pennsylvania
DEPARTMENT OF CONSERVATION
AND NATURAL RESOURCES

Ash Management in State Forest Lands Under Pressure from the Emerald Ash Borer

Prepared by

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Photo Credits

All photos by H. Liu except those credited to the original authors.

Cover page: *background* - Mature white ash tree, *center insert* - EAB adult.

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Executive Summary

The state of Pennsylvania recognizes the economic, ecological, and social benefits of trees to the long term health of the state forest systems and the quality of recreation and outdoor experience for its residents. Ash is an integral part of the state forest. White ash ranked no. 7 on the top 10 tree species list by statewide volume estimated in 2011. The introduction of emerald ash borer (EAB) to the state in 2007 significantly threatens the health and survival of the ash trees.

A dynamic and adaptive ash management plan is developed as part of the State Forest Resource Management Plan (SFRMP) against EAB for the next 10 years (2014-2023) with the following objectives: 1) Managing ash as a component in the forest; 2) Protecting endangered ash species; 3) Mitigating potential negative impacts; 4) Conserving economic value through silvilculture; 5) Managing seed orchards and collecting seeds; and 6) Conducting training and public outreach. Concrete steps will be taken by the Bureau of Forestry to reduce ash component to <10% on stands with >25% ash in basal area through silviculture measures; to protect up to 3,650 high-value white, green, black, and pumpkin ash trees at strategic locations through chemical treatment; to release natural enemies (*Oobius agrili, Spathius agrili, Tetrastichus planipennisi,* and possibly *S. galinae*) at multiple sites for EAB biological control; to survey for endangered pumpkin and blue ash trees; to remove susceptible ash trees in the forest through commercial harvests and regular maintenance; to eliminate up to 1,000 hazard trees from potential targets as part of the risk management; to explore potential ash wood utilization options; to chemically protect up to 300 seed orchard white and green ashes; and to conduct special trainings for ash management in local communities.

The total cost for this project is estimated at $1,756,100 over 10 years, ranging from $31,500 to 307,600 annually. It includes $500,000 for hazard tree removal, $1,191,100 for chemical treatment, $50,000 for biological control, and $15,000 for seed orchard protection. The real cost for tree removal and chemical control each year will be determined by actual number of trees to be removed or treated as proposed by the districts and other units involved. On the other hand, a total of $8,100,000 (ranging from $560,000-1,060,000/year) economic value from ash will be realized through harvest operations if most valuable ash trees are harvested in pre-mortality conditions according to the plan. Part of the revenue generated from the process can be used to cover the cost of this project.

The implementation of this comprehensive project will be supervised by the state foresters and co-administrated by the Program Services & Support section in the Forest Pest Management Division (FPM) and the Silviculture section, and supported by the Communications, Planning, Inventory & Monitoring, Geospatial Applications, Ecological Services, Recreation, Rural & Community Forestry, and FPM Operations sections, as well as Forest Districts and Penn Nursery within the bureau. Annual review of the project will be conducted by the professional staff from all participating units. Necessary adjustments will be made yearly based on the status of forest conditions, ash and EAB survey results, infestation levels, available management tools, personnel, budgets, etc. A state forest with retained ash genes at critical locations, healthy significant ash trees, safer recreation environment, and sustainable ash components will re-emerge from the challenge of EAB when the project is completed. Adoption of such a plan by various communities and private landowners across the state could have a positive impact on the overall ash management in Pennsylvania.

Introduction

State Forests in Pennsylvania

Slate Run Vista in Tiadaghton State Forest © PA DCNR

Forest accounts for 16.6 million acres or 58% of Pennsylvania's land. Seventy one percent of the forest land is owned by families, individuals, and other private entities. The remaining 29% is controlled by various public agencies (McWilliams et al. 2007).

Forest Districts
Counties

#1 Michaux
Adams, Cumberland, Franklin, York

#2 Buchanan
Bedford, Fulton

#3 Tuscarora
Juniata, Perry

#4 Forbes
Allegheny, Fayette, Greene, Somerset Washington, Westmoreland

#5 Rothrock
Centre, Huntingdon

#6 Gallitzin
Blair, Cambria, Indiana

#7 Bald Eagle
Mifflin, Snyder, Union

#8 Clear Creek
Armstrong, Beaver, Butler, Clarion, Jefferson, Lawrence, Mercer

#9 Moshannon
Clearfield

#10 Sproul
Clinton

#11 Lackawanna
Lackawanna, Luzerne, Susquehanna, Wayne, Wyoming

#12 Tiadaghton
Lycoming

#13 Elk
Cameron, Elk

#14 Cornplanter
Crawford, Erie, Forest, Venango, Warren

#15 Susquehannock
McKean, Potter

#16 Tioga
Tioga

#17 William Penn
Berks, Bucks, Chester, Delaware, Lancaster, Lehigh, Montgomery, Northampton, Philadelphia

#18 Weiser
Carbon, Columbia, Dauphin, Lebanon, Montour, Northumberland, Schuylkill

#19 Delaware
Monroe, Pike

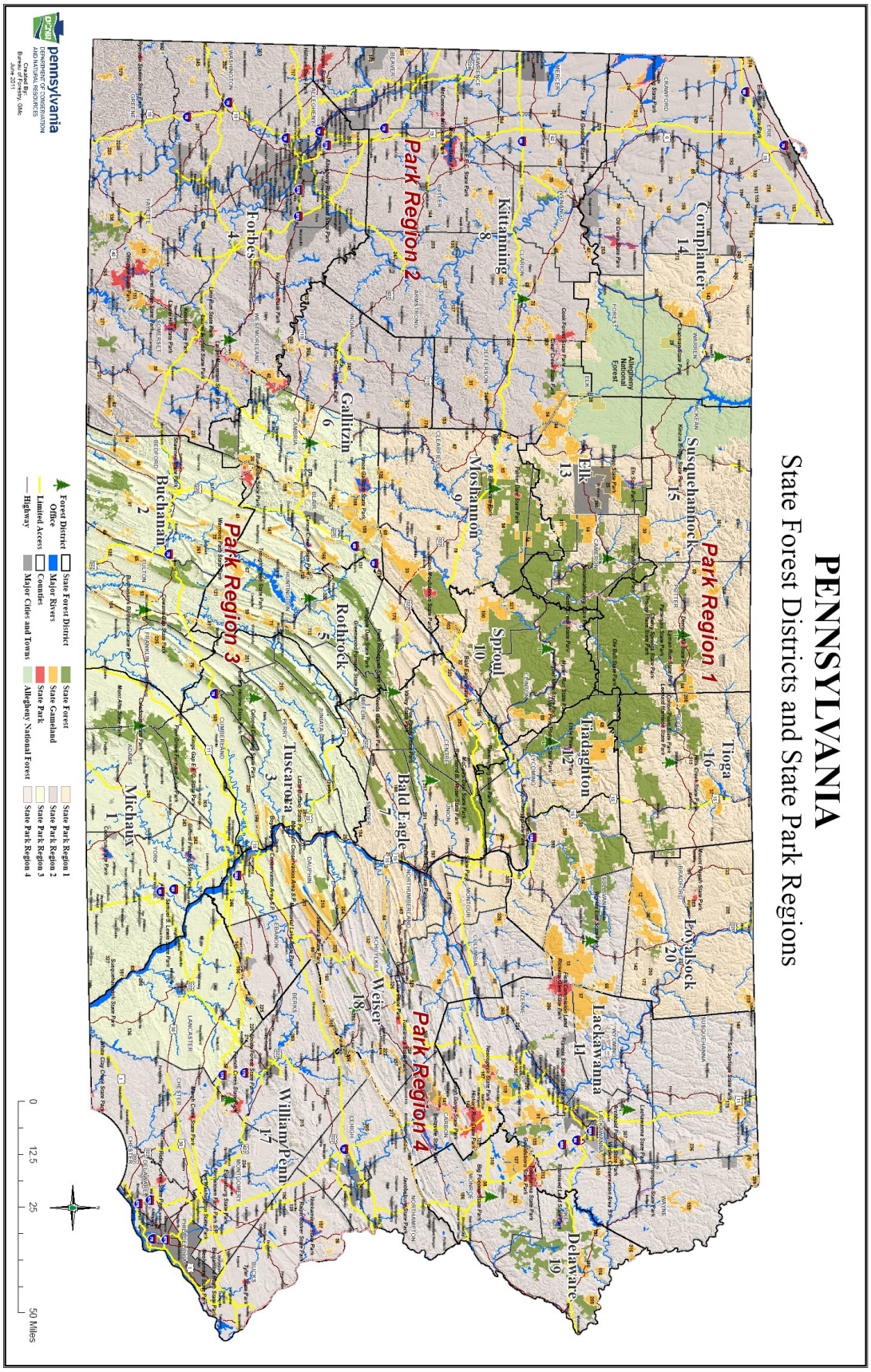
#20 Loyalsock
Bradford, Sullivan

The 2.1 million State Forest system in Pennsylvania was created to help ensure the long-term health, viability and productivity of the Commonwealth's forests and to conserve native wild plants. As the caretaker of this important public natural resource, the Bureau of Forestry will accomplish this mission by adopting sound ecosystem management to maintain biological diversity, to protect water quality and wildlife habitats, to provide low-density recreation opportunities, and to sustain timber production. Pennsylvania's State Forest system is made up by 20 Forest Districts with each covers one to nine counties.

Difficulties in the management of state forests include the lack of regeneration following harvest and other disturbance; the outbreaks of exotic insects and diseases; the rampage of forest fires; the spread of invasive plants; the drought, the acid deposition, and the ground-level ozone pollution; and most recently the activities of energy development.

The introduction of invasive species such as emerald ash borer presents unique challenges to forest managers. Certain biological characteristics such as fast growth, rapid reproduction (sexually or asexually), high dispersal ability, plastic phenotypes, wide distribution, and wide host range make them successful invaders. Billions of dollars in economic loss have been accumulated in various industries, with even deeper ecological impacts expected down the road.

As the lead agency in natural resource management in the state, the Bureau of Forestry advocates and promotes forest conservation by working on critical issues relate to forests, trees, and native plants through forest stewardship, training, education, and public outreach programs. Ash management under pressure from the emerald ash borer provides another opportunity for the bureau to lead the way. Ecologically sound strategies adopted by the bureau could have ripple effect on local communities and private landowners in their land management.


PENNSYLVANIA
State Forest Districts and State Park Regions
pennsylvania
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Created By:
Bureau of Forestry, GMc
June 2011
Forbes 4
Buchanan 2
Michaux 1
Gallitzin 6
Rothrock 5
Tuscarora 3
Kittanning 8
Moshannon 9
Sproul 10
Bald Eagle 7
Weiser 18
William Penn 17
Cornplanter 14
Susquehannock 15
Elk 13
Tiadaghton 12
Lackawanna 11
Delaware 19
Tioga 16
Loyalsock 20
Park Region 1
Park Region 2
Park Region 3
Park Region 4
Forest District
Other
Limited Access
Highway
State Forest District
Major Rivers
Counties
Major Cities and Towns
State Forest
State Gameland
State Park
Allegheny National Forest
State Park Region 1
State Park Region 2
State Park Region 3
State Park Region 4
0
12.5
25
50 Miles

Ash Species

Ash is a group of flowering plants in the genus of *Fraxinus* within the olive and lilac family (Oleaceae). Ash species are found in temperate and subtropical regions in the northern hemisphere. They are mostly large or medium-sized deciduous or evergreen trees, but some are shrubs in dry area. There are 43 recognized ash species worldwide, with 40 species in six sections (*Dipetalae*, *Fraxinus*, *Melioides*, *Ornus*, *Pauciflorae*, and *Sciadanthus)* and three unassigned species. A total of 20 species are found in North America, 20 in eastern Asia, and three in Europe and western Asia (Table 1).

