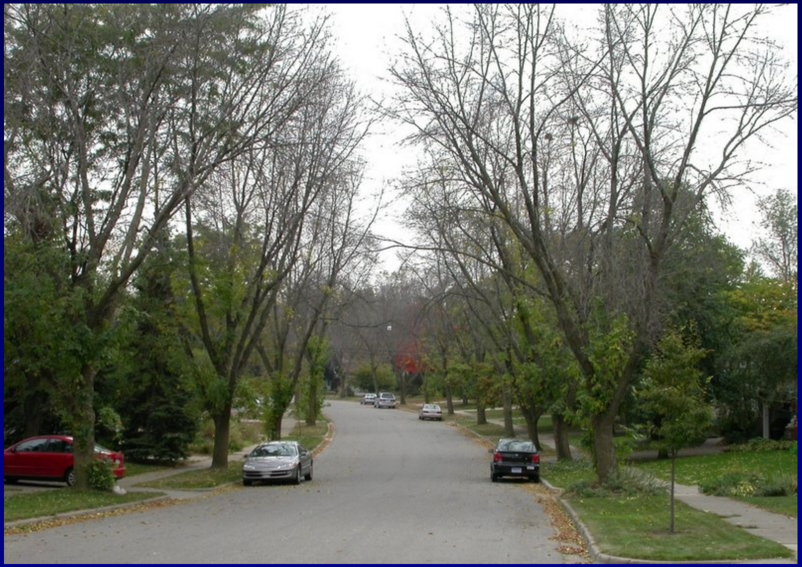
Emerald Ash Borer Update
Is the glass half-full or half-empty?



Deborah G. McCullough, Professor
Dept. of Entomology & Dept. of Forestry
Michigan State University

Special thanks to:

MSU: Andrea Anulewicz, Jacob Bournay, Rodrigo Mercader, Nathan Siegert, Sara Tanis, Andrew Tluczek

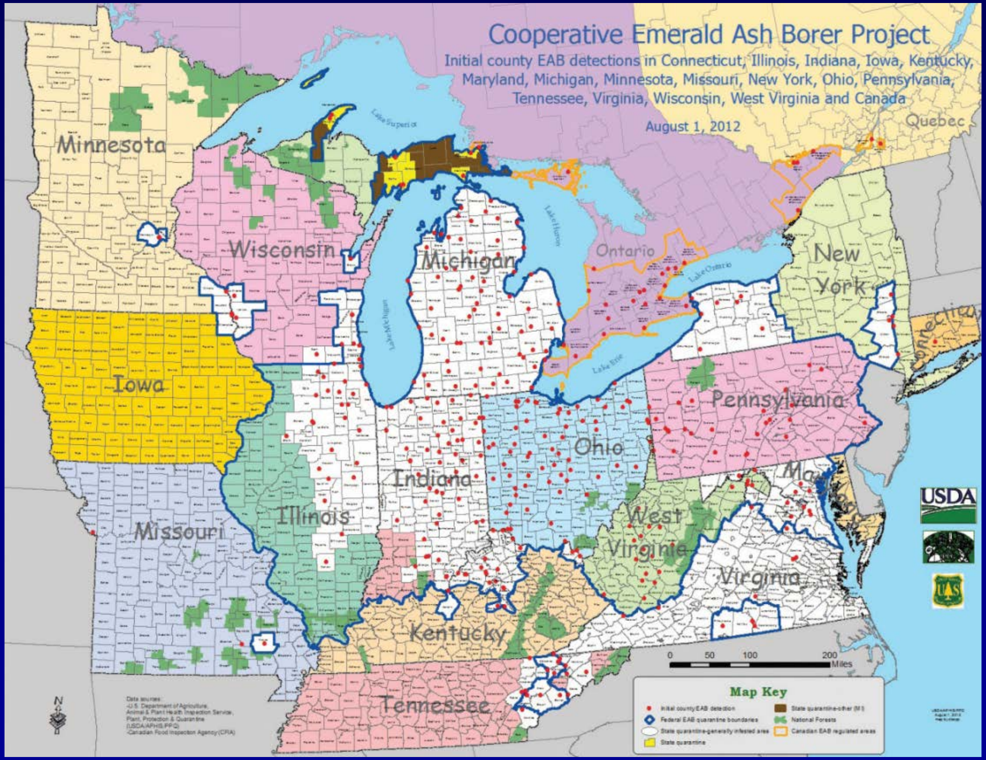
USFS: Therese Poland

Funding: USDA Forest Service, USDA ARS

July 2002: *Agrilus planipennis* first identified as cause of ash decline in Detroit, MI & Windsor, Ontario.

August 2012: EAB populations identified in 16 states & 2 provinces.

Localized “outliers” result from transport of infested ash nursery trees, logs & firewood.



www.emeraldashborer.info

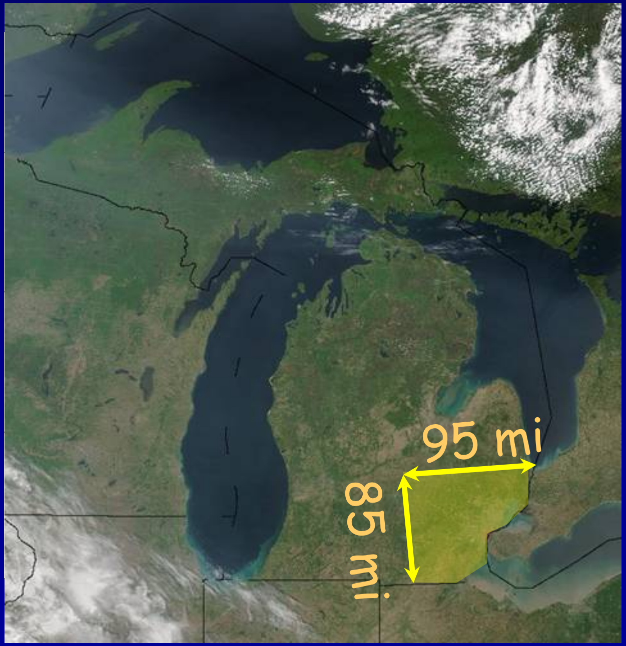
Tens of millions of ash trees in urban, rural, forest & riparian areas have been killed by EAB to date.

