.html>.

The Morton Arboretum. 2009b. Our tree collections. 18 January 2010. <http://www.mortonarb.org/tree-collections.html>.

The Morton Arboretum. 2009c. Schulenberg prairie. 18 January 2010. <http://www.mortonarb.org/schulenberg-prairie.html>.

The Morton Arboretum. 2009d. Our mission. 18 January 2010. <http://www.mortonarb.org/our-mission.html>.

The Morton Arboretum. 2009e. Before the bug comes to town: developing a state or regional readiness and response plan for exotic invasive insects. 18 January 2010. <http://www.mortonarb.org/images/stories/pdf/tree_advice/eab_readiness_plan.pdf >.

University of California Botanical Garden (UCBG) at Berkeley. 2010a. Mission. 29 January 2010. <http://botanicalgarden.berkeley.edu/about_us/about_us.shtml>.

University of California Botanical Garden (UCBG) at Berkeley. 2010b. Plant collections. 31 January 2010. <http://botanicalgarden.berkeley.edu/collections/introduction.shtml>.

USDA Animal and Plant Health Inspection Service (APHIS). 2008. Plant health: emerald ash borer. 20 March 2010. <http://www.aphis.usda.gov/plant_health/plant_pest_info/emerald_ash_b/background.shtml>.

USDA-ARS, National Genetic Resources Program. 2010. Germplasm Resources Information Network - (GRIN). National Germplasm Resources Laboratory, Beltsville, Maryland. 5 July 2010. <http://www.ars-grin.gov/cgi-bin/npgs/html/taxgenform.pl?language=en>.

USDA Forest Service. 2010. Restoration of the American elm in Ohio and the Eastern United States. 20 March 2010. <http://www.na.fs.fed.us/fhp/ded/elm_restoration_ohio.pdf>.

USDA Forest Service, Michigan Department of Agriculture, the Michigan Department of Natural Resources, and USDA Animal and Plant Health Inspection Service. 2010. Emerald ash borer. 20 March 2010. <http://www.emeraldashborer.info/index.cfm>.

U.S. Geological Survey (USGS). 2009. Invasive Species Program. U.S. Department of the Interior. 24 March 2010. <http://biology.usgs.gov/invasive/>.

V.B.T.A. vzw (The Association of Botanical Gardens and Arboreta). 2007. PLANTCOL. 12 April 2009. < http://www.plantcol.be/>.

Wallander, E. 2008. Systematics of *Fraxinus* (Oleaceae) and evolution of dioecy. Plant Syst. Evol. 273:25-49.

Widrlechner, M. 8 December 2009. Horticulturist, North Central Regional Plant Introduction Station. Personal communication.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States: assessing the relative importance of habitat destruction, alien species, pollution, overexploitation, and disease. BioScience. 48(8):607- 615.

W.J. Beal Botanical Garden. 2010a. Beal - home. Michigan State University. 15 January 2010. <http://www.cpa.msu.edu/beal/beal_frames.htm>.

W.J. Beal Botanical Garden. 2010b. Main collections. Michigan State University. 15 January 2010. <http://www.cpa.msu.edu/beal/beal_frames.htm>.

W.J. Beal Botanical Garden. 2010c. Michigan State University campus natural areas. Michigan State University. 15 January 2010. <http://www.cpa.msu.edu/beal/beal_frames.htm>.

Yin, R.K. 2009. Case study research: Design and methods. 4th ed. SAGE Publications, Inc., Thousand Oaks, CA.