Ash leaves are opposite and mostly pinnately compound and simple in a few species, with oar-shaped samara seeds. There is much variation in leaf morphology, including shape, size, texture, number of leaflets, and characteristics on leaf margin, petiolule, indumentums, epidermal papillae, rachis wings, etc. (Wallander 2008)

European Ash, *F. excelsior*
Illustration Flora von Deutschland, Österreich und der Schweiz 1885.
Image in public domain

About one third of the ash species are entomophilous (insect pollinated) and two-thirds are anemophilous (wind pollinated). Most anemophilous species are dioecious (having male and female flowers in separate plants) or polygamous (some males flowers on female plants or some female flowers on male plants). The majority of the entomophilous species are androdioecious (both bisexual and male flowers on the same plant), whereas a few are hermaphrodites (both male and female flowers on the same plants). The small ash flower has only one pistil and two stamens. The corolla may be lacking or consists of four (rarely two) petals that are white, linear, and free (rarely fused). The synsepalous calyx (if exist) is small, cup-shaped, and usually dentate. The entomophilous petaliferous flowers are borne in large showy panicles that emerge together with leaves from terminal buds, while the anemophilous apetalous flowers occur in lateral or terminal inflorescences that emerge before the leaves. There are four ovules in the syncarpous ovary although usually only one develops into samara with one seed inside (Wallander 2008).

Ash species are widely distributed across eastern U. S. and southeastern Canada, with 16 native species and one cultivated species (*F. uhdei*) in a wide range of forest ecosystems (see highlights in Table 1). White (*F. americana*) and green (*F. pennsylvanica*) ash have taxonomical significance in U.S. (Harlow et al., 1991); whereas white, green, black (*F. nigra*), pumpkin (*F. profunda*), blue (*F. quadrangulata*), and Oregon (*F. latifolia*) ash are listed as important commercial species (Stewart and Krajicek 1973). Single-leaf (*F. anomala*) and velvet (*F. velutina*) ash are found in the arid southwestern U. S. Green, velvet, and exotic European (*F. excelsior*) and Eurasian flowering (*F. ornus*) ashes are widely planted in urban areas for their tolerance to salt, drought, and soil compaction in replace of American elm killed by Dutch elm disease.

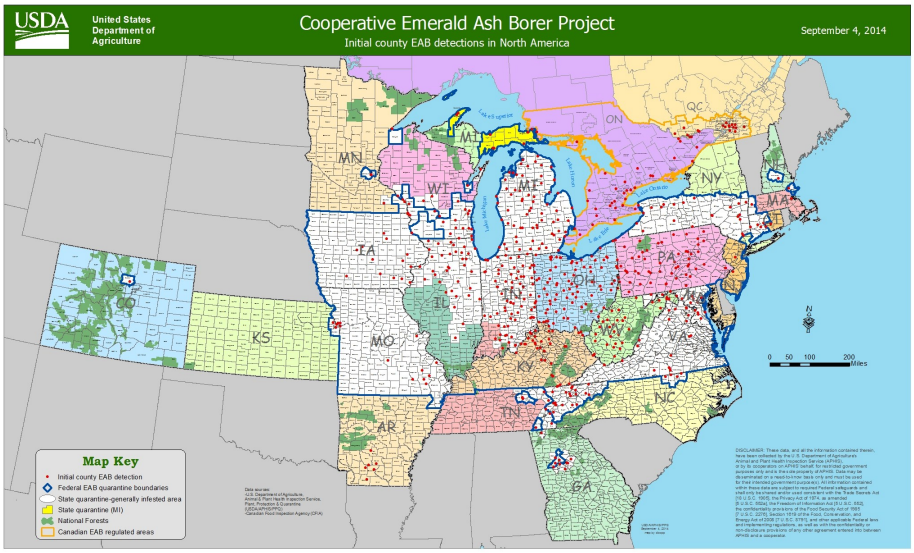
Table 1. Classification of *Fraxinus* (Oleaceae) Listing 43 Accepted Species with Geographical Distribution and Species Description

Sections and Species	Geographic distribution	Species description
Section *Dipetalae* (Lingelsh.) E. Nikolaev ***3 species***		
F. anomala Torr. ex. S. Wats.	SW USA	Shrub or small tree with two petals.
F. dipetala Hook. and Arn.	SW USA	Shrub or small tree with simple leaves.
F. quadrangulata Michx.	C & E USA, C Canada	Large tree with quadrangular twigs.
Section *Fraxinus* ***5 species***		
F. angustifolia Vahl	S & C Europe to C Asia	Displays polygamous breeding system.
F. excelsior L.	N & C Europe to W Russia	Narrow leaves.
F. mandshurica Rupr.	China, Japan, Korea, E Russia	Dioecious tree with rudimentary stamens.
F. nigra Marsh.	E USA, E Canada	Medium-sized tree with dark brown winter buds.
F. platypoda Oliv.	China	No papillose epidermis on the abaxial side of the leaves.
Section *Melioides* (Endl.) Lingelsh ***10 species***		
F. americana L.	E USA, E Canada	Large tree with concaved upper edge on the leaf scar.
F. berlandieriana DC.	SW USA, Mexico	Samaras decurrent at the base.
F. caroliniana Mill.	SE USA	No terete seed cavity.
F. latifolia Benth.	W USA	Pubescent leaves with sessile leaflets.
F. papillosa Lingelsh.	SW USA, Mexico	Small tree with sessile leaflets.
F. pennsylvanica Marsh.	C & E USA, Canada	Large tree with flattened upper edge on the leaf scar.
F. profunda (Bush) Bush	SE USA	Large leaves, twigs, and samaras.
F. texensis (Gray) Sarg.	SE USA (Texas)	Few leaflets and small samaras.
F. uhdei (Wenzig) Lingelsh.	C America	Dioecious evergreen to semi-evergreen trees.
F. velutina Torr.	SW USA, Mexico	Pubescent leaves with petiolulate leaflets.
Section *Ornus* (Boehm.) DC ***15 species***		
F. apertisquamifera Hara	Japan	Deciduous tree with slender glabrous branchlets.
F. baroniana Diels	China	Small tree with narrow leaflets, apetalous.
F. bungeana DC.	China	Shrub or tree with small leaves.
F. chinensis Roxb.	E. Asia	Medium-sized tree with glabrous branchlets, apetalous.
F. floribunda Wall.	Himalaya, E Asia	Medium-sized tree with dense brown tomoentose buds.
F. griffithii C. B. Clarke	SE Asia	Ever-green small tree with large showy panicles.
F. lanuginosa Koidz.	Japan	Leaflets distinctly serrate, apetalous.
F. longicuspis Sieb. and Zucc.	Japan	Deciduous tree with gray-brown branchlets.
F. malacophylla Hemsl.	China, Thailand	Large tree with brown tomentose leaflets
F. micrantha Lingelsh.	Himalaya	Large tree with small inflorescences, apetalous.
F. ornus L.	C & E Mediterranean	Medium-sized tree with spectacular inflorescences.
F. paxiana Lingelsh.	Himalaya, China	Medium-sized tree with near quadrangular twigs.
F. raibocarpa Regel	C Asia	Shrub or small tree with falcate samaras.
F. sieboldiana Blume	China, Japan, Korea	Twigs and leaf rachis puberulent and scurfy hairy.
F. trifoliolata W. W. Smith	China	Shrub or small tree with three leaflets.
Section *Pauciflorae* (Lingelsh.) E. Wallander, stat. nov. ***5 species***		
F. dubia (Willd. ex. Schult) P. S. Green & M. Nee	Mexico, Guatemala	Leaflets have entire margins.
F. goodingii Little	SW USA, N Mexico	Evergreen shrub or small tree with coriaceous leaves.
F. greggii A. Gray	SW USA, Mexico	Multistemmed shrub or small tree with coriaceous leaves.
F. purpusii Brandegee	Mexico, Guatemala	Leaflets with coarsely serrate margins.
F. rufescens Lingelsh.	Mexico	Ferruginous-tomentose shoots and inflorescences.
Section *Sciadanthus* (Coss. et Dur.) Lingelsh. ***2 species***		
F. hubeiensis S. Z. Qu, C. B. Shang & P. L. Su	China	Threatened species endemic to Hubei.
F. xanthoxyloides (G. Don) DC.	N Africa to China	Shrub or small tree with terete and smooth branchlets.
Incertae sedis **3 species**		
F. cuspidata Torr.	SW USA, Mexico	Small insect-pollinated tree.
F. chiisanensis Nakai	Korea	Wind-pollinated tree endemic to Korea.
F. spaethiana Lingelsh.	Japan	Large tree with stout blabrous branchlets.

Based on Ohwi, Meyer, and Walker (1965); Wei and Green (1996); and Wallander (2008)

Emerald Ash Borer

The emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), an exotic woodborer from northeast Asia, was first discovered attacking ash trees in Michigan in 2002. Since then, it has been found in 23 additional U. S. states (Arkansas, Colorado, Connecticut, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Massachusetts, Minnesota, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin), and two Canadian provinces (Ontario, Quebec) across the Great Lakes region and beyond (map *left*).



EAB Distribution Map as of September 04, 2014 ***USDA***

Adult, 7-14 mm, metallic green

Eggs, 1 mm, brown

Larva, 26-32 mm, creamy white

Pupa, 7-14 mm, creamy white

Life history

EAB has a one- or two-year life cycle depends on geographical location and infestation stage. It overwinters as young larvae (two-year generation), mature larvae or prepupae (one-year generation) in the outer sapwood or outer bark. Adults begin to emerge in early May with the accumulation of 400-500 growing degree days (GDD) based on 50°F, and reach peak emergence in early to mid June at approximately 1,000 GDD. After emergence, adults feed on ash leaves for supplemental nutrition. Adults mate one week after emergence. Females lay eggs in bark crevices or between bark layers 2-3 wk later. Each female can produce 70-80 eggs. Newly hatched larvae bore directly into the bark until reaching the cambial region and phloem where they feed, often forming serpentine galleries under the bark. There are four instars in the larval stage. By mid-October, most larvae reach the last instar or become prepupae. Pupation occurs in early April the following year. For those overwintering as young larvae (1st - 3rd instar). Pupation may not take place for another year.

Damage, signs, and symptoms

EAB damage ash trees mostly through feeding by its larvae under the bark. Larval feeding in the cambial region disrupts nutrient and water flow within the vascular system, which eventually leads to host mortality within 4-5 years. Signs and symptoms of EAB infestation include crown dieback, epicormic shoots, woodpecker damage, bark split, serpentine larval gallery, D-shaped exit holes, and dead trees.

Crown dieback

D-shaped exit hole

Epicormic shoots on trunk

Woodpecker damage on bark
© S. Katovich - Forestry Archive, Bugwood

Vertical bark splits on small trunk

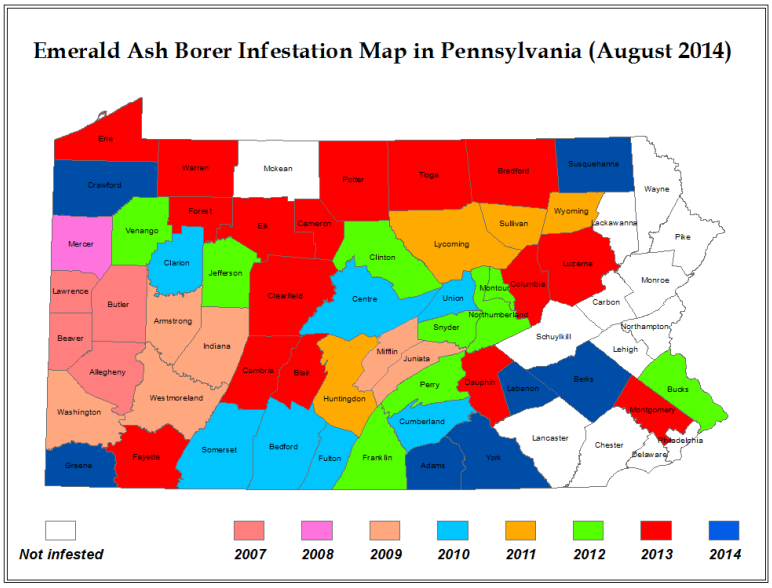
Dead ash tree

Larva in serpentine gallery

Host species

EAB attacks only ash trees. Host species in its native range include Chinese ash (*F. chinensis)* and Manchurian ash (*F. mandshurica)*. The formerly recognized Korean ash (*F. rhychophylla*) is now considered as a subspecies of Chinese ash. In North America, EAB has been recorded from green, white, black, blue, and pumpkin ash. Potentially all 16 native ash species and other cultivated species in the U. S. are threatened by this pest when it spreads to all ash growing areas.