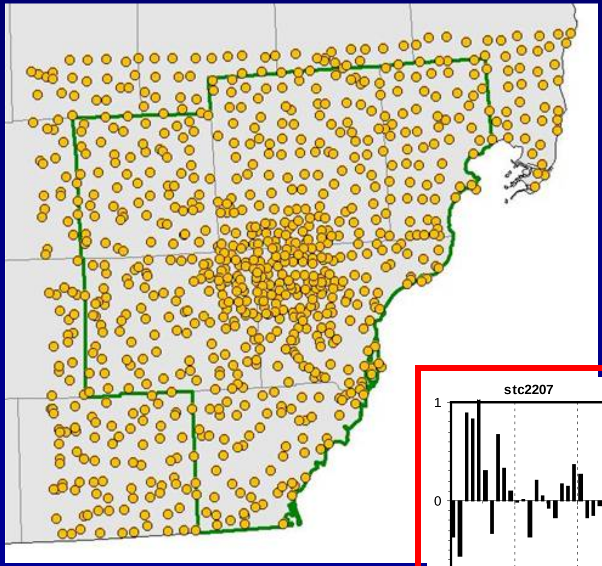
Learning from the Michigan experience: EAB & ash mortality spread surprisingly fast....

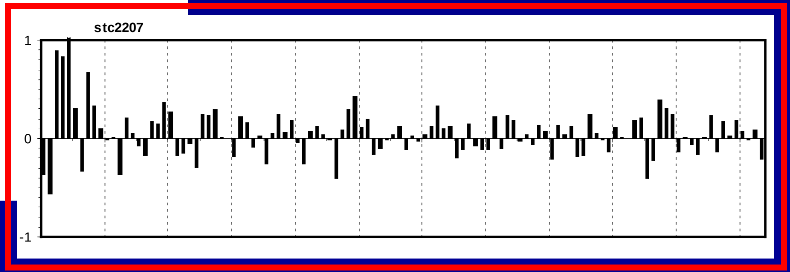
A historical reconstruction of ash mortality & EAB dynamics using dendrochronological analysis

Nathan W. Siegert, Deborah G. McCullough, Frank W. Telewski, Andrew M. Liebhold

- Increment cores (2-4 per tree) collected from 1036 ash trees in the 6 counties quarantined for EAB in 2004-2006.
- Trees sampled on 3 x 3 mile or 1.5 x 1.5 mile grid across 5800 miles^2 (15,025 km^2) .
- Growth rings measured & cross-dated to master chronologies to identify year of mortality.

