Ash and Elm
Resistance, Restoration, and Management

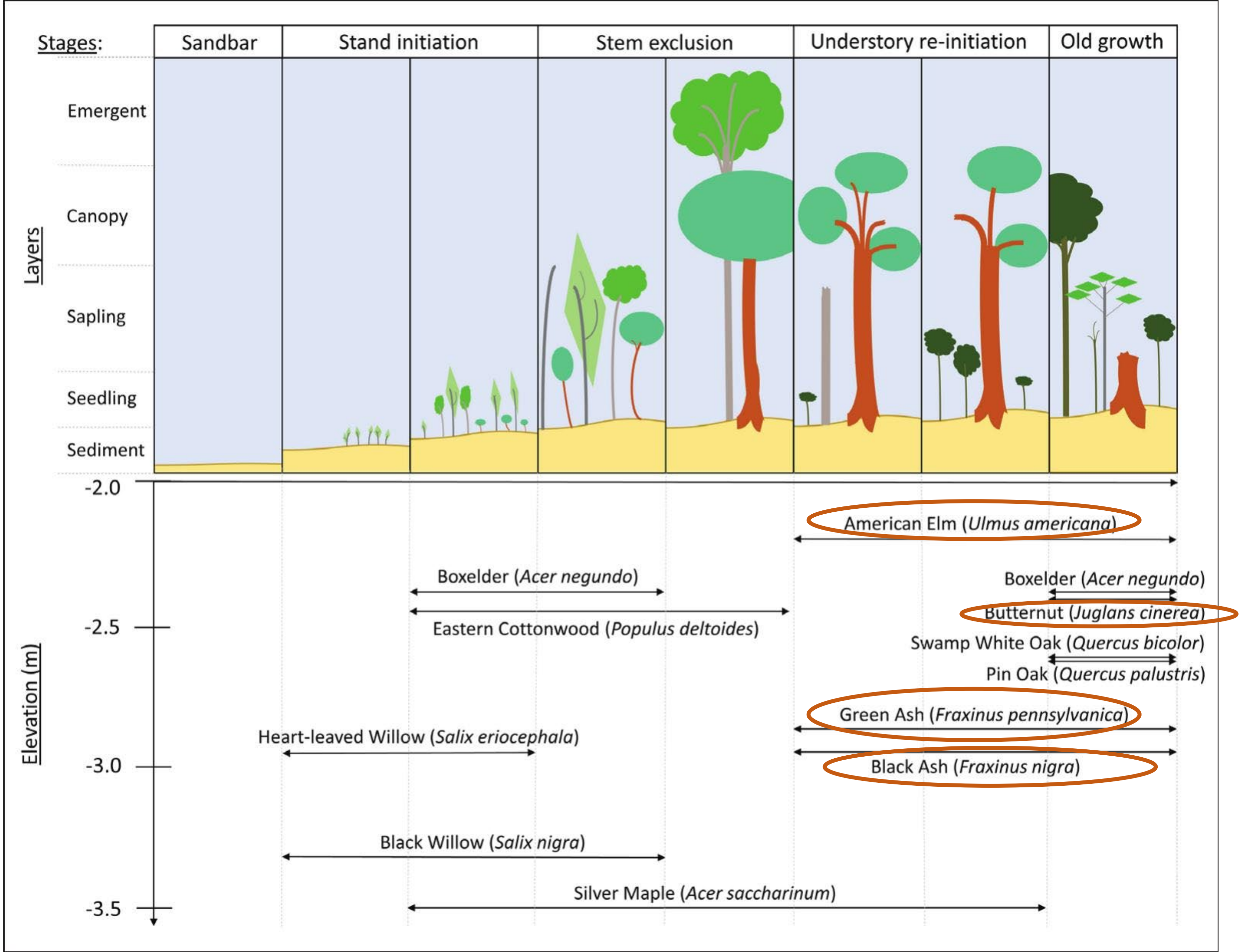
Kathleen Knight, Cornelia (Leila) Pinchot, Jennifer Koch, Charlie Flower, Brian Hoven, Rachel Kappler, Jason Kilgore, Linda Haugen, Carrie Pike, Nancy Hayes-Plazolles, Kirsten Lehtoma, Tim Fox, Josh Wigal, Mikayla Bailey, Melanie Moore, Christian Marks, Gus Goodwin, Mary Mason, David Carey, Aletta Doran, Julia Wolf, Therese Poland, Dale Lesser and Jim Slavicek

What we will discuss today

- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

Ash and Elm: Ecologically Important Species

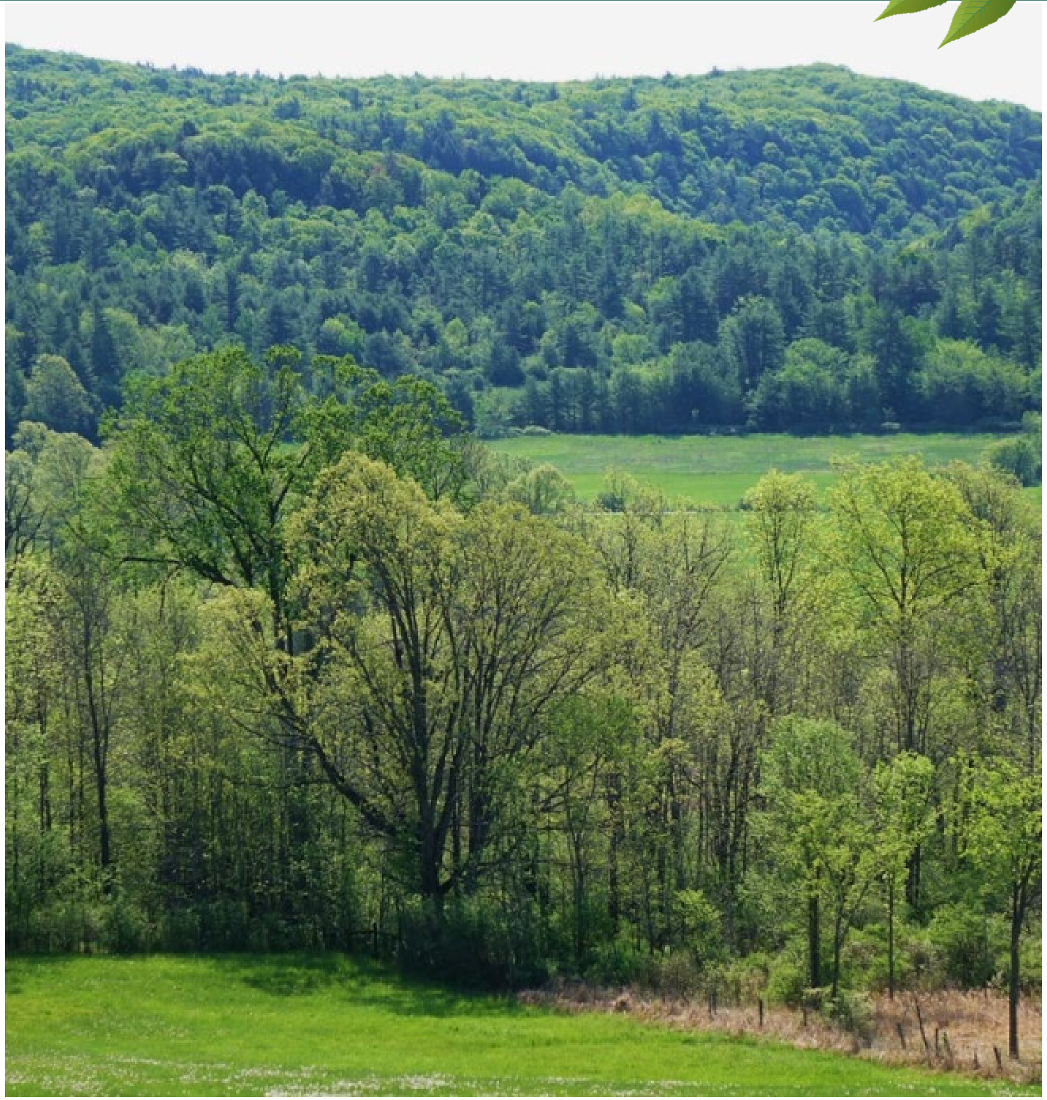
- Broad geographic range
- Multiple species
- A key niche:
  cold tolerance,
  flood tolerance, &
  shade tolerance
- Floodplain and wet forest systems



Christian Marks, 2021

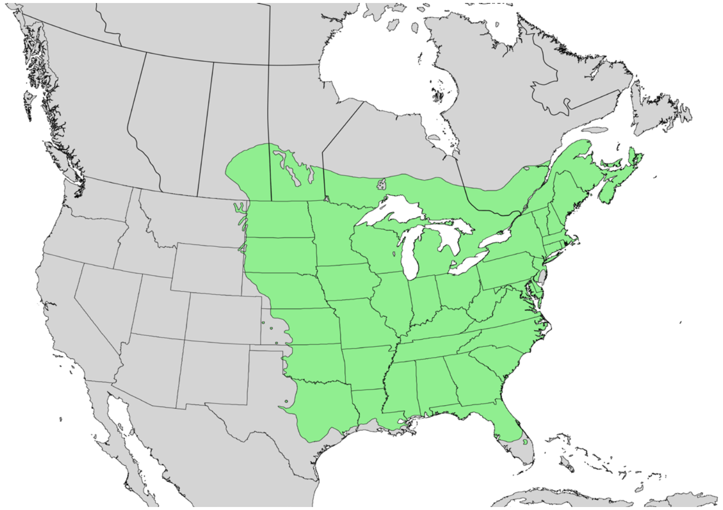
Floodplain forests

- Dynamic ecosystems due to periodic flooding
- Impacted by climate change, land use change, and invasive species
- Values:
  - Flood attenuation
  - Filter sediment and nutrients
  - Maintain/improve water quality
  - Sustain biodiversity



American elm (*Ulmus americana*)

- Early seeds support migratory birds
- Diverse lepidoptera (215 species!) including specialists
- Diverse insects (>500 species!)