Infestation in PA



EAB was first discovered in Pennsylvania in Cranberry Township, Butler County in 2007. Subsequently, neighboring counties such as Allegheny, Beaver, and Lawrence were found infested. It has since spread to Mercer in 2008; Armstrong, Indiana, Juniata, Mifflin, Washington, and Westmoreland in 2009; Bedford, Centre, Clarion, Cumberland, Fulton, Somerset, and Union in 2010; Huntingdon, Lycoming, Sullivan, and Wyoming in 2011; Bucks, Clinton, Franklin, Jefferson, Montour, Northumberland, Perry, Snyder, and Venango in 2012; Blair, Bradford, Cambria, Cameron, Clearfield, Columbia, Dauphin, Elk, Erie, Fayette, Forest, Luzerne, Montgomery, Potter, Tioga, and Warren in 2013; and Adams, Berks, Crawford, Greene, Lebanon, Susquehanna, and York in 2014. A total of 54 counties are currently infested with EAB, with the entire state under quarantine (map *above*).

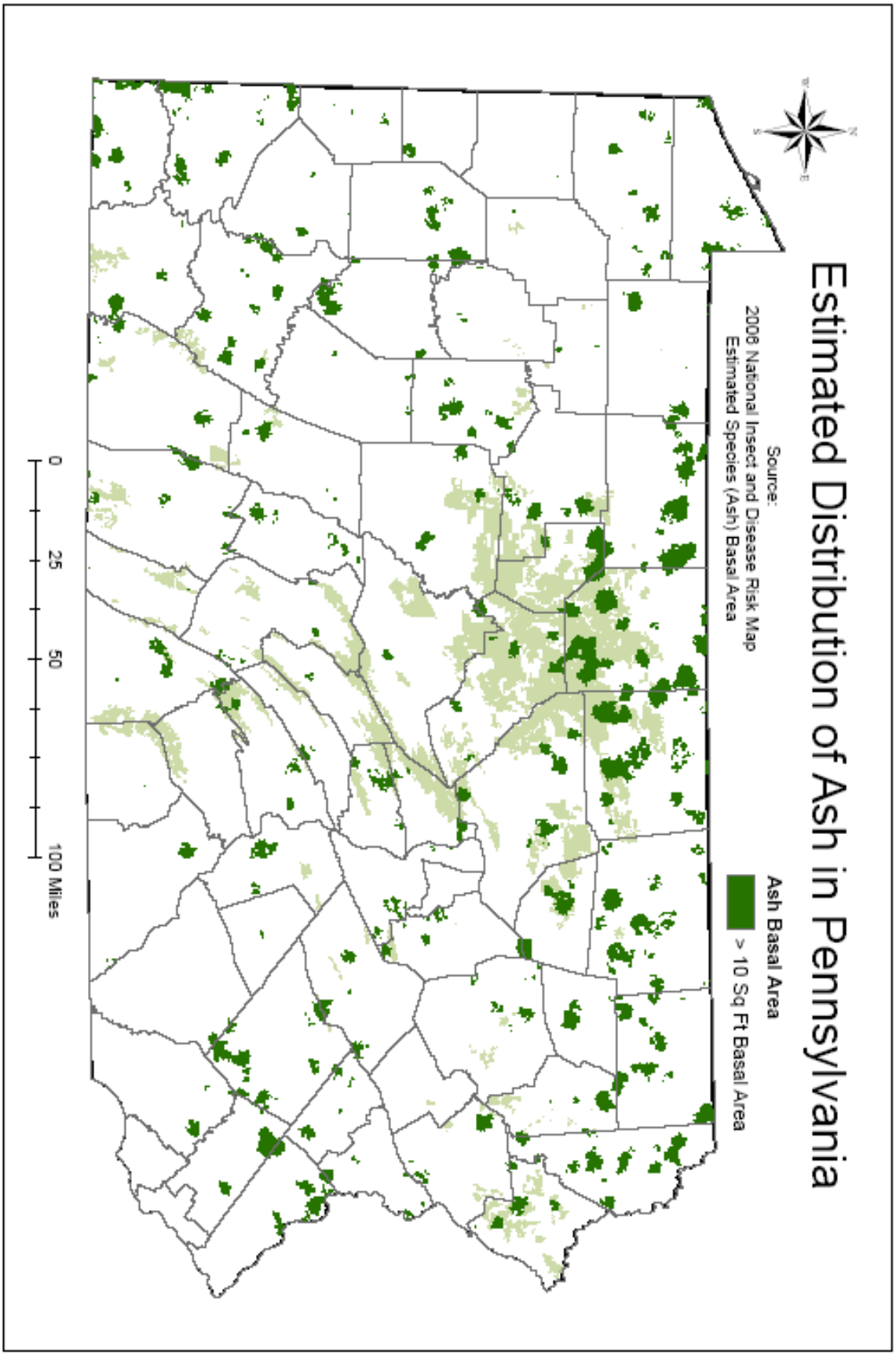
Impact on Ash Resources

National impact

Ash is a valuable resource with multiple applications as lumber and in the manufacture of tool handles, baseball bats, furniture, cabinetry, basketry, and solid wood packing material. EAB has the potential to spread and kill ash trees throughout North America. An estimated 8 billion ash trees are found in U. S. timberland, with a compensatory value of $282 billion. Green, white, and black ash make up 7% hardwood stand in northeastern Unites States and eastern Canada. An estimated 20 to 55 million ash trees have been killed by this pest in the infested areas. The potential economic damage may exceed $10 billion in 25 states expected to be affected between 2009 to 2019 (Kovacs et al. 2010).

Pennsylvania impact

Ash is an integral part of the forest in PA with four species (green, white, black, and pumpkin) totaling more than 300 million trees in the forests and millions more in the urban areas (Map *next page*). White ash ranked no. 7 on the top 10 species list by statewide volume in 2011, with an estimated 1,728 million cubic feet of live trees and 5,237 million board feet of sawtimber trees on State Forest Land (McCaskill et al. 2012). Ash is a commercial species desired and marketed by many sawmills. EAB is expected to destroy most of them in the near future.


Estimated Distribution of Ash in Pennsylvania
Source:
2006 National Insect and Disease Risk Map
Estimated Species (Ash) Basal Area
Ash Basal Area
> 10 Sq Ft Basal Area
0
25
50
100 Miles

Current Management Options

EAB larval galleries on white ash

Managing EAB in North America has proven to be difficult because of the size of initial infestation, the lack of effective early detection tools, the limitations in control options, the speed of infestation spread, as well as scarcity in available resources. Consequently, many communities across the states follow the same path chronologically in their battle against this invasive pest with mixed results: exclusion, preparedness, response, and recovery. Currently there are three control options for EAB management:

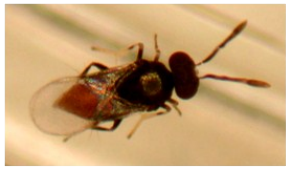
Tree Removal. Cut and remove infested ash trees and grind them to chips < 1 inch (2.54 cm) in two dimensions. It's 100% effective against EAB larvae, prepupae, pupae, and adults before emergence. The high cost associated with this option may limit its use to small and early outlier infestations.

Tree removal

Chemical Control. Individual ash trees can be protected with chemical insecticides such as imidacloprid (Merit®, Xytect™), emamectin benzoate (Tree-äge®), and dinotefuran (Safari®) applied directly into the tree through trunk injection or bark spray; or indirectly by treating the soil around the tree (imidacloprid only) (Herms et al. 2009). Treatment efficacy ranges from 60% to 99% depends on insecticide selected and lasts from 1 to 3 years. When use as directed, these insecticides are unlikely to harm woodpeckers and honey bees while posts negligible impact on fish, amphibians, or tolerant aquatic invertebrates (Hahn et al, 2011).

Biological Control. Release of parasitoids for long term EAB population control in the forest and natural areas. One egg parasitoid - *Oobius agrili* Zhang and Huang (Hymenoptera: Encyrtidae), and two larval parasitoids - *Spathius agrili* Yang (Hymenoptera: Braconidae) and *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae) are currently available to state cooperators from USDA APHIS Rearing Facilities in Brighton, MI (Gould et al. 2010). Another new larval parasitoid, *Spathius galinae* Belokobylskij & Strazanac (Hymenoptera: Braconidae) is currently being considered for field release in 2014. Nontarget effect is considered low to un-intended species.

Trunk injection with Tree-äge



O. agrili ♀ 1 mm

S. agrili ♀ 3-5 mm © J. Gould

T. planipennisi ♀ 3-4 mm

Objectives

To address the immediate and long term impact of EAB on state forest lands in Pennsylvania, we developed this comprehensive ash management plan with the following objectives:

1. Maintaining Ash as A Component in the Forest;

2. Protecting Endangered Ash Species;

3. Mitigating Potential Negative Impacts;

4. Conserving Economic Value through Silviculture;

5. Managing Seed Orchards and Collecting Seeds;

6. Conducting Training and Public Outreach;

Participating Units and Respective Roles

Listed below are participating units in the Bureau and their respective roles in this project. An ash management coordinating committee should be formed with at least one state forester and one member representing each unit to coordinate project activities. Project team should convene at least twice a year at the beginning and the end of the field season to ensure annual goals are set properly and met in all project areas.

Bureau of Forestry sections	Role	Activities
State Foresters	Supervision	Project coordination
Silviculture	Co-leader	Overall project planning and implementation
FPM Program Services & Support	Co-leader	Overall project planning and implementation
Communications	Project support	Communication & outreach
Planning	Project support	Program planning
Inventory & Monitoring	Project support	Ash inventory & monitory
Geospatial Applications	Project support	Data recording, mapping, and storage
Ecological Services	Project support	Site selection, rare & endangered species survey
Recreation	Project support	Risk management in road buffer, trails and picnic areas
Rural & Community Forestry	Project support	Forest stewardship & community outreach
FFP Operations & Planning	Project Support	Fire hazard mitigation
Forest Districts	Project execution	Field application of project activities
Penn Nursery	Project execution	Seed orchard & seed collection
FPM Field Operations	Project execution	Technical support and field assistant

Objective 1: Maintaining Ash as A Component in the Forest

Ash provides browse and protection for a variety of wildlife species. Ash seeds are consumed by ducks, song and game birds, small mammals, and insects. The existence of 21 species of ash-feeding moths also depends on the survival of the ash trees (Wagner, 2007). EAB has the potential to wipe out the entire *Fraxinus* genus, just like the chestnut blight did to American chestnut. Since its introduction to North America, much of the attention has been directed to urban forests where potential impact (Sydnor et al. 2007, Kavocs et al. 2010), control options (Smitley et al. 2010, Grimalt et al. 2011, McCullough et al. 2011), and management strategies (Sadof et al. 2011, Vannatta et al. 2012) have been studied. Communities across the infested areas have mobilized tremendous resources to save some of their significant ash trees. Ash management in forested lands under pressure from EAB, however, remains to be a frontier not only because unseen trees in the woods hold less cultural and emotional significance compared to residential and community park trees, but also because most control strategies learned from urban settings in the past decade may not be appropriate for the forests. However, The long-term ecological impact of EAB could be profound. It is therefore our recommendation to maintain ash as a component in state forest lands for ash gene retention and species conservation.