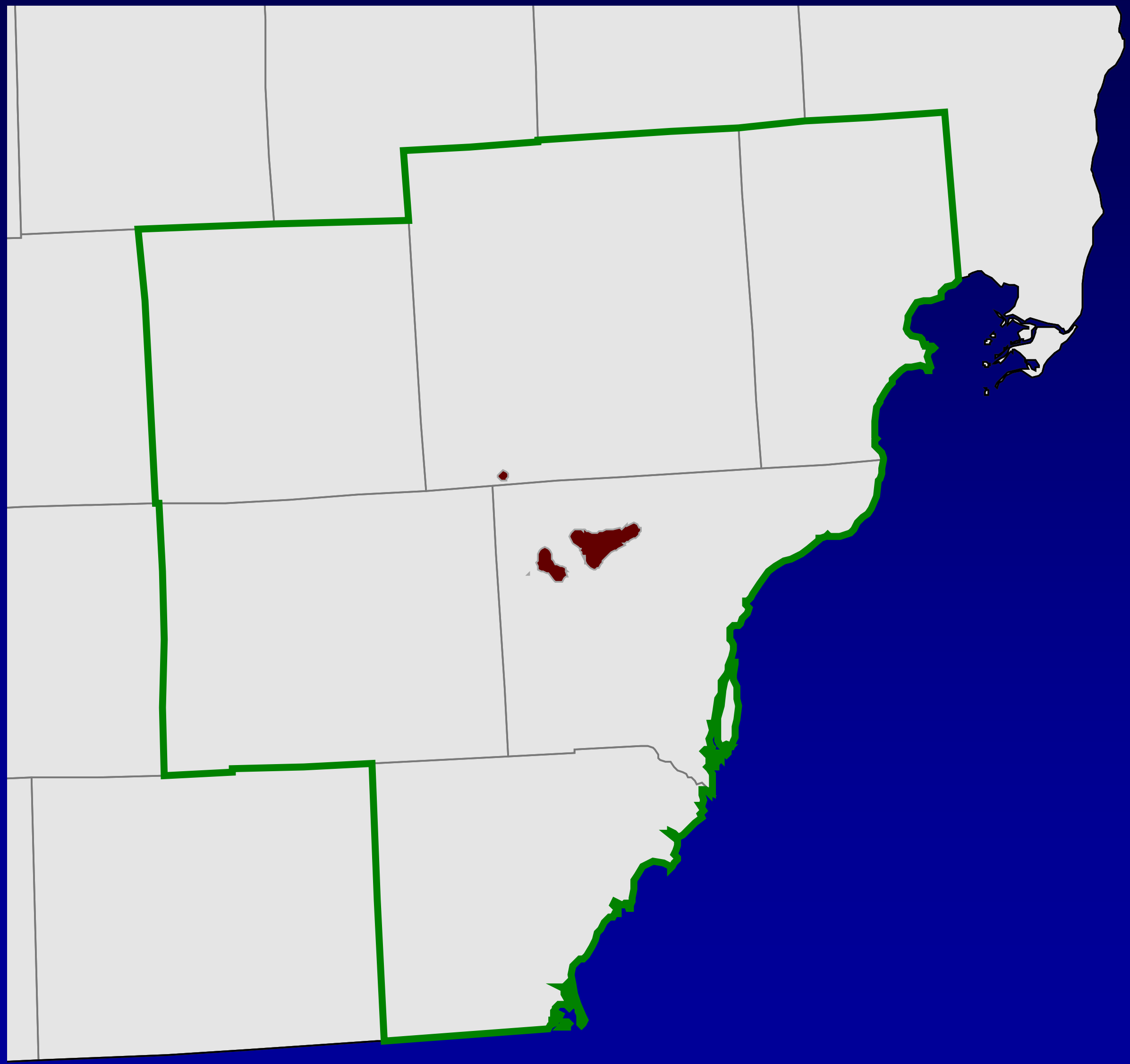






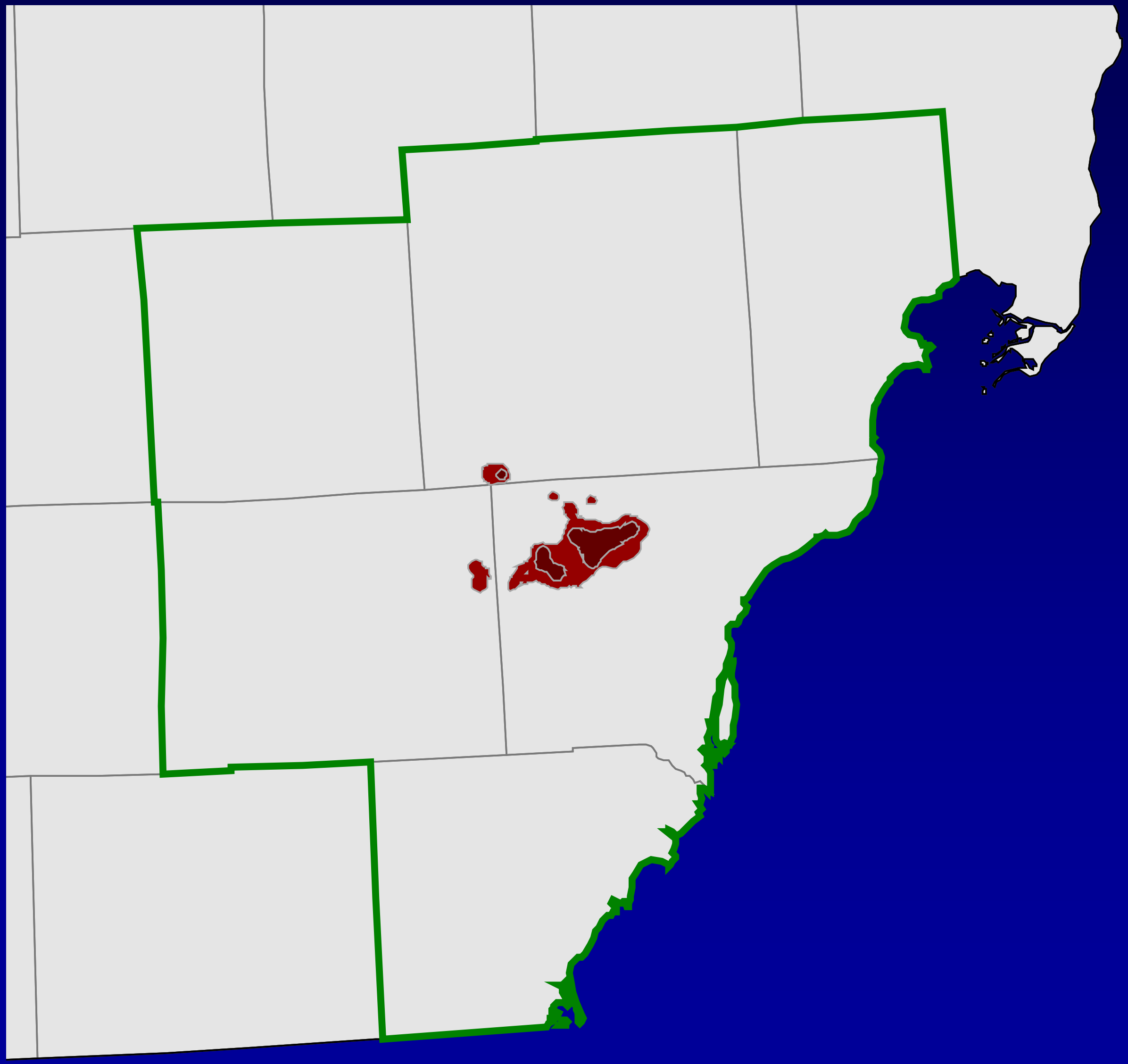
Results – Ash Tree Mortality

1998



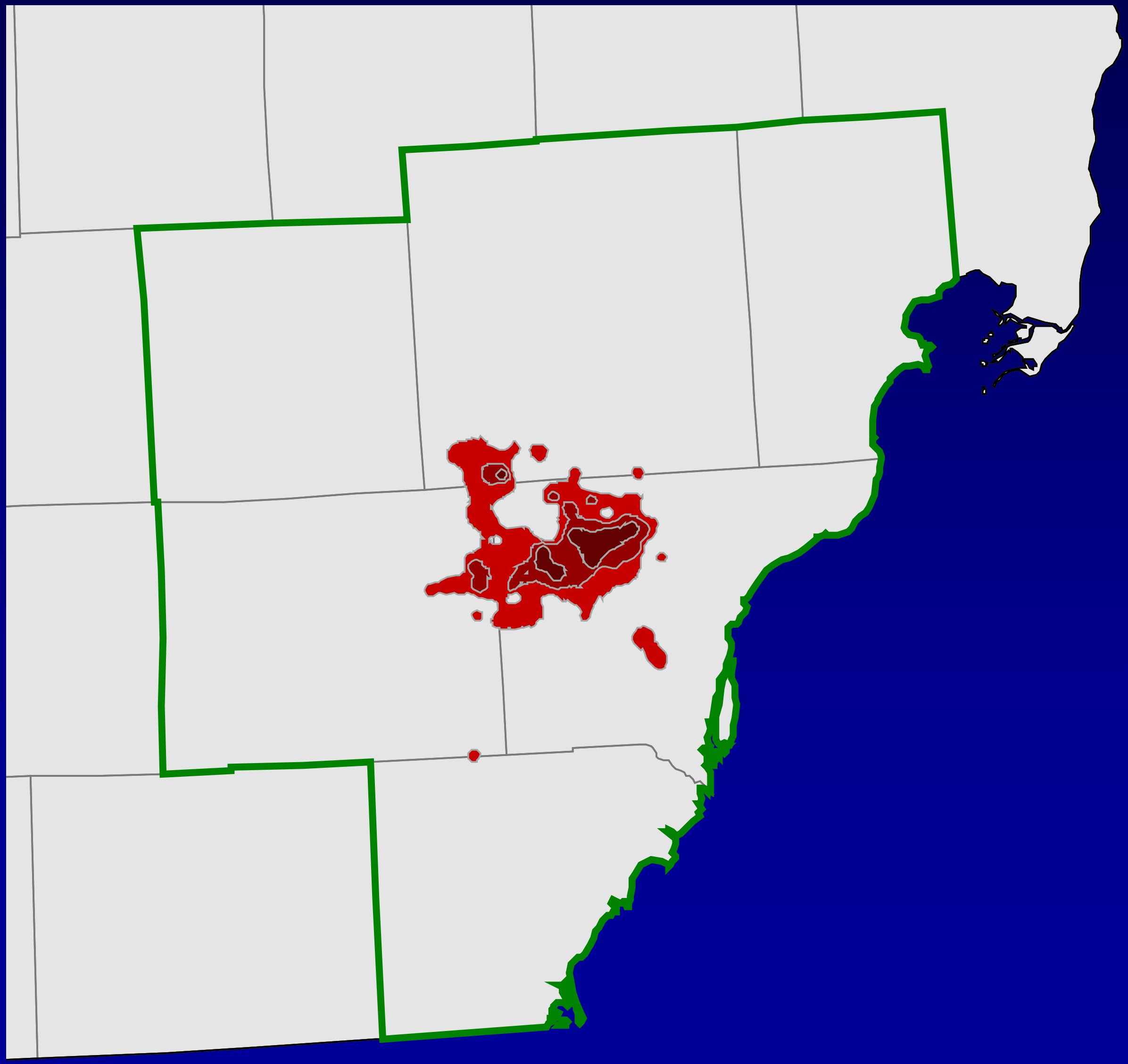
Results – Ash Tree Mortality

1998 → 1999



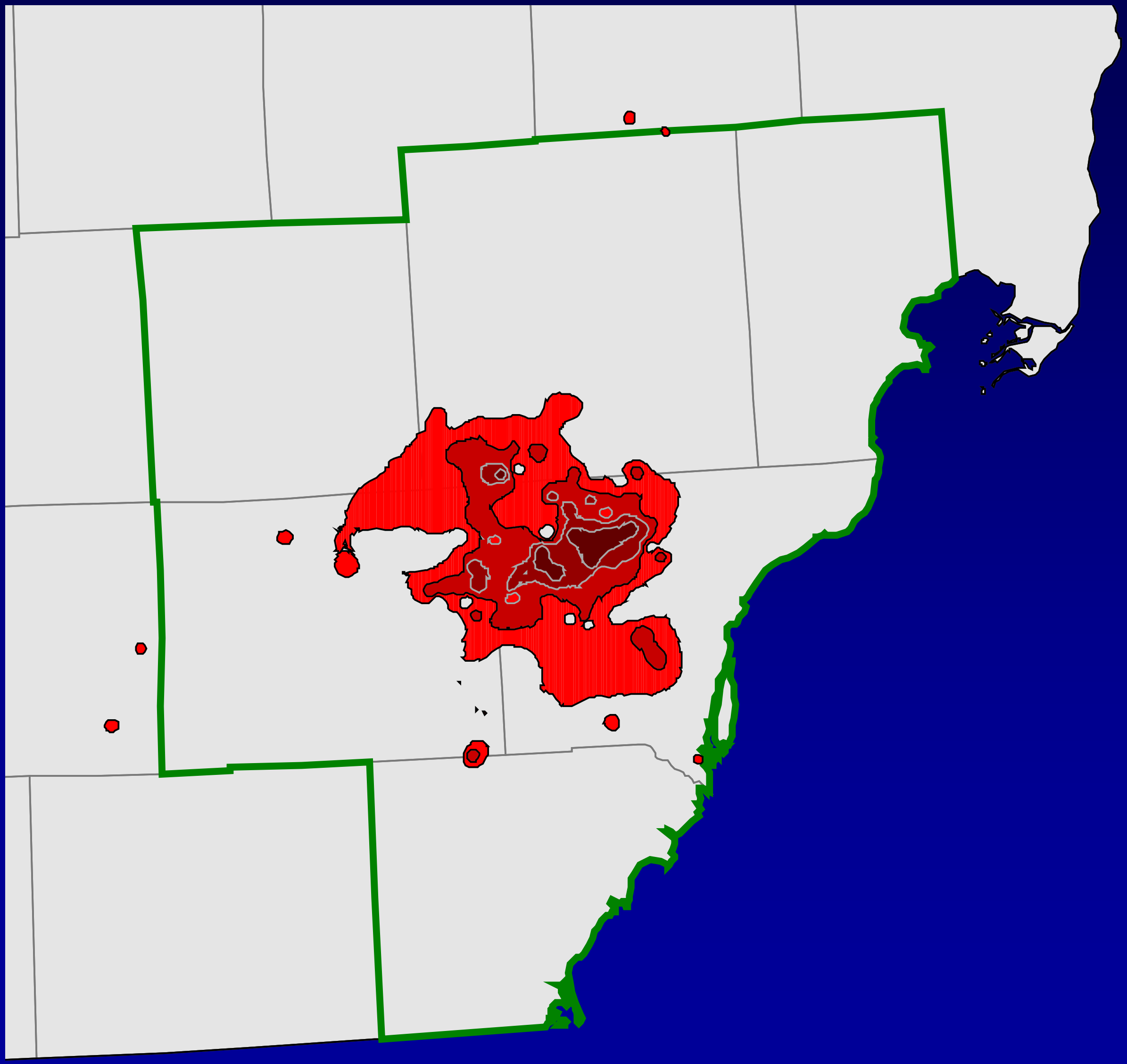
Results – Ash Tree Mortality

1998 → 1999 → 2000