U.S. Geological Survey. 1999. Digital representation of E.L. Little 1971 "Atlas of United States Trees"

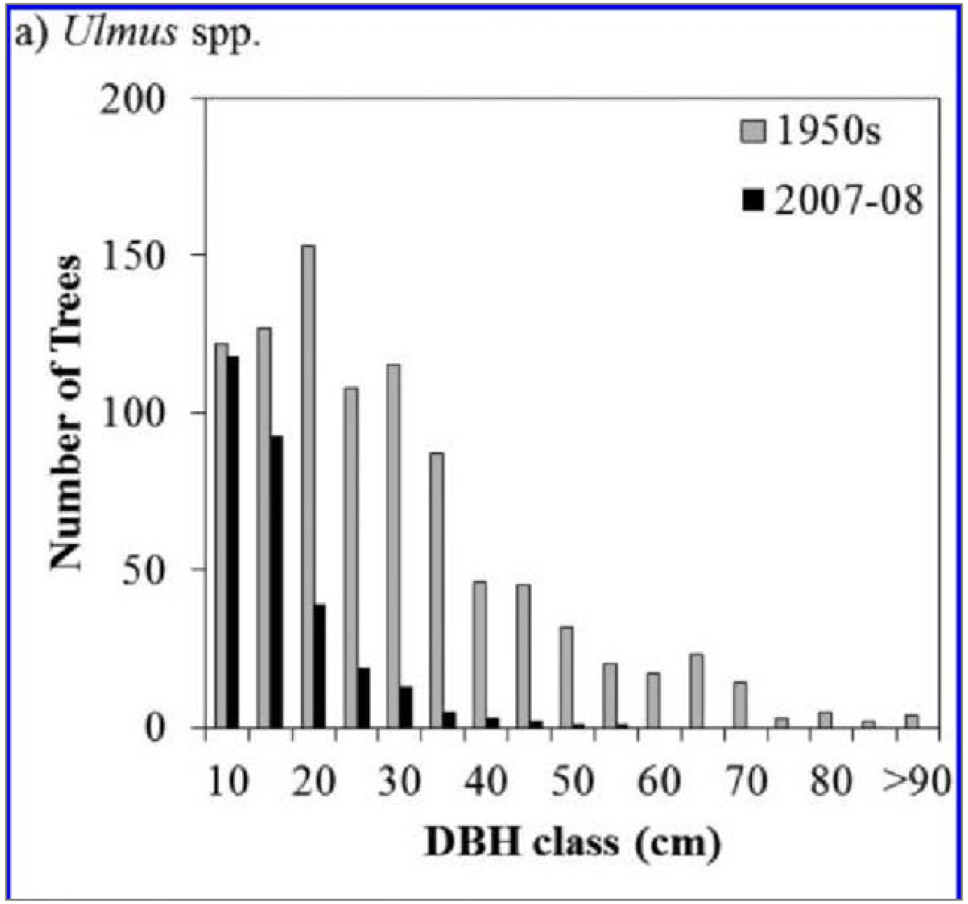
Question mark, *Polygonia interrogationis*

← Elm sphinx moth, *Ceratomia amyntor*

Dutch elm disease impact on elm populations

The smaller European elm bark beetle side view.

Photo by Mike Ferro

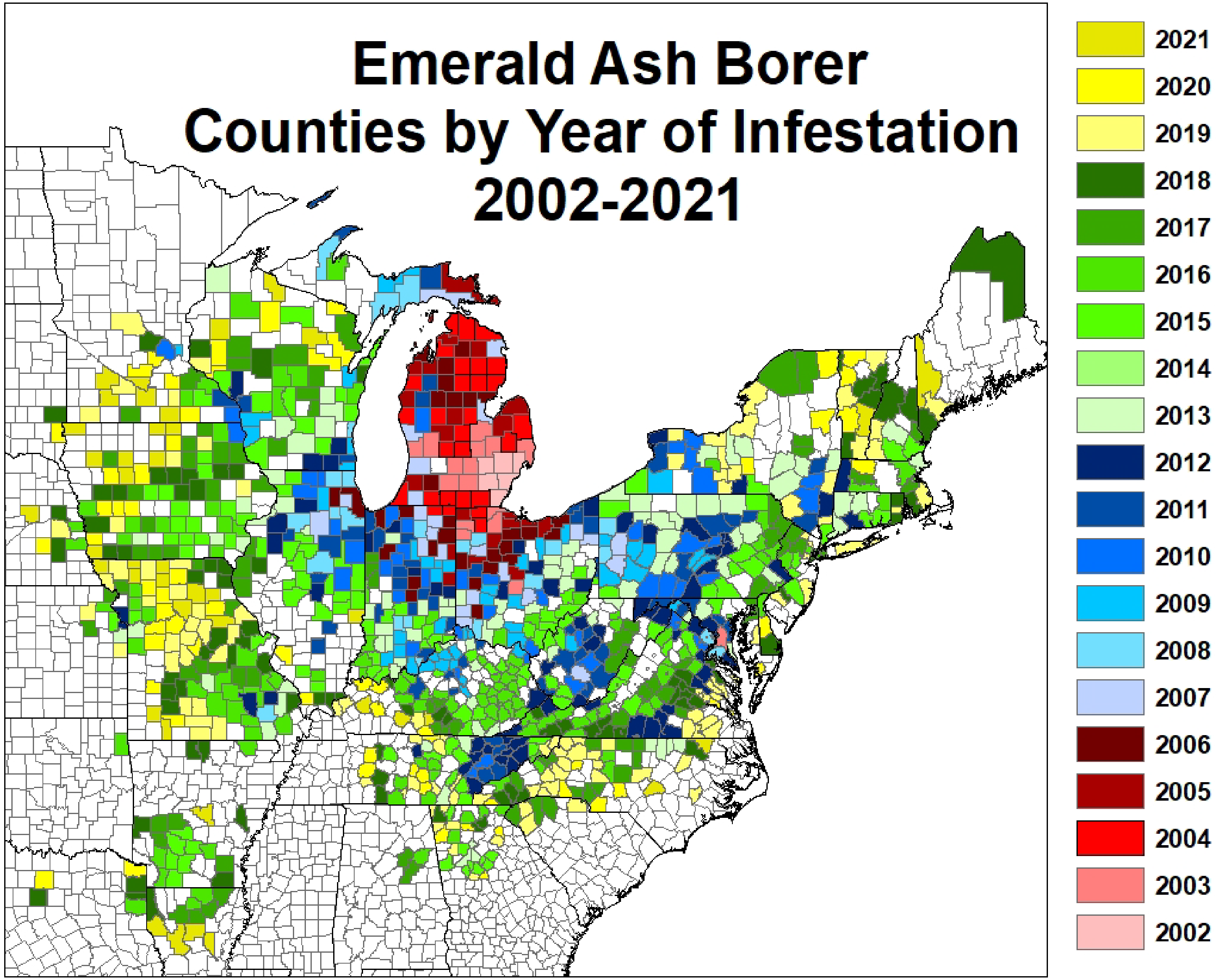


Change in elm diameter distribution in lowland forests of southern Wisconsin
Johnson and Waller, 2012

What we will discuss today

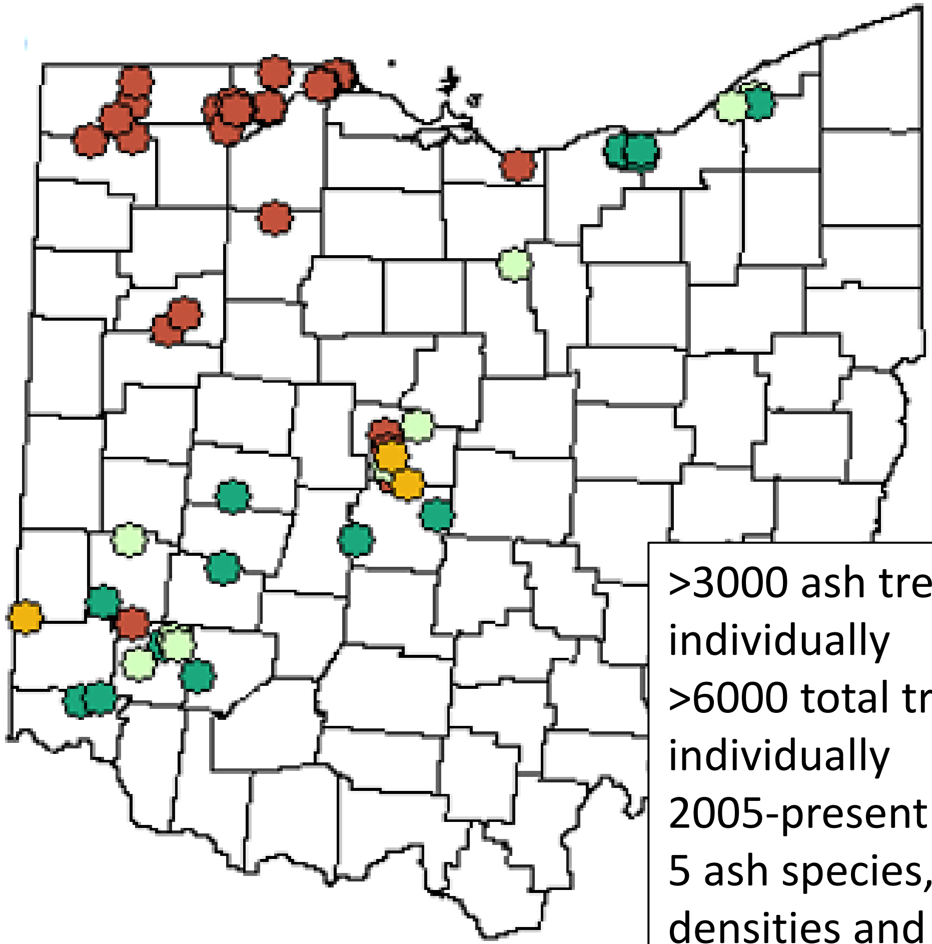
- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