Survey for Ash Resources

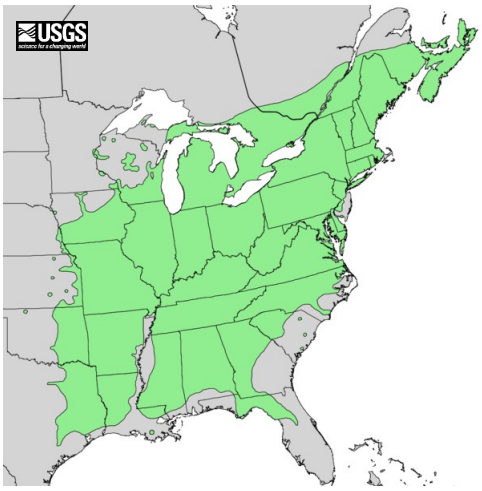
Forests can not be effectively managed unless their conditions are known. A forest inventory is required to systematically collect information on ash species, diameter-at-breast height (DBH), height, site quality, age, and defects. A timber cruise and a stand examination are then used to estimate the amount of standing timber the forest contains, with information on timber metrics (basal area, DBH, form factor, Girard form class, quadratic mean diameter, site index, and tree taper) and volume estimation (stocking, density index, volume table, and management diagram) collected. The most up-to-date forest inventory and analysis (FIA) data on state forest should be utilized to prioritize ash resources to meet the objectives outlined in this plan.

Upon the identification of priority areas with significant ash resources in each forest district, more focused tree inventories are needed to address the management impacts from existing or potential EAB infestations. A specific, partial, complete, or cover type inventory is conducted to collect data on individual trees, including location, GPS coordinates, species, DBH, height, crown conditions (dieback ratio), EAB infestation, etc. An ash distribution map should be generated from the tree inventory data for the drafting of specific ash management strategies in selected priority areas.

High ash component stand

White ash (*Fraxinus americana* L.)

White ash is an economically important native species. It is particularly sought after for handles, oars, and baseball bats due to its strength, hardness, weight, and shock resistance. White ash grows commonly on fertile soil with high nitrogen and moderate to high calcium contents. Other common name includes Biltmore ash.



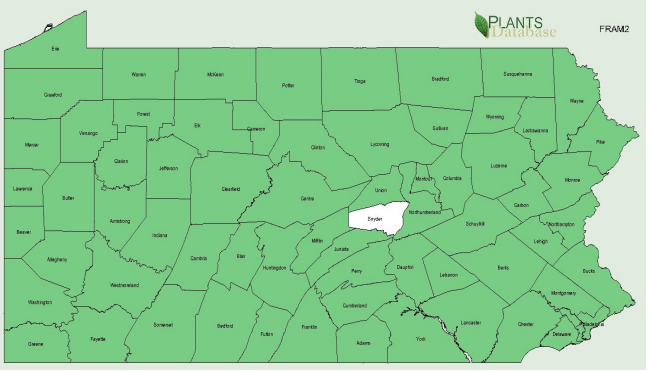
Native range. White ash is native to eastern North America from Nova Scotia and Minnesota south to Florida and Texas. It is also cultivated in Hawaii (map *right*).

Morphology. White ash is a large tree up to 80 feet tall that typically develops a straight and clear bole. The bark is gray to brown, with interlacing corky ridges forming obvious diamonds. Pinnately compounded leaf is 8-12 inches long, comprises of 7 serrate to entire leaflets that are ovate to lancelate. Twigs are stout, gray-olive-green, hairless. Leaf scar round at the bottom and notched at the top. Lateral buds reside in the notch. Flowers are light green to purplish without petals. Female flowers in loose panicles while males in tighter clusters.

White ash *© T. McDowell*

Life history. White ash is dioecious. Flowers appear with or just before the leaves in April and May. Seeds are dispersed by wind from September to December. However, they do not germinate under natural conditions because of the dormancy caused by immature embryos. A good seed crop is produced every three years in all parts of the crown. Almost 99% of the samaras contains one seed, while about 1% contains two seeds.

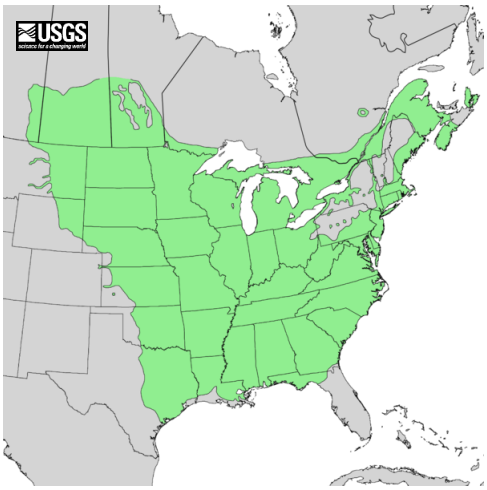
Distribution in PA. White ash is commonly found in all forest districts throughout the state (except Snyder County *in white*) in forests, hedgerows, and old fields. (map *below*).



Habitat. White ash is a species of mesophytic uplands with a general preference for brown and grey-brown podzolic soils. Although rarely form pure stands, it can be quite dense in regenerating forests and fallow agricultural fields as a pioneer species. Some of the major associated species of white ash are eastern white pine, northern red oak, white oak, sugar/red maple, yellow birch, American beech, black cherry, American basswood, eastern hemlock, American elm, and tulip poplar (Fowells 1965).

Green ash (*Fraxinus pennsylvanica* Marsh)

Green ash is the most common native ash species in North America. It naturally grows in riparian areas, and widely used as ornamental trees throughout the Unites States and much of Canada. Green ash is similar in property to white ash and marketed together sometimes. Other common name includes red ash.



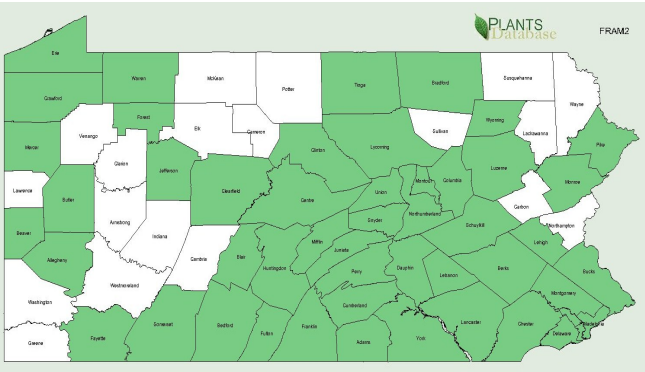
Native range. Green ash is native to eastern and central North America from New Brunswick and Manitoba and south to Oklahoma, eastern Texas and northern Florida. (map *right*).

Morphology. Green ash is a medium-sized tree reaching up to 70 feet tall with poorly formed bole and an irregular or round crown in its northern range. The bark is gray to brown in color, with interlacing corky ridges forming obvious diamonds. Pinnately compounded leaf is 6-9 inches long, comprises of 7-9 serrate leaflets that are lanceolate to elliptical in shape. Twigs are stout, gray to green-brown, glabrous or pubescent. Leaf scars near semicircular to flat across the top. Lateral buds sit on top of the leaf scar. Flowers light green to purplish in color with no petals. Female flowers occur in loose panicles, while male flowers are in tighter clusters.

Green ash *© Native Ohio Plants*

Life history. Green ash is dioecious. Its flowers are produced in spring shortly before new leaves and pollinated by wind. Seeds are dispersed as soon as they are ripen and continue in the winter. Epigeal germination may occur in the spring following seedfall. Some seeds may lie dormant in the litter for several years before germinating. Good seed crops are produced each year. Green ash seedlings establish best under partially shaded areas with moist soil.

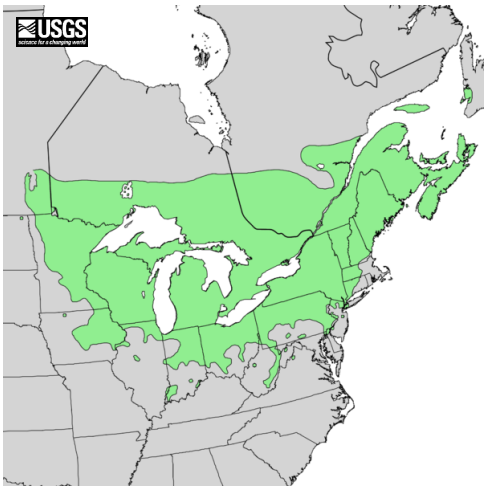
Distribution in PA. Green ash is common across Pennsylvania except high Alleghenies and a few northern tier counties (map *below*).



Habitat. Green ash is generally a bottomland species of alluvial soils in floodplains along rivers and streams. Green ash has a wide ecological distribution conferred by its resistance to salt, flooding, drought, and high alkalinity. It's commonly associated with box-elder, red maple, pecan, sugarberry, sweetgum, American sycamore, cottonwood, quaking aspen, black willow, willow oak, and American elm (Fowells 1965, Stewart and Krajicek 1973).

Black ash (*Fraxinus nigra* Marsh)

Black ash is a slow-growing tree of northern swampy woodlands. It is unique among all trees in that it does not have fibers connecting the growth rings to each other. This property is utilized by native Americans in basket making. Other common names include swamp ash, basket ash, brown ash, hoop ash, and water ash.



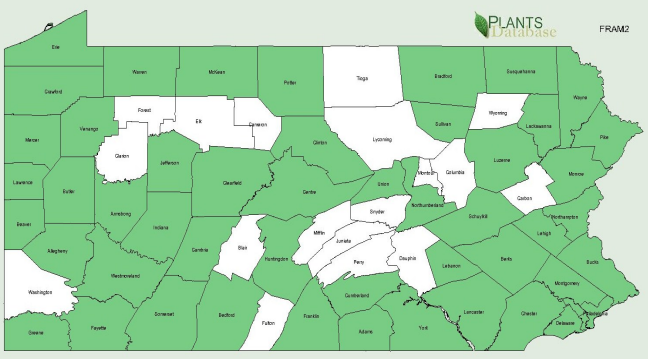
Native range. Black ash is native to eastern Canada and northeastern United States, ranging from Newfoundland to North Dakota, and south to Kentucky and Virginia (map *right*).

Morphology. Black ash is a small to medium-sized tree reaching up to 40-50 feet tall. The bark is gray, thick and corky, becoming scaly and fissures with age. Pinnately compounded leaf is 10-14 inches long, comprises of 7-11 sessile and serrated leaflets. Twigs are stout, light brown to gray, with near black opposite buds. Lateral buds appear some distance below terminal buds. Leaf scars near circular. Flowers are inconspicuous in loose panicles and with no petals. Samara is 1-2 inches long with one seed inside.

Black ash © R. Routledge

Life history. Black ash is polygamous. Its flowers are produced in spring shortly before new leaves and pollinated by wind. Seeds are dispersed from July to October. Large seed crops are produced every five or more years by mature trees. Seeds have very pronounced dormancy. Black ash seedlings establish under canopy shade on a variety of soils.

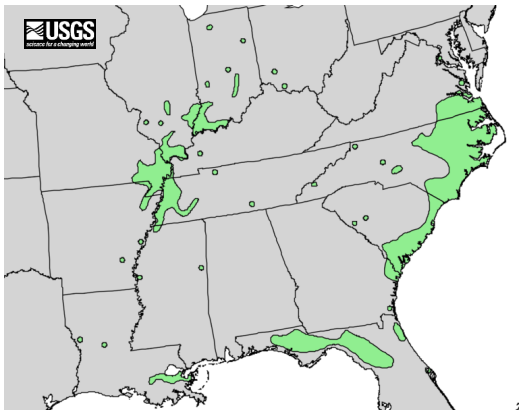
Distribution in PA. Black ash is tree of swamps, wet woods, and bottomlands throughout Pennsylvania except a few counties (*in white*) (map *below*). It occurs most frequently south of the glaciated areas.