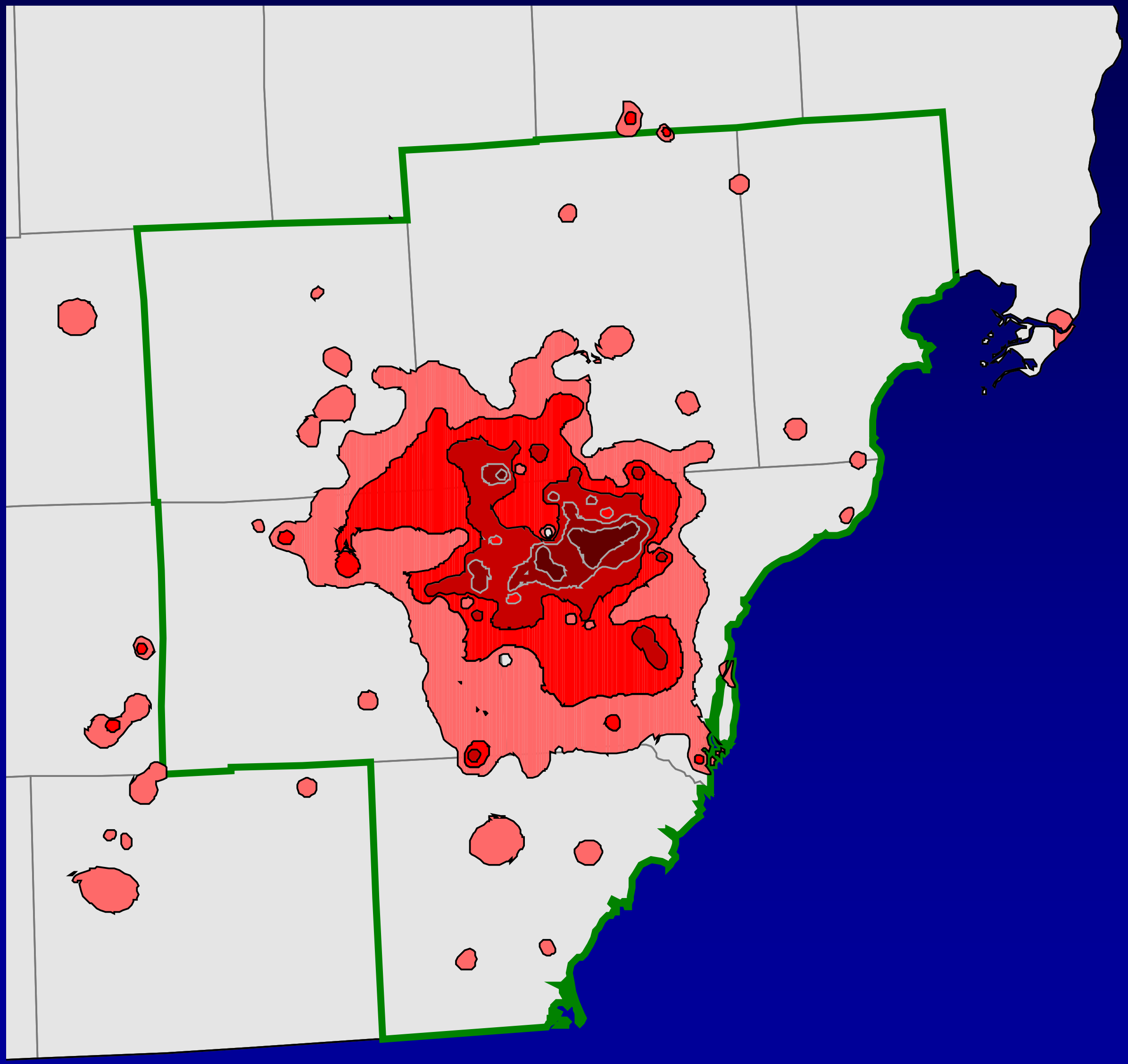
Results – Ash Tree Mortality

1998 → 1999 → 2000 → 2001



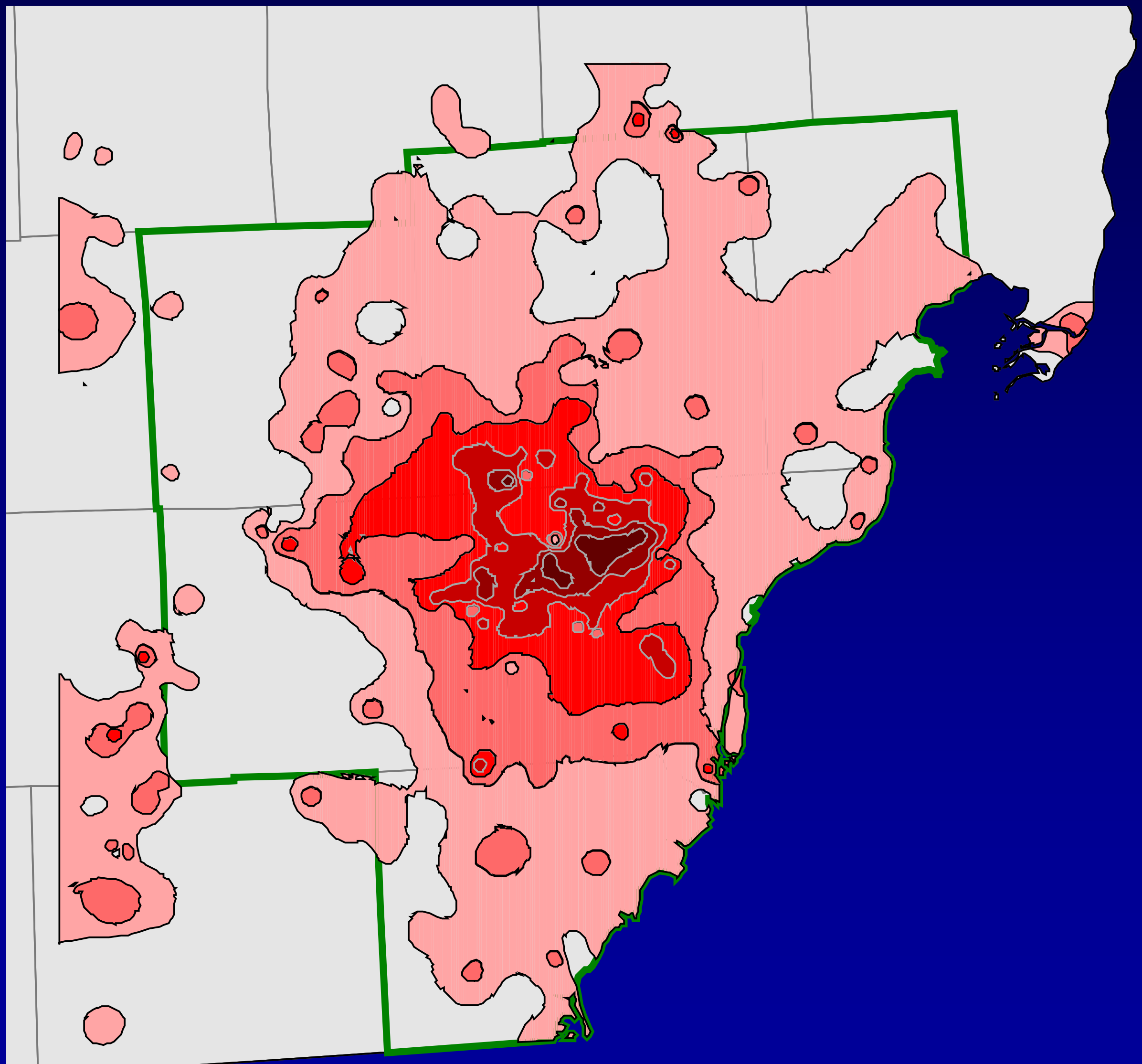
Results – Ash Tree Mortality

1998 → 1999 → 2000 → 2001 → 2002



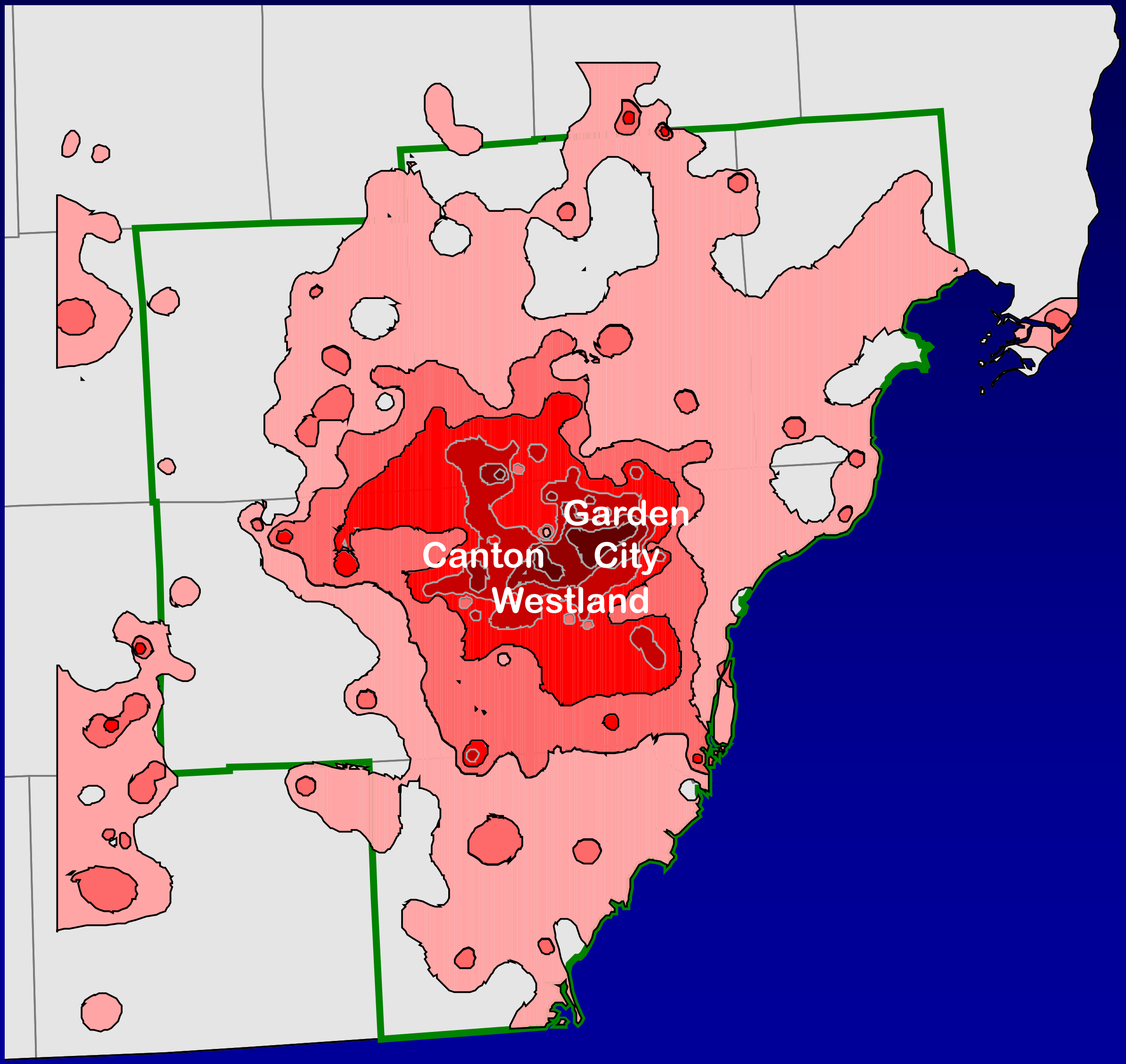
Results – Ash Tree Mortality