U.S. EAB Detections

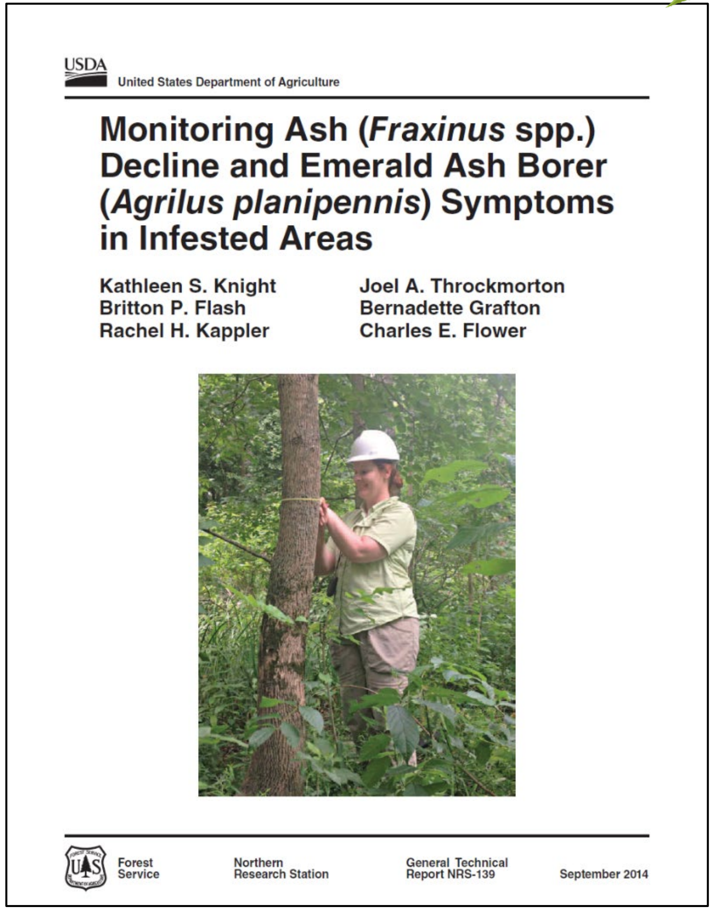


EAB Forest Ecosystem Effects Research

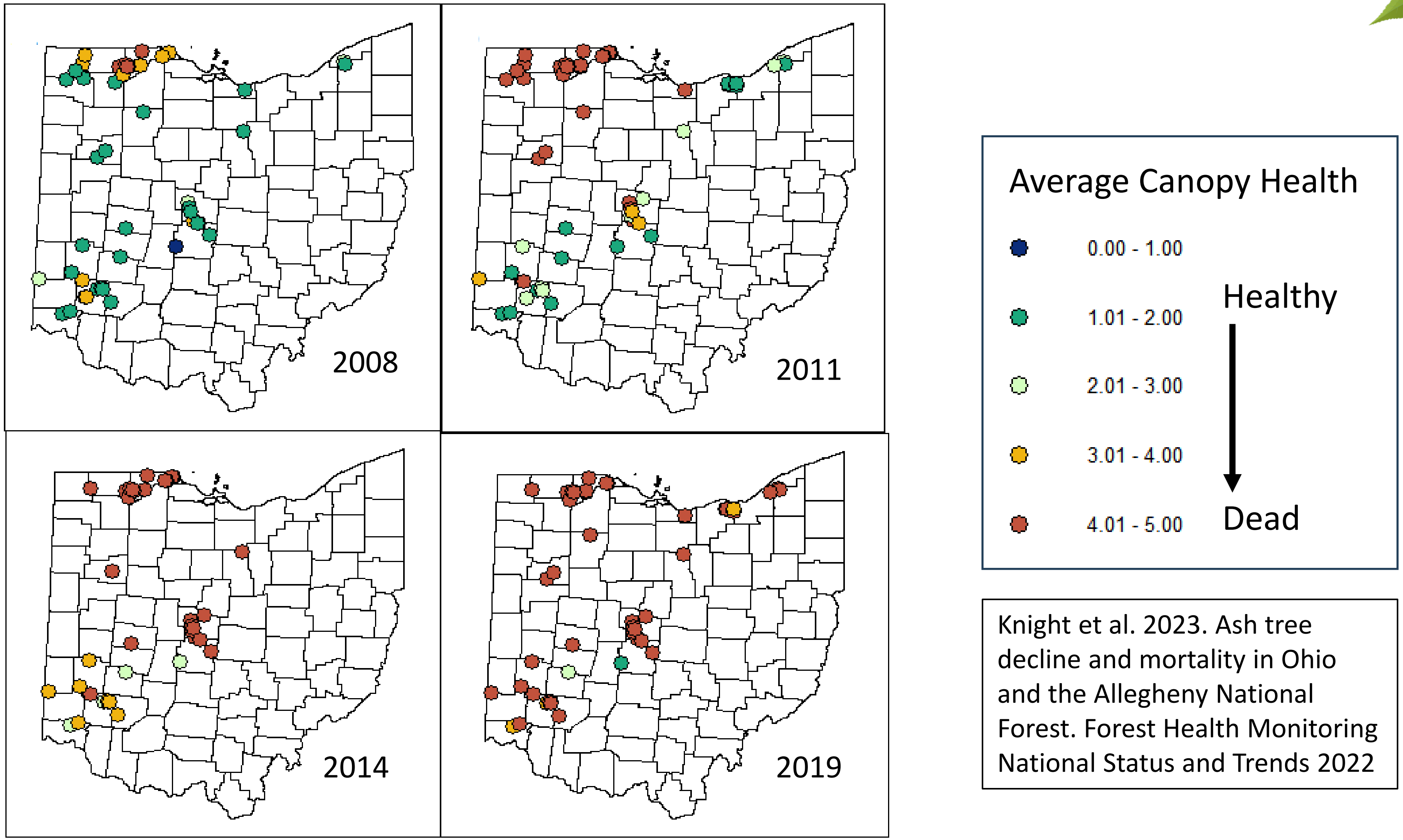
Kathleen Knight, Charles Flower, Brian Hoven, Rachel Kappler, Robert Long, Timothy Fox, Josh Wigal



>3000 ash trees tracked individually
>6000 total trees tracked individually
2005-present
5 ash species, range of ash densities and habitats



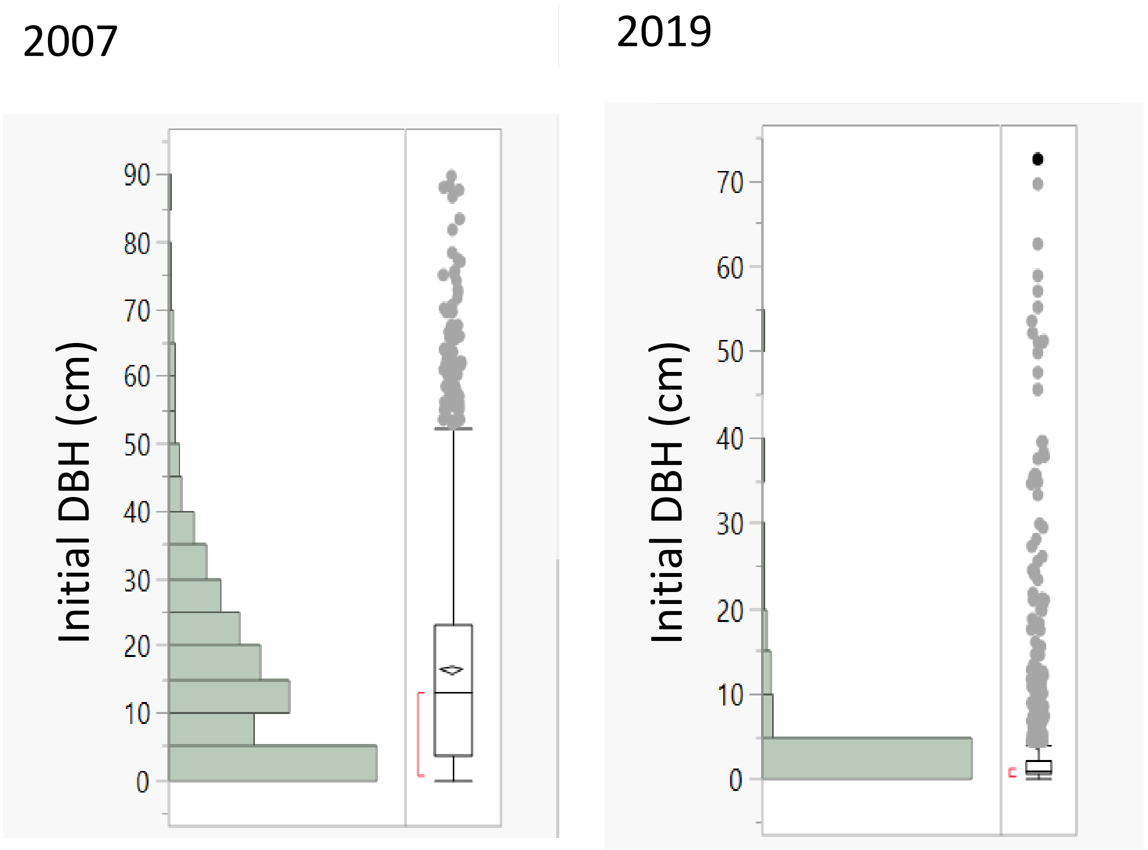
Ash mortality in Ohio



Knight et al. 2023. Ash tree decline and mortality in Ohio and the Allegheny National Forest. Forest Health Monitoring National Status and Trends 2022

Diameter distribution of trees that survived EAB

- Extreme mortality of larger ash trees
- Species differences
- Very few large surviving black ash
- Almost all surviving ash >12in is blue ash



Ash regeneration

- Seedlings and saplings too small for EAB remain and grow
- Seed bank is short-lived
  - Mast years 2008, 2018
  - New seedlings appear for 2-3 years

Biol Invasions (2014) 16:859–873
DOI 10.1007/s10530-013-0543-7

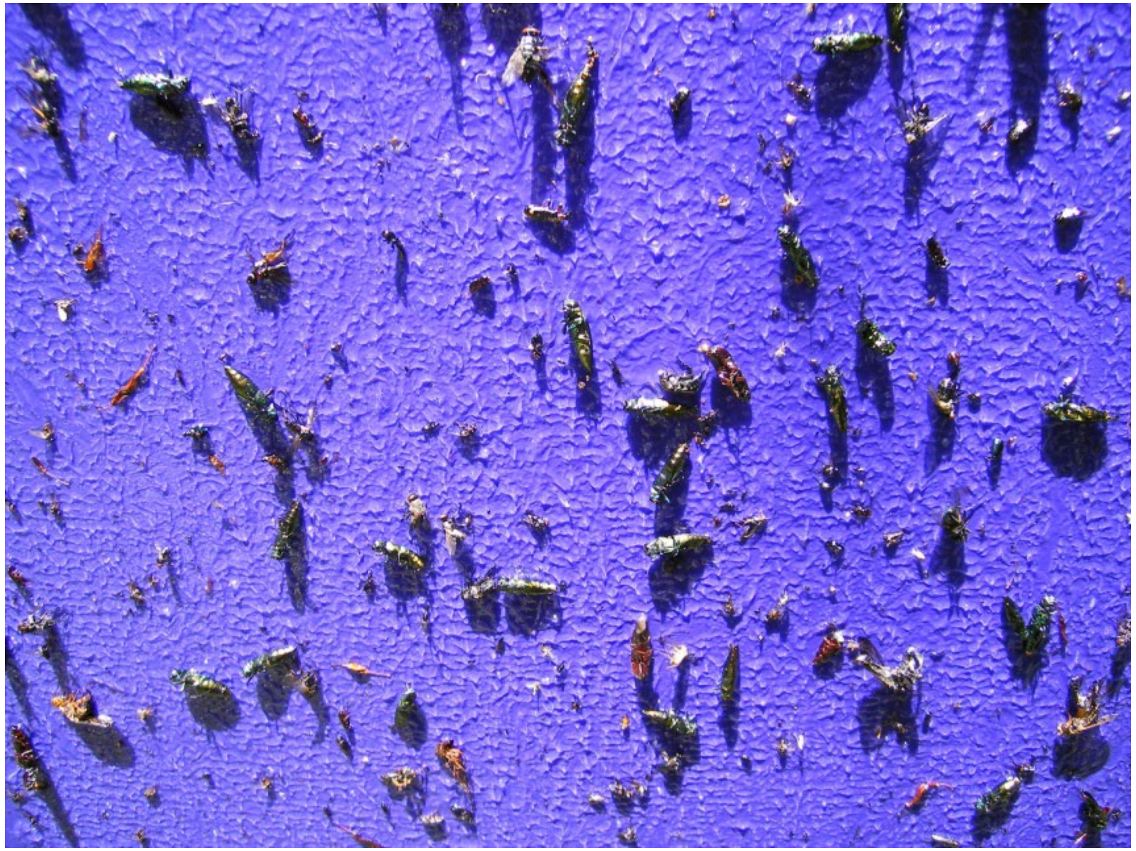
ORIGINAL PAPER

Ash (*Fraxinus* spp.) mortality, regeneration, and seed bank dynamics in mixed hardwood forests following invasion by emerald ash borer (*Agrilus planipennis*)