Habitat. Black ash is a hydric species occurring in bogs, swamps, along small streams, in poorly drained depressions and other sites with high water tables. Pure stands are found in northern portion of its range. It prefers wet muck and shallow organic peat and most frequently associated with American elm-red maple-ash forest cover type. Other associated species include ironwood, musclewood, and basswood on frequently inundated river banks; as well as scattered trees in balsam fir, black/white spruce, eastern hemlock, paper birch, and tamarack stands (Fowells 1965, Erdmann et al. 1987, Primack 2000).

Pumpkin ash (*Fraxinus profunda* (Bush) Bush)

Pumpkin ash is a large tree of swamps and bottom lands.



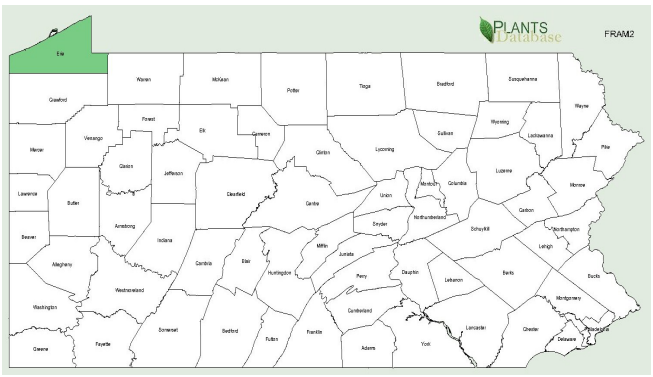
Native range. Pumpkin ash is native to eastern North America, with a scattered distribution on the Atlantic costal plains and interior lowland river valleys from southern Maryland to Indiana, northern Florida, and southern Missouri. It's also recorded in the extreme south of Essex County, Ontario. (map *right*).

Morphology. Pumpkin ash is a large tree reaching a height of 130 feet and a diameter at breast height of 68 inches. The bark is gray-brown in color, with interlacing ridges to nearly blocky. Pinnately compounded leaf is 9-18 inches long, comprises of 7-9 serrate leaflets that are elliptical to lanceolate in shape. Leaves dark green above, paler and velvety below. Twigs are stout, fuzzy, light gray-brown. Leaf scars oval without deep notch. Buds brown and scruffy. Flowers green to purple in cluster. Samara is 2-3 inches long with wing extends nearly to base.

Pumpkin ash © *R. Keim*

Life history. Pumpkin ash is a dioecious species flowering in April and May before leave flush. It is not a prolific seed producer. The winged samara contains a single seed. Pumpkin ash has the largest seed of all native ash species, with an average length of 2.4-2.8 inches and average width of 0.9 in. Seed production begins at an early age. Seeds mature in late summer and fall between October and December. Seeds remain viable in water for several months.

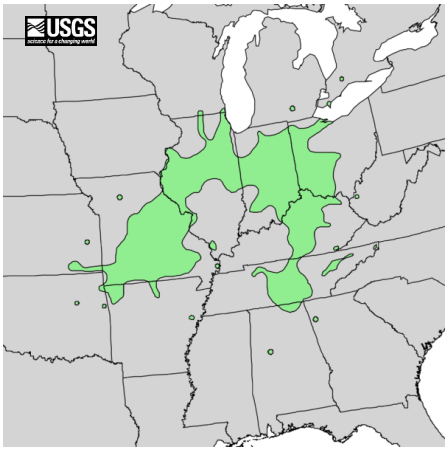
Distribution in PA. Pumpkin ash is a very rare species in Pennsylvania known only from shallow woodland ponds and wet forested flats in Erie County and possibly other counties in Cornplanter SF (map *below*). Discovered in 1992, it is proposed as endangered by the DCNR.



Habitat. Pumpkin ash is a species of moist to wet locations in swamps, floodplains, wet bottomlands, river valleys and low areas. It is usually found in the same sites as bald cypress, swamp cottonwood, and water tupelo (Stewart and Krajicek 1973). Other associated species include red maple, silver maple, black willow, Carolina ash, water elm, water locust, overcup oak, swamp chestnut oak, willow oak, water oak, water hickory, and American elm. In its wettest locations, especially those with standing water remains well into the growing season, its trunk becomes swollen or buttressed at the base.

Blue ash (*Fraxinus quadrangulata* Michx.)

Blue ash is a slow-growing and long-living tree of dry limestone uplands. Blue dye from the inner bark was used to color yarn by early settlers.



Native range. Blue ash is native primary to the Midwestern United States as well as the Bluegrass region of Kentucky and the Nashville Basin region in Tennessee. Isolated populations exist in Alabama, southern Ontario and small sections of the Appalachian mountains. (map *left*).

Morphology. Blue ash is a medium-sized tree typically reaching a height of 50-75 feet and with a trunk of 20-40 inches in diameter. The bark is gray to brown, becoming scaly and fissures with age. Pinnately compounded leaf is 7-11 inches long, comprises of 7-11 serrate leaflets that are ovate or lanceolate. Twigs are stout, distinctly four-angled, light brown to gray, with gray to reddish brown buds. Leaf scars notched. Flowers are perfect (hermaphrodites) and pale green in color. Samara is one-seeded and 1 to 1 1/2 inches long.

Blue ash *© R. Routledge*

Life history. Blue ash is a polygamous species and pollinated presumably by wind. Clusters of apetulous bisexual purplish flowers appear in April to May before leaves. Fruits ripen in the fall and may persist on the tree throughout the winter. Seeds are produced irregularly, and in mast years weevils frequently destroy most of the seeds. Seeds can remain in seed banks for decades.

Habitat. Blue ash is an upland species on calcareous soils or on rich bottoms. It is tolerant of high PH and drought (Harlow et al. 1991). Blue ash is found with northern red oak, mockernut hickory, sweetgum, white oak, American/slippery elm, and sugar maple (Stewart and Krajicek 1973).

Distribution in PA. Blue ash is thought to be present in Pennsylvania based on old herbarium specimens. It is a proposed endangered species by DCNR. Pennsylvania Natural Heritage Program (PNHP) and DCNR are working together to confirm this occurrence. More explorations in surrounding areas may be needed to verify the status of this species in PA.

Blue ash tree in Kentucky *© M. Brock*

Silviculture Measures

Field operation © D. Haubrick, DCNR Bureau of Forestry

Harvesting ash trees reduces the amount of phloem available to developing EAB larvae, which in term slows EAB population growth and possibly spread (McCullough and Siegert 2007, McCullough and Mercader 2012). Districts should begin to apply harvesting operations wherever possible by focusing on high value ash stands. However, cutting above and beyond allocation goals is not recommended. Districts should begin working normal and pre-salvage harvests into work plans and current allocation goals, prioritizing by the criteria below.

The following general silviculture recommendations should be considered for stand management in all districts:

1. As much as possible, priority should be given to those stands that have heavy ash component within multiple used commercial stands when planning harvest allocation goals.

2. Where ash is greater than 25% of the basal area except in riparian areas, harvests should be planned to regenerate the stand, and reduce ash to less than 10% of the reserved trees. This will allow some ash to continue to disperse seeds until it succumbs to EAB.

3. Since ash seed does not bank well in the soil, once ash is removed as a seed source, it most likely will be lost from the site for some time into the future. It is recommended to still count ash as desirable regeneration species, as long as it does not dominate the stocking. There is also evidence that EAB needs at least 1-2 inches of stem diameter to establish itself in the host trees.

4. When stands constitute less than 25% ash in the basal area, logging is discouraged where the impetus to harvest is based on pure salvage. Stands that constitute less than 25% basal area of ash should be left to run their courses with EAB. The stress of logging for salvage is not worth the benefit to be gained from removing the threatened ash. In addition, stands with an ash component this low will most likely reach full stocking again within a decade or so following mortality. If districts wish to harvest stands with less than 25% ash basal area, careful evaluation will need to be made on the stress that may follow harvesting on the residual stand. Mitigating efforts, such as logging in the winter to reduce root compaction, and avoidance of spring logging when bark slip could easily occur in high BA residual stands, should be considered as well as the value to be gained from removing ash trees. Situations with extremely high value logs might be considered, but is discouraged where ash trees are average to below average in quality.

Harvested ash logs © D. Haubrick, DCNR Bureau of Forestry

5. Road buffer stands should also be given priority where ash is a heavy component. Use criteria in #2 , and #3 for prescription guidelines.

Chemical Control

Individual ash trees can be effectively protected from EAB with selected chemical insecticides. EAB-infested trees with signs of canopy decline at time of treatment may continue to decline in the first year before improving due to time lag associated with the healing process of the vascular system. Trees exhibiting >50% canopy decline are unlikely to recover even if treated.

Imidacloprid (*Merit®, Xytect™, IMA-jet®, Imicide®, Pointer™, Bayer Advanced Garden™ Tree & Shrub*)**.** Imidacloprid is a systemic insecticide that mostly applied through soil application (drench and injection). Soil application is most effective when made at the base of the trunk in moist but not saturated soils between mid-April to mid-May. Mulch and dead leaves need to be removed before soil drench to reduce binding of imidacloprid with organic matters, whereas soil injection places insecticide directly into the root zone 2-4 inches beneath the soil within 18 inches of the trunk to avoid run off. Allow four to six weeks for uptake and distribution of the insecticide within the tree. Annual application is needed, with variable efficacy observed among different products and site conditions.

Dinotefuran (*Safari™ 20 SG*). Dinotefuran is a neonicotinoid insecticide acts on the synapses of the insect nerve system. It is labeled as a noninvasive, systemic bark spray on the lower 5-6 ft trunk for EAB control. Insecticide penetrates the bark and move quickly throughout the tree due to its high water solubility. Test of Safari™ 20 G showed that it caused 56-77% mortality on adults fed on treated ash foliage. Annual application is needed.

Emamectin Benzoate (*TREE-äge™*). Emamectin benzoate is the benzoate salt of emamectin, a compound produced by the fungus *Streptomyces avermitilis* and exhibits toxicity to arthropods and nematodes. TREE-äge™ is a special formulation of emamectin benzoate for EAB control. It's a systemic insecticide that must be injected into the trunk to kill EAB larvae and adults. It is highly effective against EAB larvae with 99% efficacy. A single injection may provide up to three years' of control.

To chemically protect important ash trees from EAB in the ecosystems in state forests, selected white, green, and black ash trees in groves in strategic ecological landscape types (ELTs) will be treated with emamectin benzoate every 2-3 years for 10 years. Healthy white and green trees or trees with less than 20% crown decline at the sex ratio of 5:1 (females : males) are selected to ensure successful seed production, whereas such requirement is not needed for black ash as it is polygamous. Big trees with heavy seed crop in or close to known infestation will be selected first. Treatment efficacy will be evaluated yearly based on crown conditions.

Each district should try to identify 100 white, 50 green, and 20 black ash trees for chemical treatment. At least 10 dominate ash trees in each grove will be selected from 5-10 white, 3-5 green, and 1-2 black ash groves in various ELTs respectively. Site conditions (name, location, size, GPS coordinates, county, township, forest type, elevation, aspect, position, ash percentage, dominate species, understory, year of initial EAB infestation, etc.) and tree information (Tree#, tag#, GPS coordinates, species, sex, DBH, EAB infestation, canopy decline, seed production potential, surveyors, treatment plan, etc.) are recorded before the treatment.

Biological Control

EAB is generally considered a sporadic pest of Chinese and Manchurian ash in its native range of northeastern China mainly due to host resistance and natural enemies. However, in North America, native ash species have shown little resistance to EAB infestation. In addition, native parasitoids such as *Phasgonophora sulcata* Westwood (Hymenoptera: Chalcididae), *Spathius floridanus* Ashmead (Hymenoptera: Braconidae), and *Balcha indica* (Mani & Kaul) (Hymenoptera: Eupelmidae) exerted very limited impact on pest populations in the field. Significant parasitism was observed for a newly discovered larval parasitoid, *Atanycolus cappaerti* Marsh and Strazanc (Hymenoptera: Braconidae) in Michigan. However, the long term management of EAB will most likely depend on the success of classical biological control—the intentional introduction and permanent establishment of exotic agents for long-term pest control. The following four parasitoid species are currently being utilized for EAB biological control in North America:

Oobius agrili. *O. agrili* is a solitary parthenogenetic parasitoid of EAB eggs discovered in northeastern China. Females lay single eggs in EAB eggs. At least two generations was observed in the field, with a parasitism of 56.3 - 61.5%. A portion of parasitoid population in the 2nd generation diapauses inside host eggs and emerge the following year (Liu et al. 2007).