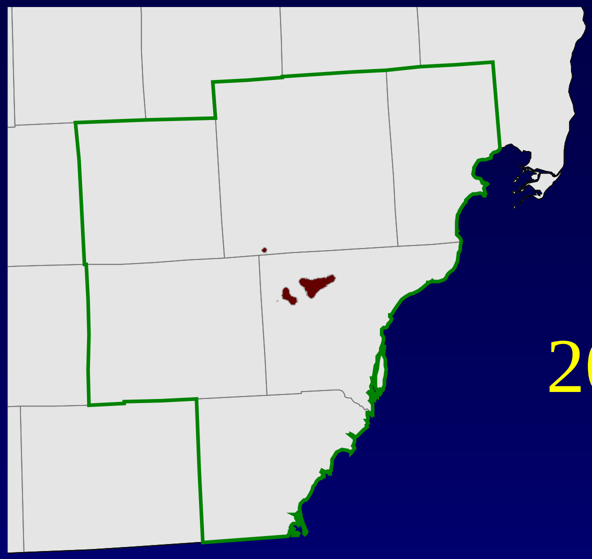
1998 → 1999 → 2000 → 2001 → 2002 → 2003



Results – Ash Tree Mortality

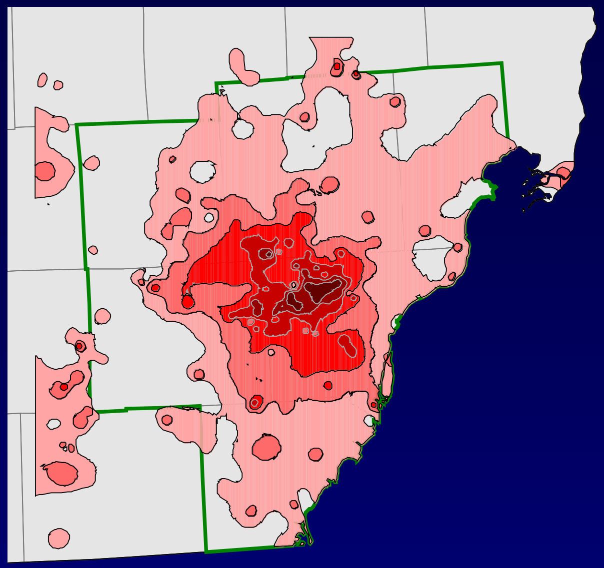
1998 → 1999 → 2000 → 2001 → 2002 → 2003





1998: ~ 24 mi^2

2003: ~ 4094 mi^2



- In 5 years, the area encompassing ash trees killed by EAB increased 170-fold.