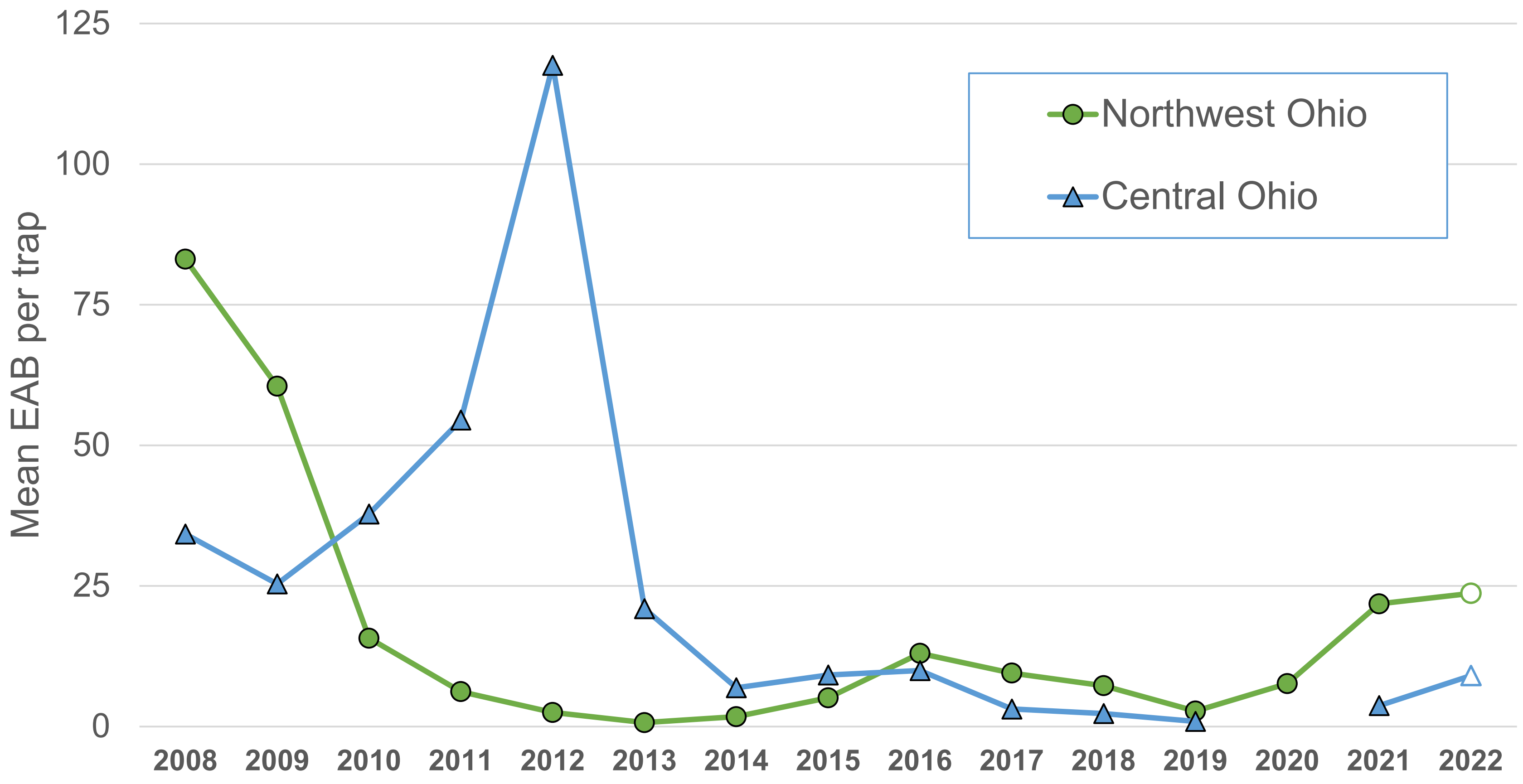
Wendy S. Klooster · Daniel A. Herms · Kathleen S. Knight · Catherine P. Herms · Deborah G. McCullough · Annemarie Smith · Kamal J. K. Gandhi · John Cardina

EAB Population Dynamics

- Counts of EAB on purple panel traps



EAB Population Dynamics



Surviving "lingering" ash

- <3% of the larger ash trees remain alive at some sites, <1% healthy "lingering" ash
- We performed complete surveys of a few sites and are tracking surviving ash populations
- After the 1st wave, declining trees often died while healthy trees remained healthy for several years
- Healthy 4" to 12" green and white ash
- Much larger healthy blue ash

Surviving “lingering” ash

- Many smaller ash that were too small for EAB during the first wave remain and grow into larger size classes while EAB populations are low
- During second wave of EAB, rapid mortality of some of the “lingering” ash

Management Implications – EAB Impacts

- Ash mortality and EAB population dynamics follow a predictable pattern, allowing for planning of management actions (e.g., underplanting, removal of hazard trees, treatment of invasives)
- Most ash trees >4 inches DBH die, though there are some "lingering" trees that survive
- There are species differences in survival, particularly with blue ash

Management Implications – EAB Impacts

- Thinning and other silvicultural actions are unlikely to slow mortality during first wave
- Ash trees become brittle and fall rapidly, creating a pulse of coarse woody debris. Pre-emptive removal of hazard trees is safer than removal after mortality.

Matt Higham et al. 2017 Patterns of coarse woody debris in hardwood forests across a chronosequence of ash mortality due to the emerald ash borer.

Management Implications – EAB Impacts

- Other tree species, when present, may respond with rapid growth *in lock step* with mortality, preventing large canopy gaps
- Loss of ash impacts invasive plants, tree seedlings, and carbon uptake
- In summary, EAB has a major impact on ash populations and forest ecosystems.

Costilow et al. 2017. Disturbance severity and canopy position control the radial growth response of maple trees in forests of northwest Ohio impacted by emerald ash borer. Annals of Forest Science

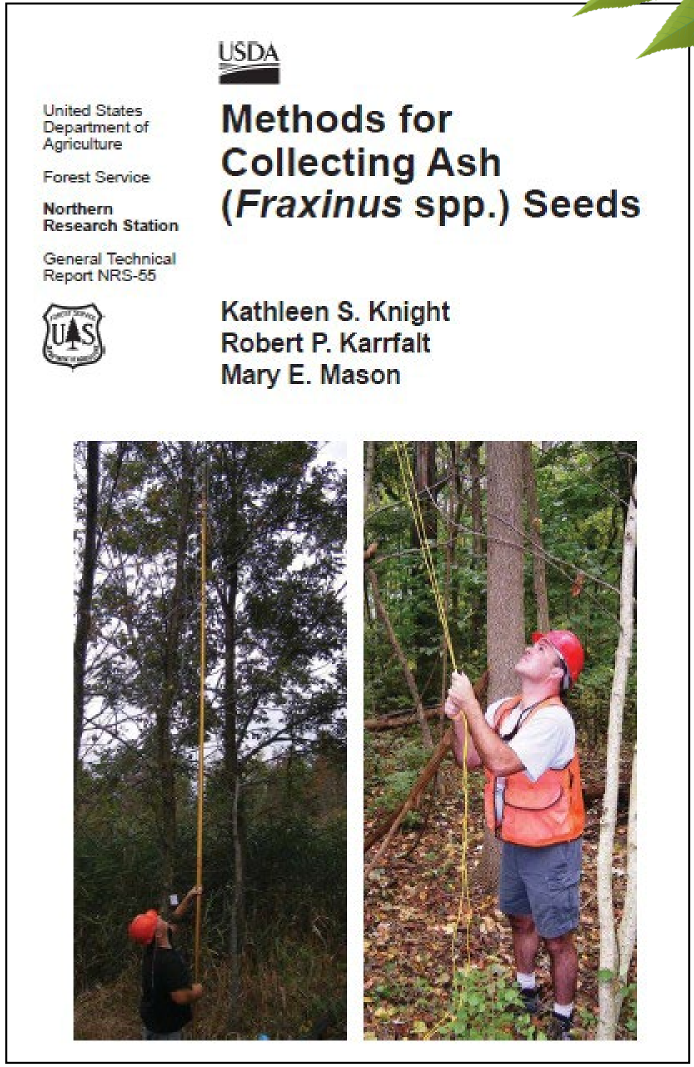
What we will discuss today

- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

Genetic Conservation

- Preserve the genetic diversity of ash before it's killed by EAB
- Ex-situ genetic conservation: seed collection
- In-situ genetic conservation: insecticide protection


USDA

United States Department of Agriculture

Forest Service

Northern Research Station

General Technical Report NRS-55

Methods for Collecting Ash (*Fraxinus* spp.) Seeds

Kathleen S. Knight
Robert P. Karrfalt
Mary E. Mason

Insecticide treatment for in-situ conservation

- Maximize efficiency by treating many unique populations with at least 10 trees per population
- Insecticide is most successful in trees that are healthy at the time of treatment
- Insecticide treatment may provide some protection for untreated nearby trees