Tetrastichus plannipennsi. *T. plannipennsi* is a gregarious endoparasitoid of EAB larvae found in northeastern China. Females penetrate tree bark using their saw-like ovipositors and lay 4-172 eggs inside each EAB larva feeding in the cambial region. Up to four generations were observed in the field, with a average parasitism of 22.4% (Liu et al. 2003, 2007).

Spathius agrili. *S. agrili* is a gregarious ectoparasitoid of EAB larvae found in northern and northeastern China. Females drill through tree bark and lay 1-35 eggs on the body surface of each EAB larva. A total of four generations were observed in the field, with a parasitism up to 90% (Liu et al. 2003, Yang et al. 2005).

Spathius galinae. *S. galinae* is a gregarious ectoparasitoid of EAB larvae found in the Far East of Russia and South Korea. Females deposit 1-16 eggs on the body surface of each EAB larva underneath after overcoming the bark with their long ovipositors. Two to three generations were observed in the field, with a parasitism of 50% (Belokobylskij et al. 2012).

The Division of Forest Management (FPM) has been working with USDA APHIS and Forest Service on EAB biological control in since 2011, with more than 31,000 parasitoids released at five selected sites in four counties (Allegheny, Union, Bedford, and Huntingdon) by the end of 2013. Establishment of *O. agrili* and *S. agrili* has been confirmed at Deer Lakes and North Park in Allegheny County, respectively. Monitoring on parasitoid establishment continues in other release sites. Now is the time to expand EAB parasitoid release to state forest lands, especially in north tier counties where most of the ash resources are located. Up to 10 sites from state forest/park/game land will be selected for parasitoid release in the next 10 years. Idea release site should be 10-40 acres in size, with light to moderate EAB infestation, and contain at least 10% ash in its species composition. The species and number of parasitoids to be released each year will be determined by their availability from USDA APHIS rearing facility.

Objective 2: Protecting Endangered Ash Species

An endangered plant species is "a classification of plant species which are in danger of extinction throughout most or all of their natural range within the Commonwealth, if critical habitat is not maintained or if the species is greatly exploited by man. This classification also includes populations of plant species that have been classified as Pennsylvania Extirpated, but which subsequently are found to exist in this Commonwealth" (PA DCNR , 1988) . The introduction of EAB in the forest brings additional pressure to the future of the endangered ash species in Pennsylvania.

Pumpkin Ash

Pumpkin ash is an endangered species found in Erie County. Small populations may also exist in neighboring Crawford and Warren counties along the border lines. To protect this endangered species, harvesting of live pumpkin ash across the state should be prohibited while salvage sales involve this species should subject to state review under current laws and regulations. At the same time, dominate healthy trees should be treated chemically to protect them from EAB infestation. Biological control is not recommended for this species giving its small population size and the low efficacy of this option on single trees.

Penn Nursery and FPM has been working with Erie Bluffs State Park and Cornplanter SF since 2009 to chemically treat selected number of trees in the park as part of the seed orchard management (see section 8). A total of 32 pumpkin ash trees were preemptively treated with imidacloprid and emamectin benzoate between 2009-2010. Continuous treatment on those trees with emamectin benzoate is planned for 2014.

Penn Nursery and FPM should work with ecological services, Cornplanter SF, state game commission, area state parks, and private landowners to identify 1-2 additional pumpkin ash populations to bring the total number of pumpkin ash trees protected to at least 50.

Recording data from treatment trees

Sampling branches for Species identification

Blue Ash

Blue ash is considered an endangered species in Pennsylvania although its existence has yet to be confirmed. Effort should be focused on tracing those early records, as well as conducting targeted surveys to identify potential populations in the state. If confirmed, chemical control should be considered immediately for dominate healthy trees.

Objective 3: Mitigating Potential Negative Impacts

Ash trees are valuable natural resources with compensatory values ecologically and economically. On the other hand, dead or dying ash trees in the forest present real threats to public safety. As part of the management plan, districts should have specific measures in place now to mitigate the potential negative impact of EAB on ash trees in state forest.

Significant Trees

Chemical treatment of high value ash tree

Ash trees at certain locations (e.g. landmarks, historic, ecologically significant, offices buildings, popular trails, wild areas, natural reserves, and sanctuaries) may have significant values compare to others found in the forest. Some of these trees may worth protecting from EAB as the cost of removing and replacing would be significantly higher than treatment. Chemical treatment is generally considered for the protection of these trees. A survey for significant ash trees should be conducted in each district. The total number of significant ash trees to be protected in the entire state forest will be determined by the availability of resources, the significance of the trees, and other factors to be decided through consultation with stake holders.

Risk Management

Up to 99% of the ash trees will be killed within a few years of EAB infestation. Dead ash trees post potential safety hazard on buildings, roads, and trails. Forest districts can manage this risk by planning ahead with accurate information on EAB infestation and tree inventory. Ash trees around buildings, major roads and trails that are not designated for treatment need to be removed as quickly as logistically feasible to reduce risk due to the quick decaying nature of dead ash trees. This can be accomplished by using contracted tree removal, maintenance staff, timber harvesting or through the sale of fuelwood permits. Wherever possible, fuelwood permits may also be utilized to remove ash along right-of-way corridors and roads. Work cooperatively with Pennsylvania Department of Transportation (PennDOT) and utility companies to address road areas within their jurisdictions.

Tree removal along utility lines

Tree removal along the road

Objective 4: Conserving Economic Value through Silvilculture

Coring ash logs for baseball bats © PA DCNR

Ash has significant economic value as logs and timber, especially for those with a diameter above 18 inches. This value should be conserved as much as possible before it completely disappears with EAB. Normal harvests should continue as planned in currently un-infested areas, whereas pre-salvage harvests /salvage sales and wood utilization should be considered for ash trees in or near areas with different EAB infestation levels. It is important to recognize that delay in action has the potential to dramatically reduce the economic value of ash trees.

Normal and Pre-Salvage Harvests

Normal harvest is the result of a stand prescription to change current structure and conditions for specific management goals that are done routinely to satisfy district management goals. It includes regeneration (even-aged, two-aged, and un-even aged) harvest, intermediate harvest, and commercial thinning. Planned treatment in each harvest may vary from clear cut, seed tree, to shelterwood cut based on site conditions. Pre-salvage harvests are similar to normal harvests but differ by deliberately targeting high component stands (> 25% basal area) ahead of harvest schedule to capture the value of specific tree species before it's lost to insect and other damaging factors. In either case, it involves sales of target species before pest infestation (e.g. EAB). Districts should follow Silviculture Measures described before in this plan for recommendations on normal harvests and pre-salvage operations.

Presently, ash only makes up about 4% of the total volume harvested from State Forest Lands. By moving ash stands up on the harvest schedule for districts, these pre-salvage operations may generate additional revenue each year. However, the economic value of ash trees can only be realized when harvests are done prior to mortality. Ash deteriorates quickly once a tree experiences mortality, which in turn results in quick value loss. Normal and pre-salvage harvests are therefore critical to the maximization of ash stand values. Not every ash tree will be harvested, nor should they be. Ash trees left behind still have value beyond timber. Dead trees provide shelters and habitats for wildlife. Those survived EAB infestation may contain important genetic materials for potential resistance. Stands with ash harvested should be noted. Site locations should be forwarded to FPM for resistance monitoring and survey.

Logging operation in forest district

Trees with a diameter of 18 inches or above have the highest value for ash logs. Years of destruction from EAB in many Midwest states may have reduced ash supply dramatically. State forests with economically matured ash trees in un-infested areas should proceed now with planned harvests to maximize the potential economic value of those trees. In 2012, Bureau of Forestry harvested a total of 1,703 MBF of live white ash and 0.2 MBF of green ash sawtimber, generating about $350,000 timber revenue based on the weighted average price of $224/MBF (Bureau of Forestry Silviculture Report 2012).

Assuming the normal harvest of ash timber will be at the level of 2,000 MBF/year for the next 10 years (2014-2023), the total revenue from normal harvest of ash trees could reach $500,000 each year based on the weighted average price of $250/MBF. In addition, an additional 2,000 MBF of live white and green ash trees could be harvested as pre-salvage harvests on top of the normal harvest quota each year, generating another $500,000 per year for the next five years (2014-2018) as a proactive measure to capture the maximum value of the ash trees. This kind of economic benefit, however, may not be available for the following five years (2019-2023) as damage on ash trees prevents pre-salvage harvests completely. It is therefore critical for districts to prioritize their pre-salvage harvests before EAB renders ash material to much less valuable firewood or snags.

Salvage Sales

Salvage sales are designed to remove diseased, insect infested, dead, damaged, or down trees, trees affected by fire or imminently threatened by disease or insect attack, or trees associated with ecosystem rehabilitation projects. Salvage sales are usually used to capture the commercial value of dead or dying trees before it evaporates through decay. Salvage sales can improve forest health and reduce safety hazard, and preparing affected forest stands for regeneration. Not all dead and dying trees are salvageable. For example, trees deteriorate quickly have little or no salvageable value, whereas trees in nature reserves, wild areas, and remote locations are generally inaccessible legally or economically. Districts are encouraged to evaluate ash conditions and conduct salvage sales accordingly based on existing guidelines.

In 2012, Bureau of Forestry harvested a total of 233 MBF of dead white ash sawtimber as salvage harvests, generating about $30,000 timber revenue based on the weighted average price of $125/MBF (Bureau of Forestry Silvilculture Report 2012). Revenue from ash firewood is considered very minimum. No data is available for pre-salvage sale for ash trees so far. However, this could change quickly as the bureau adopts new strategies to deal with the increasing EAB infestation in the forest across the state. Assuming the salvage of ash timber will double for the next 10 years (2014-2023) when the bureau deals with EAB infestation over constantly enlarging areas, the total revenue from salvage sale of ash trees could reach $60,000 per year.

Wood Utilization

EAB damage is limited to the outer 1-2 inches of sapwood. Ash logs from infested ash trees are still commercially valuable as trees, lumber, and veneer in the construction, furniture, cabinetry, millwork, flooring, biomass, pellets, sporting goods, specialty products, and engineered parts industries (Table 2). Districts should actively seek local industries and vendors for wood utilization. Care should be taken through compliance agreements with PA Department of Agriculture and USDA APHIS to ensure no infested ash materials (barks, outer sapwood, branches, etc.) will cross quarantine boundaries without being treated by approved methods (heat treatment, fumigation, etc.).