- Sites are typically infested for *at least* 3-4 years before symptoms become apparent or trees decline.
- Therefore, EAB likely was established in SE Michigan by the early 1990’s & perhaps earlier.

EAB detection, delimitation & survey is very difficult

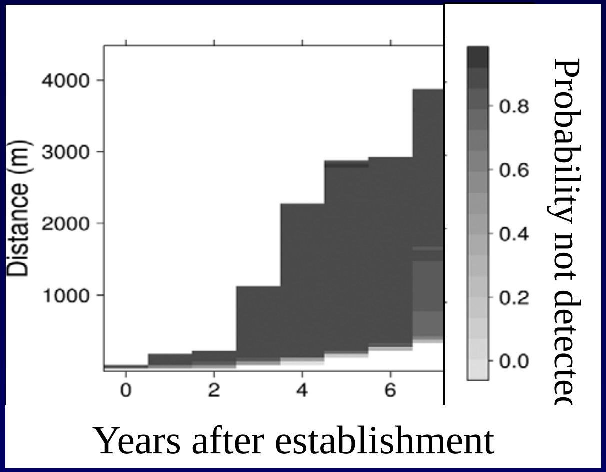
Determining EAB distribution is complicated by:

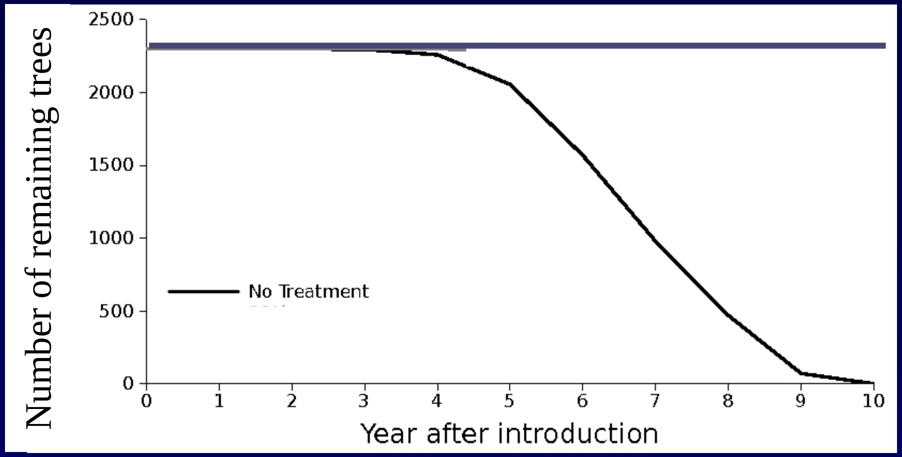
1. No long range pheromones.
2. Girdled & debarked ash effective, but not often used.
3. Canopy traps are not highly effective.
4. Surveys end once county or state found to be infested.