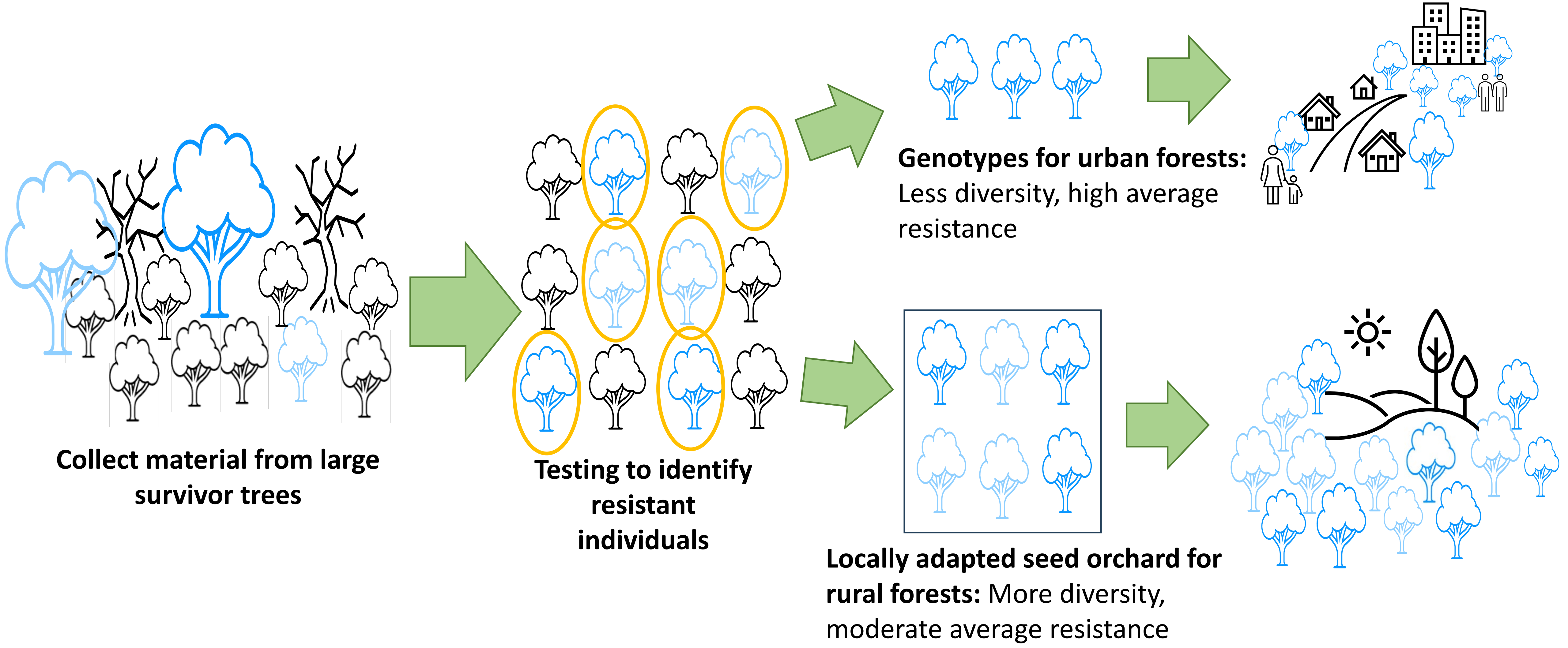
What we will discuss today

- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

Tree survival and resistance

- There are many mechanisms that allow trees to survive: Ability to kill or slow the pest or pathogen, tolerate the infestation/infection while remaining healthy, or lower likelihood of being infested/infected in the first place
- Resistance is a gradient, not an on/off switch!
- Even moderate amounts of resistance are useful in a breeding program

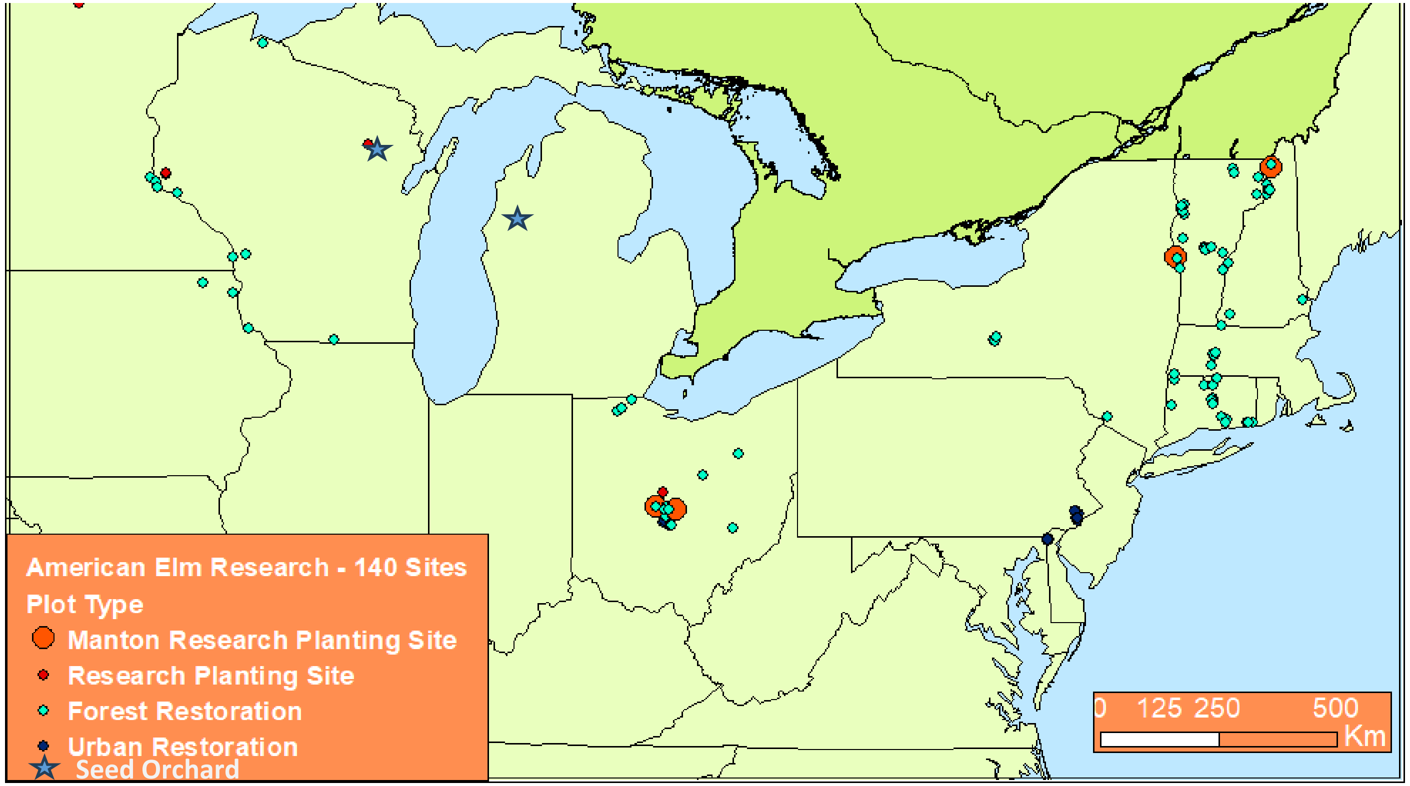
Tree Breeding General Process



NRS American elm restoration research

Primary Goal: Develop methods and work with partners to produce genetically diverse, locally adapted DED-tolerant American elm for restoration