Table 2. Market and Utilization Options for Ash Logs (base on Brashaw et al. 2012)

Product Name	Product considerations	Quality Specifications	Market Opportunities	Trade Associations
Trees	> 20 inches in diameter	Straight, uniform, defect-free	Demonstration projects	American Institute of Architects
Lumber	> 8 ft long > 8 inches in diameter	Straight grained w/ coarse uniform texture	Hardwood sawmills	American Hardwood Export Association Appalachian Hardwood Association
Veneer	8-12 ft long 12-14 inches in diameter	Round, straight, free of knots, centered heart	Full-sized panels Laminated substrates	Architectural Woodwork Institute Composite Panel Association Hardwood Plywood &Veneer Association
Furniture	Clear lumber cuttings Quarter-sawn lumber	Visual appearance	Residential/commercial furniture producers	American Home Furnishings Alliances American Woodwork Institute Business & Institutional Furniture Manufacturer's Association Hardwood Manufacturers Association National Home Furnishing Association Wood Component Manufacturers Association Wood Products Manufacturers Association
Cabinetry	Clear lumber cuttings Quarter-sawn lumber	Dry lumber with a moist content of 6-8%	Residential/commercial settings	Cabinet Manufacturers Association Kitchen Cabinet Manufacturers Association
Millwork	Long, clear wood strips	Dry lumber with a moist content of 6-8%	Local woodshops Large manufacturers	Architectural Woodwork Institute Association of Millwork Distributors U.S. Green Building Council
Flooring	Kiln-dried lumber Thick veneer	Moist content of 6-8%	Residential/commercial markets	Hardwood Manufacturers Association National Wood Flooring Association Wood Floor Covering Association
Biomass	Low grade tree or lumber	Quarantine compliance	Home owners, schools, mulch and soil companies, pulp and paper companies	Biomass Thermal Energy Council National Firewood Association Northeast Biomass Thermal Working Group Pellet Fuel Institute
Pallets	Lower grade logs sawn into cants	Sound but contains knots or visual defects	Packing/transporting companies, railroad companies	American Wood Protection Association Canadian Pallet Council National Wooden Pallet & Container Association Railway Tie Association
Sporting goods	High-quality white ash log	Clear straight-grained log without defects	Sports market	National Sporting Goods Association Sporting Goods Manufacturers Association
Specialty products	High strength & excellent durability white ash log	Straight grain and defect free	Wood handle producers Craft makers	American Association of Woodturners Wood Component Manufacturers Association
Engineered parts	Low grade lumber	Mechanically graded lumbers, trusses, I-joists	Forest products industry	N/A

Objective 5: Managing Seed Orchards and Collecting Seeds

Ash is a prolific and regular seed producer which readily establishes itself naturally in its native ranges. Seed orchards and seed collections are rarely needed although ash seeds do not bank well in the soil. However, the arrival and spread of EAB has changed this dynamic dramatically as most seed-producing trees will be destroyed in a few years, leaving virtually no seeds for regeneration after infestation (Herms et al. 2010). It is therefore important to protect seed orchards and preserve seeds for ash restoration in the future.

Seed Orchards

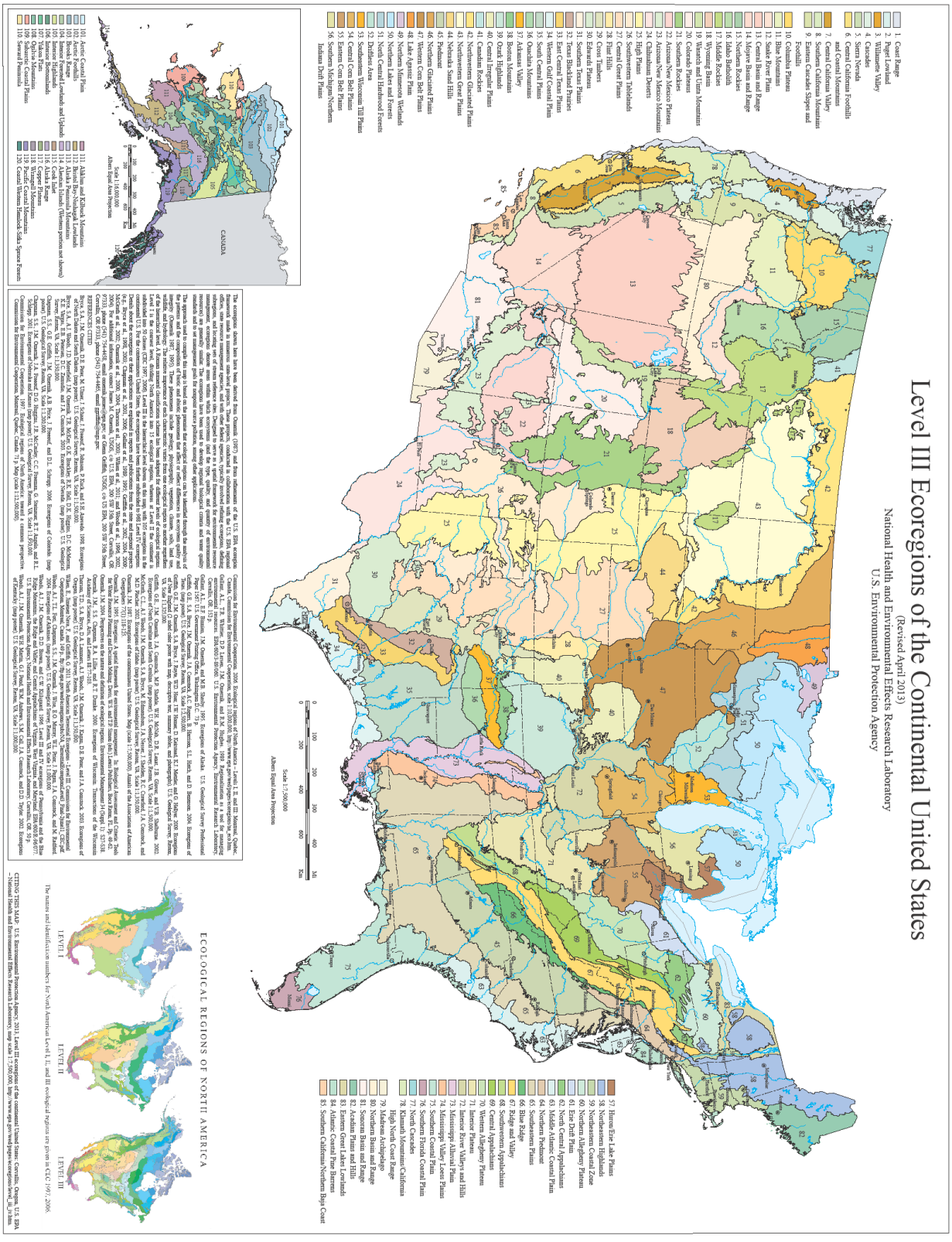
There are three artificial seed orchards established by the Bureau of Forestry in the past few decades, including the 30 -year old Dague white ash orchard in Clearfield County, the 15-year old white ash orchard in Greenwood Nursery, the 1 -year old green ash orchard in Bald Eagle State Park. Penn Nursery has been maintaining these orchards throughout the years. We recommend continuous support to Penn Nursery for the protection of these orchard trees through chemical treatment. In addition, wild populations of blue ash, black ash, green ash, and even white ash should be identified and protected as natural seed orchards. This can be done in combination with maintaining ash as a component in the forest through Chemical control.

Dague white ash seed orchard in Clearfield County

Seed Collections

White ash seeds

Seed collection is the most convenient and economical way of genetic conservation. Like other species on the planet, ash adapts to its environments through genetic selection over time. Ash seeds have been successfully stored for almost 40 years in subzero temperatures. To preserve this adaptation from being lost to EAB infestation, USDA Forest Service National Seed Laboratory launched an ash seed collection project in 2011. The objective of this project is to collect seeds from 50 trees in each Momernik level III ecoregion (map *next page*). It is expected that over 90% of the ash genes will be saved by collecting seeds in this manner. Pennsylvania is part of the seed collection effort since 2011. We recommend continue cooperation with Forest Service on seed collection in the coming years.


Level III Ecoregions of the Continental United States
(Revised April 2013)
National Health and Environmental Effects Research Laboratory
U.S. Environmental Protection Agency
ECOLOGICAL REGIONS OF NORTH AMERICA
LEVEL I
LEVEL II
LEVEL III
Albers Equal Area Projection

Objective 6: Conducting Training and Public Outreach

The Bureau of Forestry's mission calls for the promotion of forestry and forestry knowledge through advising and assisting other government agencies, communities, landowners, forest industry, and the general public in the wise stewardship and utilization of forest resources. Outreach and public education play an important role in EAB survey, detection, management, and prevention. This effort should be carried out by all bureau staff, especially service foresters, rural and community forestry specialists, forest insect and disease coordinators, and forest pest management personnel.

Training

Bureau staff need to be trained on ash and EAB management before they can serve the public well. A few training sessions will be organized each year to provide information on ash identification, EAB biology, infestation status, resources at risk, survey and detection efforts, management options, cost and benefit analysis and general strategies. Guidelines and procedures for the development of individual ash management plan for communities will be discussed. Techniques on how to conduct tree inventory, assess infestation and damage, remove dead and dying ash trees, chemical control, biological control, seed collection will be demonstrated in the field. This can be achieved through regular meetings, seminars, webinars, conference calls, etc.

Public Outreach

As mentioned before, 71% of the forest lands is privately owned in Pennsylvania (McWilliams et al. 2007). The success of ash management on those lands depends on the stewardship of the Bureau of Forestry. Bureau staff are therefore encouraged to promote ash management strategies to other government agencies, communities, landowners, forestry industry, and general public by using this plan in the forest, and the Greenwood Furnace Plan (Liu et al. 2012) and the Community Plan (Liu 2012) for parks and general communities, respectively. Technical assistance will be provided to interested entities and individuals across the state. Projects in state forest lands can serve as examples as well as training sites for the general public.

District Strategy

Each district should develop its own ash management plan to fit its specific conditions based on the six objectives outlined in this document. Ash inventory data is a prerequisite for the development of such a plan. Additional field surveys may be needed as a result of outdated, incomplete, or lack of information on certain species. Management options for each species correspond to management objectives are listed in Table 3. Ask yourself the following questions when develop an ash management plan:

1. **Does ash (white, green, black, blue, pumpkin) exist in my district?**
2. **Where is the nearest EAB infestation?**
3. **Is ash greater than 25% of the basal area in some stands?**
4. **Where do I want to see ash continue as a major species in the forest?**
5. **Are there significant ash trees in my district?**
6. **How will the district manage the risk caused by dead or dying ash trees?**
7. **Is there a program for normal /pre-salvage harvest of ash trees?**
8. **Is there a program for salvage sale of ash trees?**
9. **Is there a program for ash wood utilization?**
10. **How much will the management plan cost?**

Table 3. Ash Management Options for Forest Districts (***N/A - not applicable***)

Ash species	**Objectives**					
	Maintaining ash component	*Protecting R&E species*	*Mitigating impacts*	*Conserving value*	*Orchards & seed collecting*	*Training & outreach*
White	1. Silviculture 2. Chemical control 3. Biological control	N/A	1. Significant trees 2. Risk management	1. Normal/pre-salvage harvests 2. Salvage sales 3. Wood utilization	Work with Penn Nursery on all species	Work with related units in Bureau of Forestry Central Office
Green						
Black						
Blue	N/A	Rare	N/A	N/A		
Pumpkin	N/A	Endangered	N/A	N/A		

Basic Components of District Ash Management Plan

At least the following components should be included in the district's ash management plan:

- Δ Ash distribution map
- Δ Silviculture measures to reduce ash to less than 10% basal area in forest stands
- Δ Number and location of **white** ash trees to be protected chemically
- Δ Number and location of **green** ash trees to be protected chemically
- Δ Number and location of **black** ash trees to be protected chemically
- Δ Potential biological control sites
- Δ Number of significant ash trees to be protected chemically
- Δ Number trees to be removed as part of the risk management
- Δ Programs on normal/pre-salvage harvests, salvage sales, and wood utilization
- Δ **Blue** and **pumpkin** ash populations
- Δ A 10-year budget with yearly distribution

Budget and Fiscal Planning

Cost of the Management Plan

The estimated total cost of this management plan is $1,756,100 over 10 years as described in Table 4. Total costs include $500,000 for tree removal, $1,191,100 for chemical treatment, $50,000 for biological control, and $15,000 for seed orchard protection.