Rural elm restoration research site



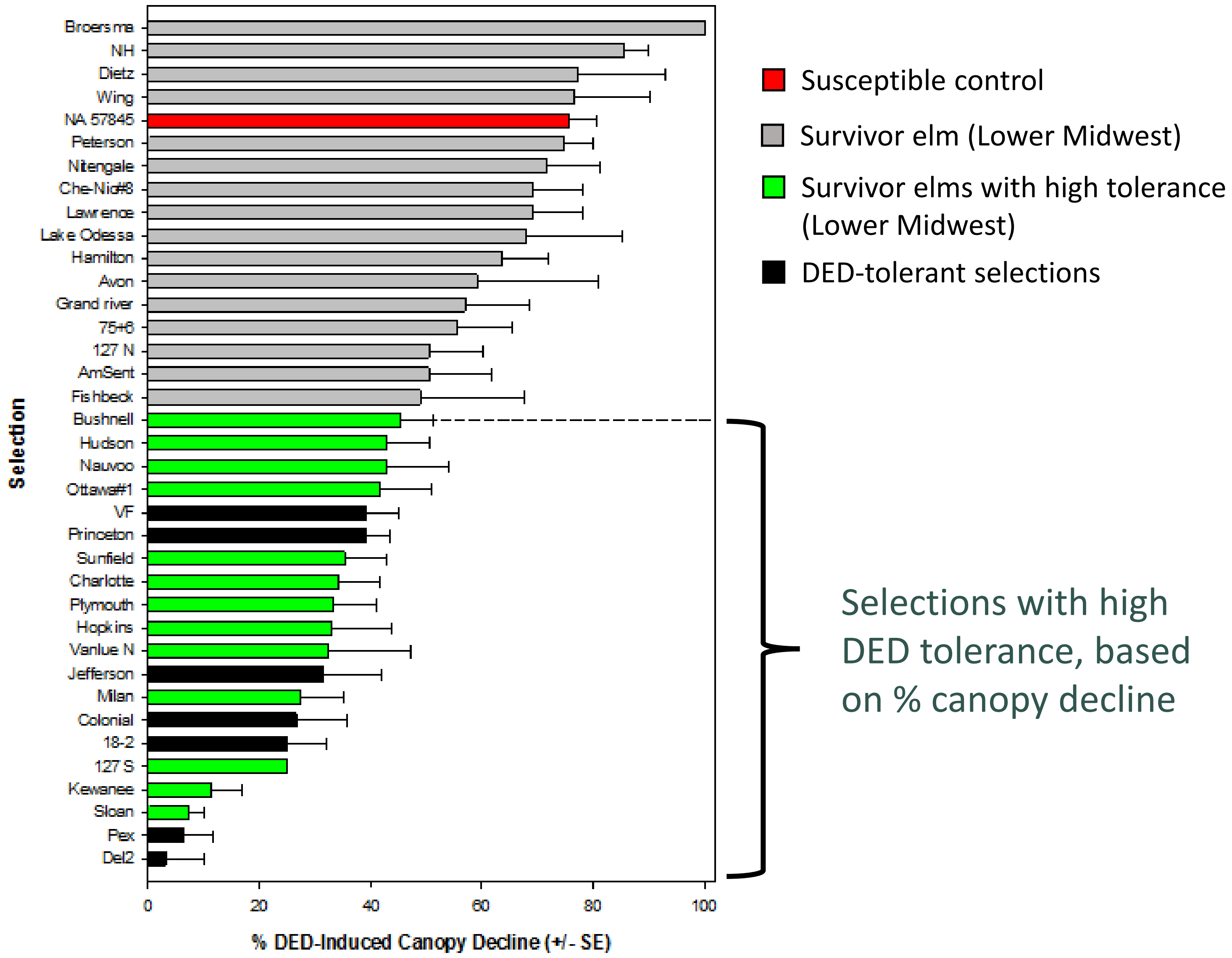
Urban elm restoration research site

Propagation of survivor trees

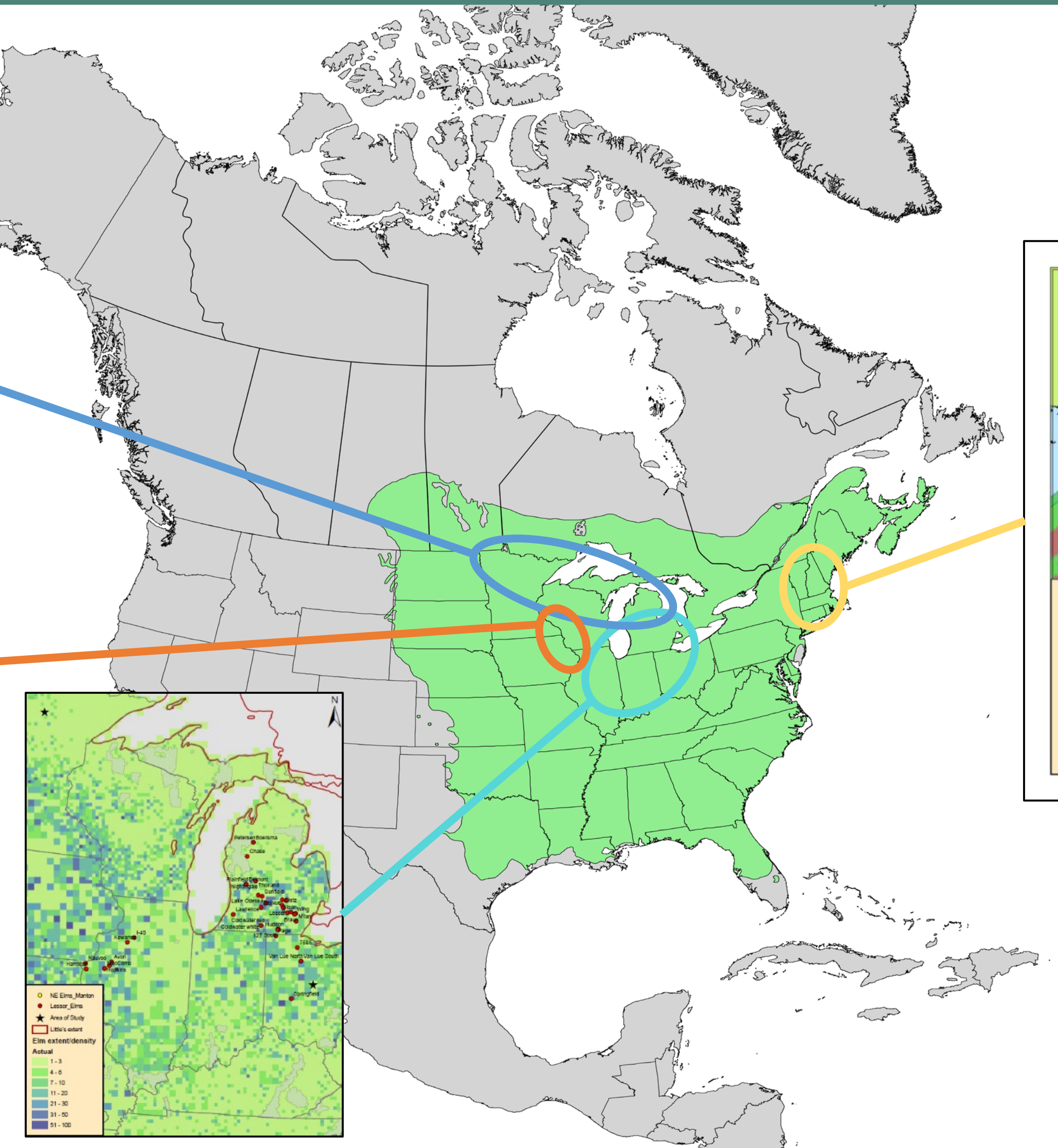
Inoculation with DED and Canopy Rating

DED inoculation trial results

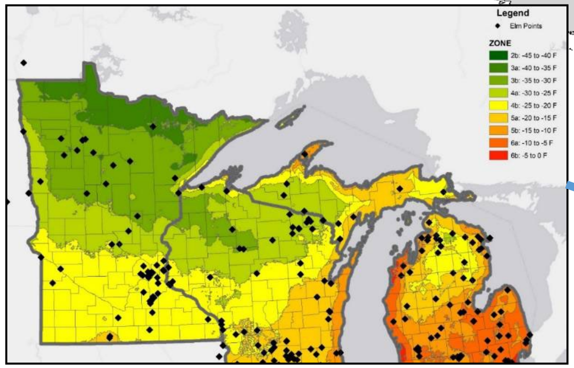
Clones of 29 survivor American elms were planted in complete replicate blocks in Delaware, OH and inoculated with DED ~ 10 years after planting.



Identify additional DED-tolerant American elms: Survivor elm populations



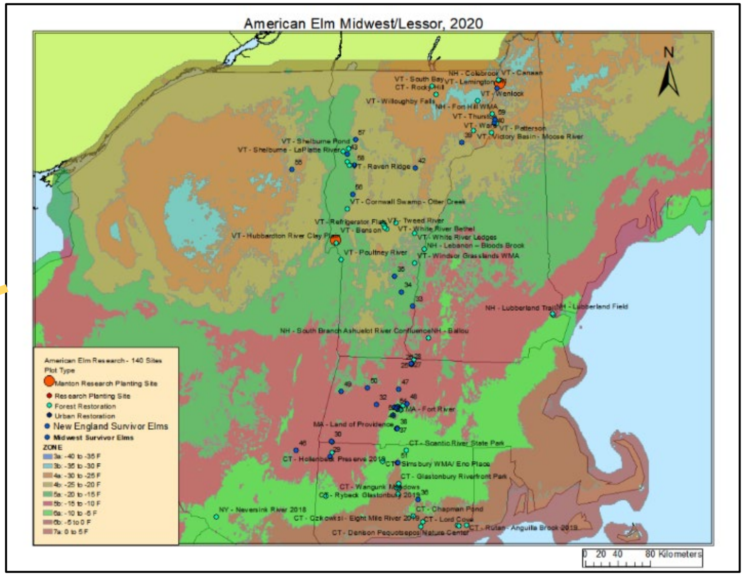
Cold-Hardy Lake States
~38 accessions, Zone 2b to 4a



Upper Mississippi
Starting Feb 2024!
Zone 4b to 5b

Lower Midwest
~40 accessions
Zone 5b and 6a

New England Connecticut River



26 accessions, Zone 2b to 5b

How long does it take?

Survivor elm

≥ 1 year

Propagate elm

1-2 years

Clonal or progeny resistance test planting

5-7 years

Inoculate and assess

2 years

Plant winners in seed orchards

≥ 1 year

10-15 years

What if I want to plant elm trees now?

- Appropriate material does not yet exist for large scale forest plantings.

If you want to incorporate a small amount of elm to test methods:

- Collect open pollinated seeds from large survivor trees. Understand that many of these may have low levels of resistance. Manage expectations accordingly.
- For small plantings in urban forested parks, clones could be used.
- For both, maximize diversity (both species diversity and genetic diversity within a species) as much as possible and consider adaptation to the local climate.

How can you get involved?

- Watch for, preserve, and report large survivor elms
- Expanding to additional populations requires partners. If you’re able to help with any of the steps in the process, contact us!
    - Scion collection
    - Propagation and growing trees in a greenhouse or nursery
    - Hosting and maintaining a testing site or seed orchard

NRS ash EAB-resistance research

Breeding is a part of Integrated Pest Management

Jennifer Koch, Dave Carey, Mary Mason, Toby Petrice, Therese Poland

⬆ Host-Resistance + ⬇ Insect Population = Sustainable ash species in N. America

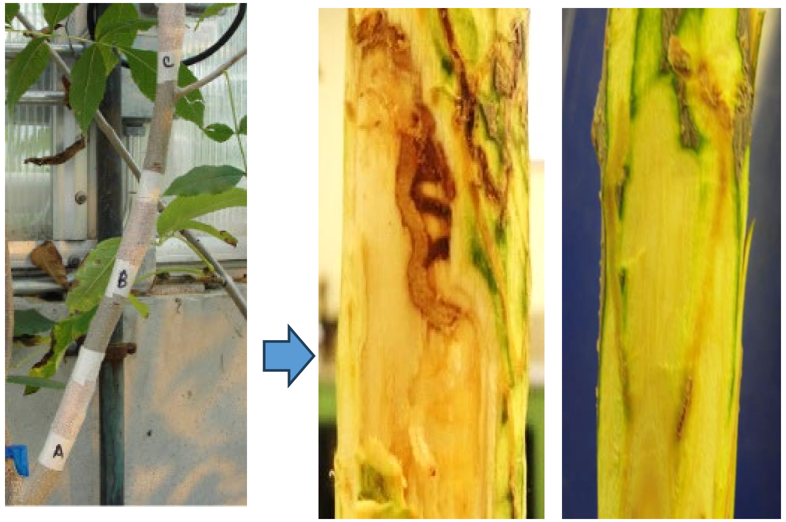
(selection & breeding) (biocontrol)

Bring best trees together, Get better seed!

Less stem damage

Healthy crown

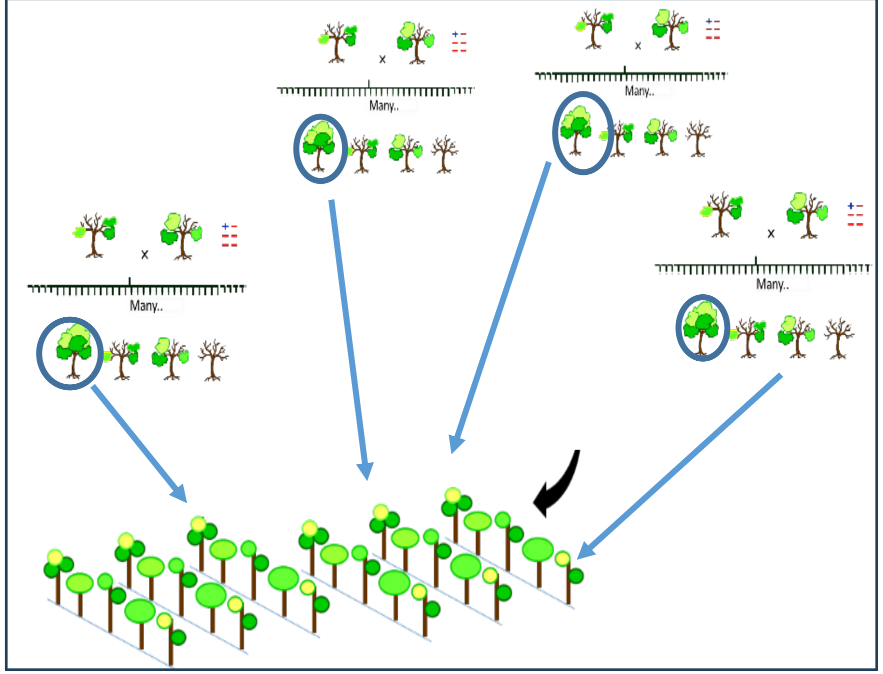
Step 1-Select "Lingering Ash"



Egg transfer bioassay

S R

Step 2-Test for resistance



Step 3- Seed orchard

Selection & propagation of "lingering ash"

"Lingering ash" Criteria:

- Area long infested by EAB
- Large enough to have been infested during peak EAB
- Healthy canopy, at least 2 years after mortality rate leveled off

Once selected, trees are propagated and "moved" into the program:

Hot callous grafting

Bud Grafting

Grafted replicates for experiments & archive

Archive plot (Clone bank)

Pollinations

Test for resistance: lingering green ash selections

EAB egg bioassay

Healthy larva

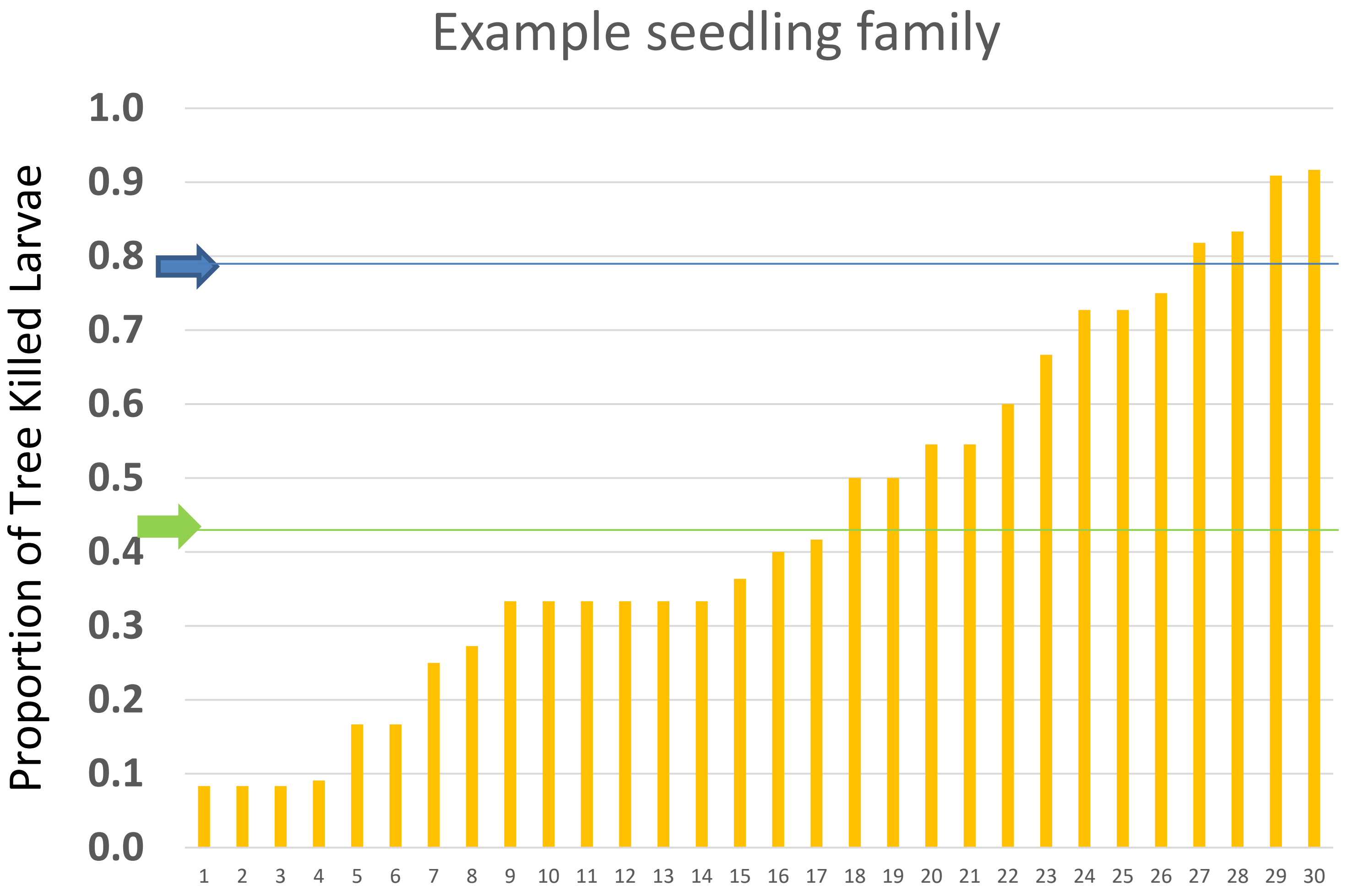
Host-killed larva

- Not all lingering ash have resistance (~50 %)
- Best lingering 45 % larvae killed
- Best susceptible 12 % killed, average 5 %
- Top 10 lingering ash average 19 % larvae killed
  - Enough to allow tree to live longer
  - Still at risk of death

Field Trials

- Confirm bioassay indicative of field performance
- Assess environmental impacts on resistance

Test for resistance: lingering ash x lingering ash seedlings



Indicates highest % killed from LA selections

Indicated % killed by Manchurian ash resistant control

Breeding increases resistance!

- 855 seedlings (27 families) screened
- All families have susceptible progeny BUT – higher % of resistant trees, and higher level of resistance!
- This family:
  - 40 % of seedlings more resistant than parents
  - 4 seedlings as resistant as Asian ash species
- Select best seedlings/trees!

First improved green ash seed orchards

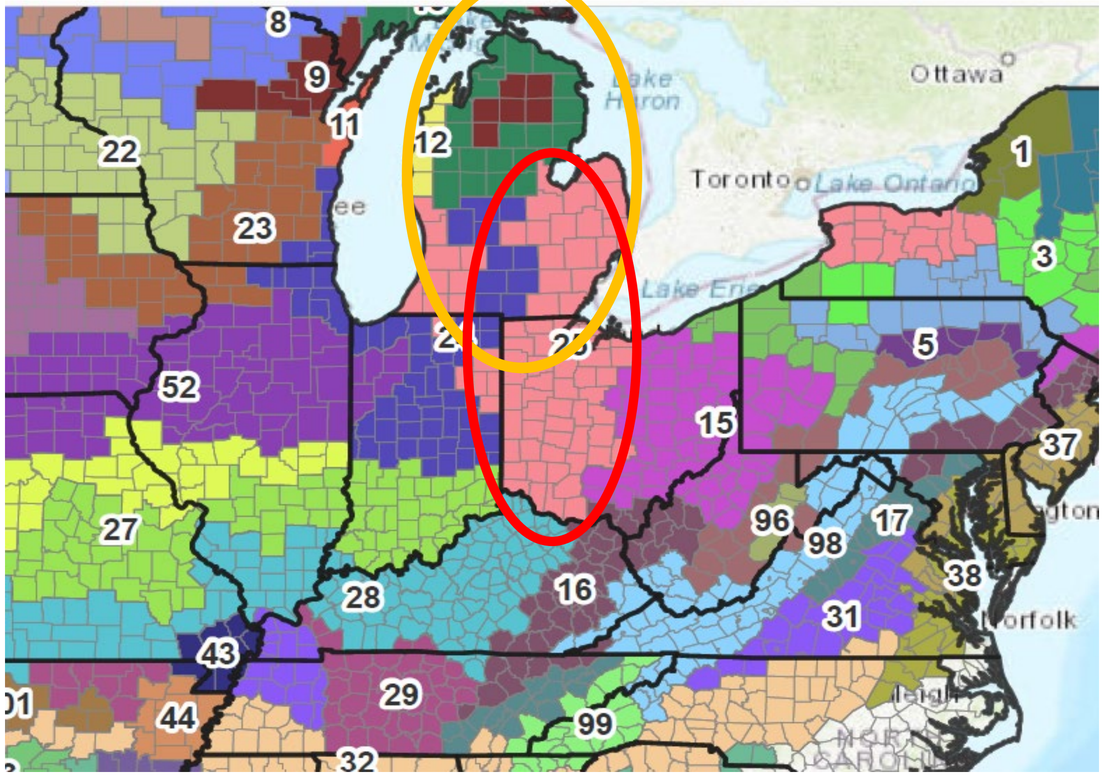
1st lingering ash selections clonal orchard

- Selections from eastern seed zone #25
  - suitable for MI, IN, OH
  - N or NW for assisted migration?
- Best of 40 green ash will be kept
- Seed production ~ 12-15 years

Lingering ash x lingering ash seedling orchard

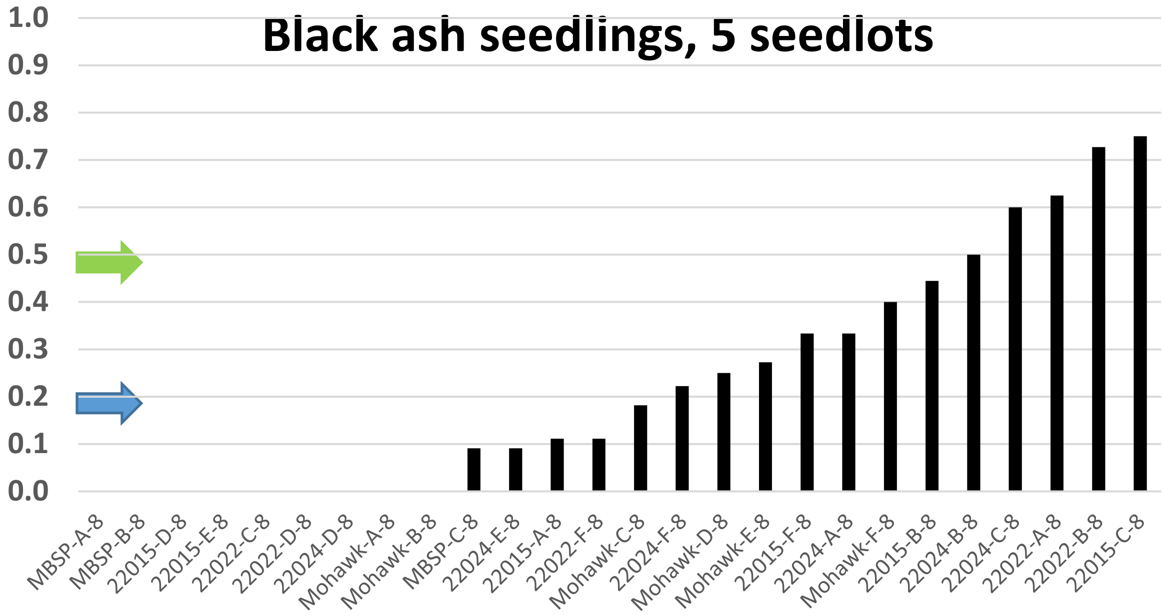
- 600 trees from 31 families
- Best trees will be kept
- Suitable for deployment in MI
  - or shift north
- Seed production ~ 15-20 years

www.EasternSeedZones.com



*Need to replicate the whole process
(Select, test, seed orchard)
To produce seed adapted to other zones

Black ash: possibility of proactive breeding?