Table 4. Cost of Ash Management Plan in State Forest Lands 2014-2023 * Recurring

Year	*Tree removal*		*Chemical control*			*Biological control*			*Seed orchards*		Total
	Trees	*Cost*	*Trees*	*Insecticide*	*Equipment*	*Sites*	*Supplies*	*Equipment*	*Trees*	*Insecticide*	
2014	150	75,000	0	0	40,600	2	6,000	20,000	200	500	**142,100**
2015	150	75,000	3,650	219,000	11,100	0		0	300	2,500	**307,600**
2016	150	75,000	0	0		2	6,000	0	200	500	**81,500**
2017	150	75,000	3,650	219,000	11,100	0		0	300	2,500	**307,600**
2018	150	75,000	0	0		2	6,000	0	200	500	**81,500**
2019	50	25,000	3,650	219,000	11,100	0		0	300	2,500	**257,600**
2020	50	25,000	0	0		2	6,000	0	200	500	**31,500**
2021	50	25,000	3,650	219,000	11,100	0		0	300	2,500	**257,600**
2022	50	25,000	0	0		2	6,000	0	200	500	**31,,500**
2023	50	25,000	3,650	219,000	11,100	0	0	0	300	2,500	**257,600**
Total	**1,000**	**$500,000**	**3,650***	**$1,095,000**	**$96,100**	**10**	**$30,000**	**$20,000**	**300***	**$15,000**	**$1,756,100**

Tree removal

Most trees will be removed through commercial harvests that generate revenue, or by maintenance crews felling affected ash trees. In situations where removal cannot be done safely without adverse risk to potential targets (i.e. pavilions, maintenance sheds, other infrastructure), professional removal crews should be brought in to safely remove the hazard trees. It is estimated that up to 50 trees must be removed in this manner in each district over 10 years in this plan, with the majority to be removed early in the plan as the initial front moves through the state. Removal cost is estimated about $500 per tree, as most of these will require bucket trucks for removal. Cost will vary under different circumstances. It is therefore recommended the actual request from each district to be used each year.

Chemical control

Chemical control will be applied bi-annually to 100 white ash trees (10-20 trees/site for 5-10 sites), 50 green ash trees (10-20 trees/site for 3-5 sites), 20 black ash trees (10-20 trees/site for 1-2 sites), and 10 high value ash tree for each of the 20 districts. In addition, a total of 50 pumpkin ash trees (at least 10 trees/site for 3 sites) will be treated every other year. Insecticide cost is estimated at $60/tree based on an average tree diameter of 12 inches and $5/inch of diameter. Equipment include 7 Injection kits @ $3,000/kit, 28 IV kits @ $700/kit in 2014, and 222 packs of injection plugs @ $50/pack of 100 in 2015, 2017, 2019, 2021, and 2023, respectively.

FPM Program Services & Support is responsible for the purchase and distribution of all chemicals and treatment equipments for this project. It will also provide training on chemical treatment to forest districts and Penn Nursery. Forest districts and Penn Nursery are responsible for the identification of treatment sites/trees, field application of chemical treatment, and efficacy evaluation in their own areas with technical/field assistant from Ecological Services, FPM Field Operations, Program Service & Support, and other bureau units. Staff time spent on survey and field applications is not counted toward the total cost. Potential treatment cost for blue ash, if found, is not included in this table either.

Biological control

Biological control is planned for 10 sites in state forest lands. All EAB parasitoids are currently provided free of charge by USDA APHIS Rearing Facility at Brighton, MI according to interagency cooperative agreements between the federal and state governments. This effort will continue in Pennsylvania as long as the parasitoids are made available to us in the project period. Equipment cost for biological control includes two biological incubators at $10,000/ unit; whereas supplies includes chemicals, laboratory apparatus, and field tools budgeted at $6,000 every other year. FPM is responsible for parasitoid release, establishment confirmation, and impact evaluation with help from participating forest districts.

Seed orchards

To protect ash trees in seed orchards, $500 is budgeted annually for imidacloprid to be used as soil treatment at Greenwood and Bald Eagle seed orchards. In addition, a total of $2,000 is budgeted bi-annually for emamectin benzoate to be used as trunk injection in Dague seed orchard. Cost for imidaclopird Xytect 75 WSP is estimated at $500/drum with each drum contains 110 water soluble bags(1.6 oz /bag). A drums of imidacloprid can treat a total of 1,320 – 5,280 cumulative inches of tree trunks diameter (about 200 trees) at the rate of 1.6 oz/12-24 trunk diameter. Cost for emamectin benzoate is estimated at $20/tree for 100 trees based on an average tree diameter of 8 inches and $2.5/inch of diameter. Penn Nursery is responsible for the treatment of seed orchard trees with help from FPM and correspondent forest districts.

Fiscal Planning

The total cost of this project is estimated at $1,756,100 over 10 years from 2014-2023, with 28.5% budgeted for tree removal; 67.8% for chemical treatment to protect trees at strategic locations, rare and endangered species, and significant trees; 2.8% for biological control, and 0.9% for seed orchard tree protection. On the other hand, a total of $8,100,000 (ranging from $560,000-1,060,000/year) economic value from ash will be realized through harvest operations if most valuable ash trees are harvested in pre-mortality conditions according to the plan. Part of the revenue generated from the process can be used to cover the cost of this project. This total is considered the maximum for the project and is subject to change by future policies and real time field conditions.

Table 5. Examplary Annual Budget for Ash Management on State Forest Lands

Year	Units	Tree removal	Chemical control	Biological Control	Seed Orchards	Total
2014	FPM	0	$40,600	$26,000	0	$66,600
	Districts	$75,000	0	0	0	$75,000
	Penn Nursery	0	0	0	$500	$5000
	Subtotal	***$75,000***	***$40,600***	***$26,000***	***$500***	***$142,100***
2015	FPM	0	$230,100	0	0	$230,100
	Districts	$75,000	0	0	0	$75,000
	Penn Nursery	0	0	0	$2,500	$2,500
	Subtotal	***$75,000***	***$230,100***	***0***	***$2,500***	***$307,600***
2016	FPM	0	0	6,000	0	$6,000
	Districts	$75,000	0	0	0	$75,000
	Penn Nursery	0	0	0	$500	$500
	Subtotal	***$75,000***	***0***	***$6,000***	***$500***	***$81,500***
2019	FPM	0	$230,100	0	0	$230,100
	Districts	$25,000	0	0	0	$25,000
	Penn Nursery	0	0	0	$2,500	$2,500
	Subtotal	***$75,000***	***$230,100***	***0***	***$2,500***	***$257,600***
2020	FPM	0	0	6,000		$6,000
	Districts	$25,000	0	0	0	$25,000
	Penn Nursery	0	0	0	$500	$5,000
	Subtotal	***$25,000***	***0***	***$6,000***	***$500***	***$31,500***

The annual cost ranges from $31,500 to $307,600. Each district is required to produced an tree removal budget each year based on its own risk management priorities. Districts are also expected to identify ash trees at key locations for chemical treatment at the beginning of the project. Insecticide used for chemical control will be acquired by FPM for use in forest districts, and Penn Nursery for use in seed orchards. Chemical and biological control equipment is an one time expenditure for FPM. See Table 5 for an examples of annual budget.

A detailed yearly budget will be assembled within the boundaries outline in Cost of the Management Plan by bureau's central office. All associated units within the bureau will be consulted before its finalization. This budget does not include the cost of time various bureau staff are expected to spend executing the plan.

Time Table

Time table keeps everything and all involved units in perspective through the duration of the project. Accurate information on current ash resources and EAB infestations is required for the implementation of this plan. Stands with a need to reduce ash component need to be identified, so do ash groves at strategic locations, rare and endangered species, and significant ash trees. On the other hand, potential negative impacts from EAB should be mitigated, and the economic value of ash trees will be conserved through normal/pre-salvage harvests, salvage sales, and wood utilization. Some activities occurs annually or bi-annually, whereas others may happen only in certain years. See Table 6 for detailed activities expected each year.

Table 6. Time Table for Ash Management in State Forest Lands 2014-2023

Year	Activities	
2014-2023 (Yearly)	Hazard tree removal	Timber harvests, Salvage sales, Wood utilization
	Tree protection in seed orchards with young trees	Hazard tree identification for risk management
	Training and outreach	Data recording, mapping and storage
	Ash seed collection	Project planning and reviewing
2014	Identify stands to reduce ash basal area to <10%	Identify ash tree for chemical control
	Identify rare and endangered ash species	Biological control (parasitoid release)
2015	Identify stands to reduce ash basal area to <10%	Chemical control (field treatment)
	Identify rare and endangered ash species	Biological control (establishment evaluation)
2016	Identify stands to reduce ash basal area to <10%	Chemical control (efficacy evaluation)
	Biological control (parasitoid release)	
2017	Chemical control (field treatment)	Biological control (establishment evaluation)
2018	Chemical control (efficacy evaluation)	Biological control (parasitoid release)
2019	Chemical control (field treatment)	Biological control (establishment evaluation)
2020	Chemical control (efficacy evaluation)	Biological control (parasitoid release)
2021	Chemical control (field treatment)	Biological control (establishment evaluation)
2022	Chemical control (efficacy evaluation)	Biological control (parasitoid release)
2023	Chemical control (field treatment)	Biological control (establishment evaluation)

Data Collecting and Reporting

Project activities should be documented properly. It is ideal to have a contact person from each unit for this project. Field data will be collected in standard format and stored centrally within the bureau. Data should be analyzed in a timely fashion with results utilized for future adjustments. Progress reports are expected from each unit on its activities in the project. A project report will be issued by the end of each year.

Data Collecting

Data will be collected on every activity in the project. The Silviculture section and FPM Program Services & Support section is responsible for the creation and distribution of the standard data forms. Participating units are expected to collect field data with those forms by following detailed instructions. All data should be reported to Geospatial Applications section for recording, mapping, and storage. Data will be shared among all units within the bureau.

Reporting

Progress report from all aspects of the project is required every 6 months to ensure the implementation of the management plan. Field data will be summarized and analyzed by Silviculture section and FPM Program Services & Support section. An annual report will be published online.

Conclusions and Perspectives

EAB is the most destructive exotic forest pest in North American since chestnut blight and Dutch elm disease, with the ability to potentially destroy the entire *Fraxinus* (ash) genus. Tens of millions of ash trees have succumbed to EAB in 24 central and eastern states in the U. S. since its initial introduction to Detroit, MI in 2002. In Pennsylvania, EAB was first discovered in Butler county in 2007. It has since spread to 54 counties, threatening the health and survival of millions of ash trees in local communities and the state forest.

While individual trees of significance can be saved through chemical treatment alone in urban and forest settings, an integrated approach is obviously needed to address the long term conservation of ash genetics in the state forest systems. The Bureau of Forestry within the Department of Conservation & Natural Resources is taking concrete steps toward that goal by drafting this ash management plan. It contains general principles and guidelines for ash management in state forest lands under pressure from the emerald ash borer, from life history to potential impacts, species identification to tree inventory, silviculture operations to risk management, chemical control to biological control, timber harvests to wood utilization, seed orchards and seed collection, community training and public outreach, budget analysis and

fiscal planning, time table and activity scheduling, and data collecting and report preparation. Each forest districts can use appropriate components from this document to develop its own ash management plan with the help of all participating Bureau of Forestry units.

Upon implementation of the plan in the next 10 years (2014-2023), ash component in state forest lands will be reduced to slow population growth of the pest, dominate ash (white, green, and black) trees in strategic habitats will be saved in an attempt to maintain ash component in the forest, endangered pumpkin and blue ash trees will be surveyed and protected, the potential negative impact of EAB infestation to the state forest will be mitigated, the economic value of a major portion of the ash trees will be conserved through silviculture measures, ash seed orchards will be actively managed against EAB infestation and ash seeds will be collected from a wide range of ecoregions regularly in corporation with federal seed laboratories, and finally technical training and public outreach will be carried out throughout the state to promote sustainable ash management strategies in local communities and private woodland owners.

It's very likely that the majority of the ash trees in state forest lands will still end up being killed at the onslaught of this voracious beetle. However, by taking a proactive approach like this, genetic materials for all native ash species at strategic locations in state forest will be safely maintained for future generations, while the current economic values of ash trees are conserved. In addition, concerns over endangered ash species and potential risk from EAB infestation will be addressed. Duplication of this plan by local communities and private woodland owners will provide positive impact on the overall management of ash and EAB throughout the state in the coming years.

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