Best lingering green ash selection

Best unselected green ash

Pilot study screening "wild" black ash seedlots:

- ~50 % of black ash seedlings had some EAB-resistance (0 % in "wild" green seedlots)
- BUT … it takes fewer EAB to kill black ash
- Additional challenge …but can still be successful
- May be able to select & breed black ash without having to wait for >95 % to die
- Collect and conserve black ash seed

Actions for each stage of EAB infestation

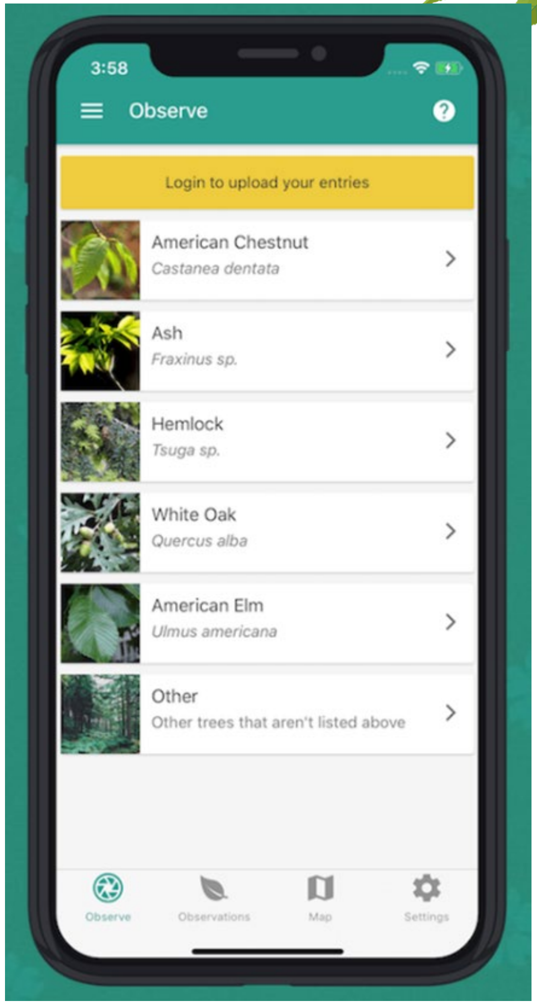
<table>
<tr><th>Pre-infestation
EAB not yet present</th><th>Early infestation
Some EAB signs; some dead ash along w/ healthy and declining trees</th><th>Mid-infestation
Widespread EAB signs; higher ash mortality; few healthy trees</th><th>Late infestation
Ash largely dead, with remainder very unhealthy except for very rare lingering ash</th></tr>
<tr><td colspan="4">Assess ash presence/importance</td></tr>
<tr><td colspan="2">Decide which trees to be treated vs. cut vs. left for mortality monitoring/lingering ash detection</td><td></td><td></td></tr>
<tr><td colspan="4">Identify sites where mitigation needed (for invasive plants, hydrological changes, etc.)</td></tr>
<tr><td colspan="2">Document infestation onset</td><td></td><td></td></tr>
<tr><td colspan="4">Establish/use mortality monitoring plots; detect when thresholds reached</td></tr>
<tr><td></td><td></td><td colspan="2">Record, report, protect potential lingering ash</td></tr>
<tr><td colspan="3">©2017 - 2018 Ecological Research Institute</td><td>Find/mark lingering ash, report for possible scion collection, possibly collect their seed</td></tr>
</table>

How can you help?

- Watch for and preserve lingering ash
- Submit them to a database
  - Treesnap https://treesnap.org/
  - Monitoring and Managing Ash (MaMA) http://www.monitoringash.org/
- Great Lakes Basin Forest Health Collaborative
  - https://holdenfg.org/great-lakes-basin-forest-health-collaborative/
  - Coordinator:Rachel Kappler rkappler@holdenfg.org
    - Provides training
    - Builds network of partners to establish breeding programs
  - Northern Great Lakes Basin Forest Health Collaborative

Coming Soon (hopefully)**!!**

Email Rachel to sign up for newsletter for updates



What we will discuss today

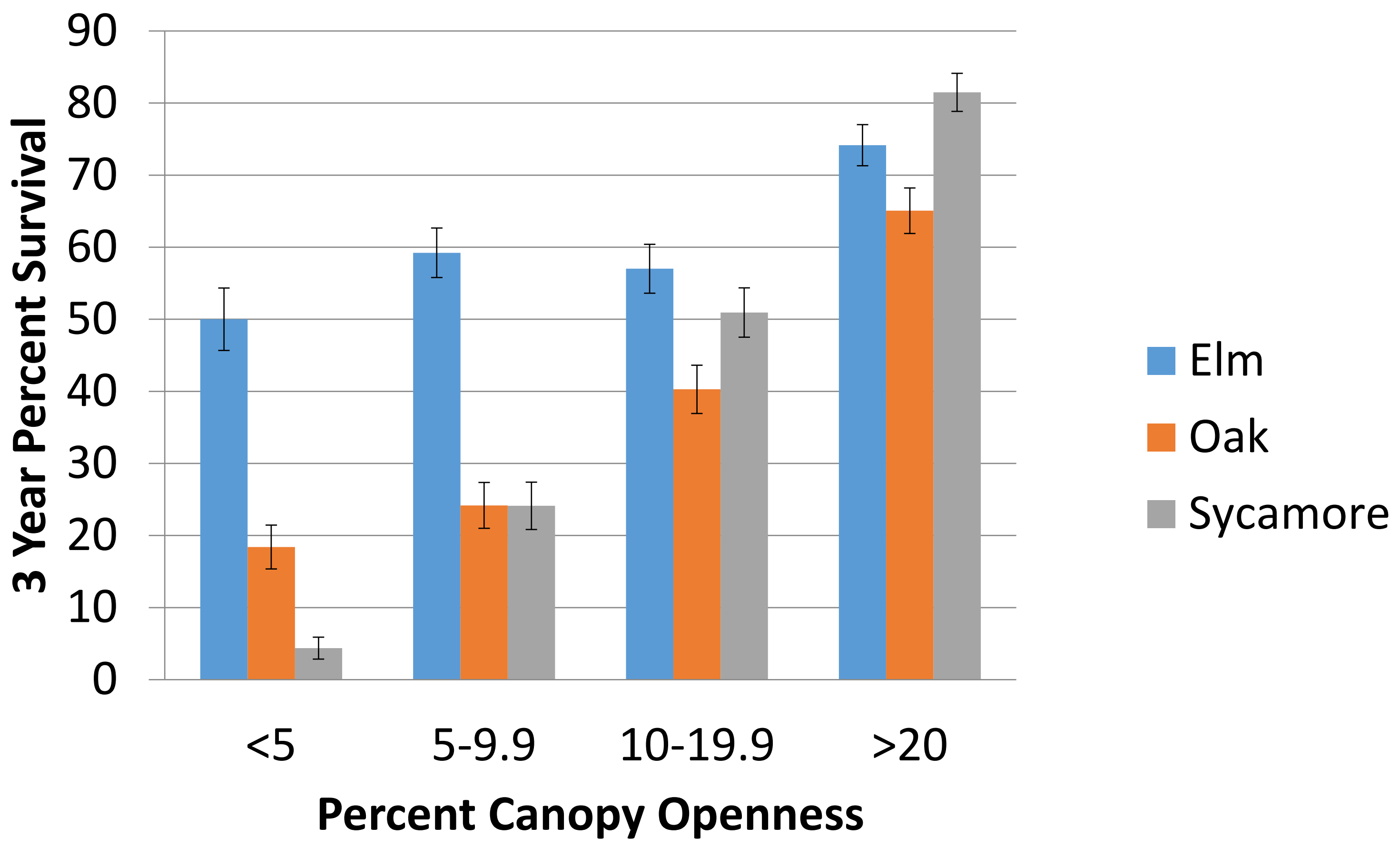
- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

Restoration of EAB-impacted floodplains

What factors affect the growth and survival of planted tree seedlings, including DED-tolerant American elm, in floodplains impacted by EAB?

Restoration of EAB-impacted floodplains

Survival of Small Planting Stock



Restoration of EAB-impacted floodplains

- Floodplains are challenging places to do restoration!
- Variation among sites
- Larger planting stock and well-secured deer protection are key
- DED-tolerant elm can perform well in ash floodplain restoration plantings
- Planting techniques and microsite selection can improve success

What we will discuss today

- Ecological importance of ash and elm
- Impacts of EAB: A view from the epicenter
- Genetic Conservation & Insecticide
- Tree Resistance Breeding
- Restoration
- Implications

Management Implications

- Understanding impacts on forest ecosystems and long-term population dynamics allows for management planning
- Management options can reduce impacts
- Species restoration through resistance breeding programs
- Situation-specific combinations of different tools can be used to achieve management goals

Urban vs. Rural Protection and Restoration

Because they have different objectives, challenges and opportunities…
… We use different management approaches: protection tools and plant materials.

Protecting what we have and **restoring tree species**

Urban ⟷ Urban Wildland (Interface) ⟷ Rural

- Protect population with sanitation
- Protect individuals with fungicides or insecticides
- Protect people and infrastructure from hazard trees!
- Plant clones with high level of resistance
- Provide high protection and maintenance

- Reserve, protect, and report large survivor trees during management
- Consider genetic conservation and biocontrol for ash
- Sustain forest cover and function through restoration, invasive plant control, and underplanting with other species
- Plant high diversity, locally adapted or assisted migration trees with moderate to high resistance (once they are available from seed orchards).

Intersection with climate change

- Climate change and invasive species threaten sensitive and dynamic floodplain and wet forest systems.
- Restoration of ash and elm will increase diversity of canopy tree species and may increase forest resilience.
- Tree resistance, disease pathogenicity, and pest insect biology may change with climate change. We get some insights by testing gene x environment interactions.
- Seed orchards will provide an excellent opportunity for assisted migration, allowing managers to decide which populations to plant on their sites.
- Cold tolerance of southern tree populations limits use in far northern climates. Estimates of how far we can move populations will improve as test plantings and provenance trials provide data.
- Genetic diversity is important to allow further adaptation of tree populations!

Gaps and Needs

- Monitoring long-term dynamics of EAB and ash mortality in different ash species, climates, and ecological contexts
- Understanding synergy of different combinations of ash management options
- Provenance trials to determine appropriate seed transfer zones
- Long-term infrastructure and partnerships to support tree breeding programs

Acknowledgements

Funding sources

MANTON FOUNDATION

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

APHIS

RECOVERY.GOV

USDA NIFA

United States Department of Agriculture
National Institute of Food and Agriculture

DEPARTMENT OF NATURAL RESOURCES DNR MICHIGAN

Pennsylvania DCNR FORESTRY

Partners

The Nature Conservancy
Protecting nature. Preserving life.

HOLDEN FORESTS & GARDENS

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

WASHINGTON & JEFFERSON COLLEGE

THE OHIO STATE UNIVERSITY

METROPARKS TOLEDO AREA
Your Clean, Safe, Natural Places To Be

Metro Parks

US Army Corps of Engineers

OHIO DEPARTMENT OF NATURAL RESOURCES

UNIVERSITY OF NOTRE DAME

DNR
Indiana Department of Natural Resources

PRESERVATION PARKS DELAWARE COUNTY

DCNR

And many teams of summer interns!

Contact

Kathleen.S.Knight@usda.gov