APHIS
canopy trap

Double-decker
trap

Girdled trees - debarked





Long distance EAB dispersal occurs but little known. Actual EAB distribution is likely 2+ miles or more beyond detection threshold, 6 years after establishment.

New satellite populations usually "simmer" for 4+ years before tree decline becomes apparent.

Urban ash trees: If trees left untreated, expect very high rates of ash decline & mortality over a 3-4 year period.

Mercader & McCullough. 2012. J. Econ. Entomol. 105: 272-281.

Mercader & McCullough. 2012. Int. J. Pest Manage. 58: 9-23.

Landscape ash trees in Toledo, Ohio: Before & After EAB

June 2006

August 2009

Photos courtesy of D. Herms, OSU

Management efforts to date…

- Detection surveys ongoing (but low density infestations difficult to detect)
- Regulation of ash trees, logs, wood
- No overall national strategy for EAB management.
- Landowners, foresters, municipalities left to deal with EAB on their own.
- Economic costs are staggering.

Potential Economic Costs of EAB

Kovacs et al. 2010. Ecological Economics 69:569-578.

- Landscape trees account for greatest economic impact.
- We projected annual EAB distribution, 2009 to 2019.
- Acquired tree inventories from 16 cities in 13 states.
- Assumed ≈ 45% of landscape ash would be treated at 2-yr intervals (TREE-äge) or replaced.
- Estimated discounted costs from 2009 to 2019.

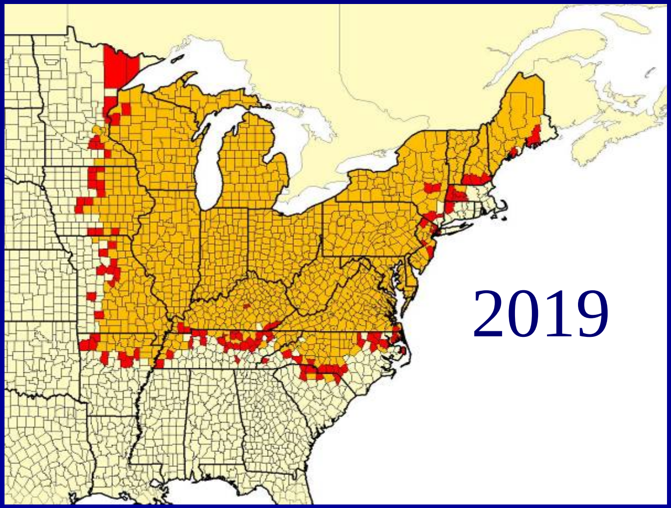
Kovacs et al. 2010. Ecological Economics 69: 569-578

Approximately 38 million ash trees occur on urban land in the 25 state area where EAB is likely to be in 2019.

We estimated 17 million landscape ash trees in urban areas would be treated or removed & replaced.

Average discounted cost = $10.7 billion over 10 years.

Including developed suburban land ***nearly doubles*** the number of affected ash trees & the associated cost.



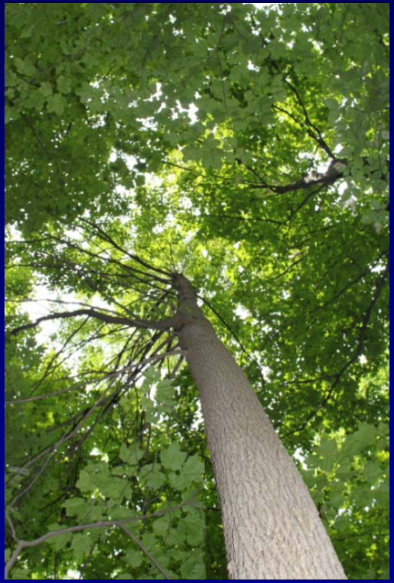
EAB is already the most destructive & economically costly forest insect to ever invade the U.S.

Annualized marginal damages in $ millions

	Government		**Households**		**Timber**
	Federal	Local	Spent	Property values	Private land
EAB	38	850	350	380	60
Gypsy moth	33	50	46	120	5
Hemlock adelgid	4	66	44	100	1

Aukema et al. 2011. PLoS One Vol. 6: 1-7.

EAB & our progress since 2002: Is your glass half full or half-empty?



Host Preference & Resistance: Are there differences among *Fraxinus* species in adult EAB leaf feeding, oviposition or larval survival & development?

Continental US: 16 native ash species; Ash are also common in landscapes.

Michigan: 5 ash species: Green, White, Black, Blue, Pumpkin

EAB adults must select hosts for feeding & egg-laying

- Beetles select hosts & leaf-feed throughout life span.
- Females lay eggs between bouts of feeding & resting.
- Adults feed on ash foliage for 2-3 weeks before egg-laying even begins – provides opportunity to control adults before new larvae produced.

Larvae must survive & develop – no choice of hosts

Larvae feed on phloem & cambium, mid summer to fall. Complete 4 instars. Most larvae overwinter as prepupae in outer sapwood or outer bark. Pupate in spring.

L2, L3 & L4 larvae in Sept.

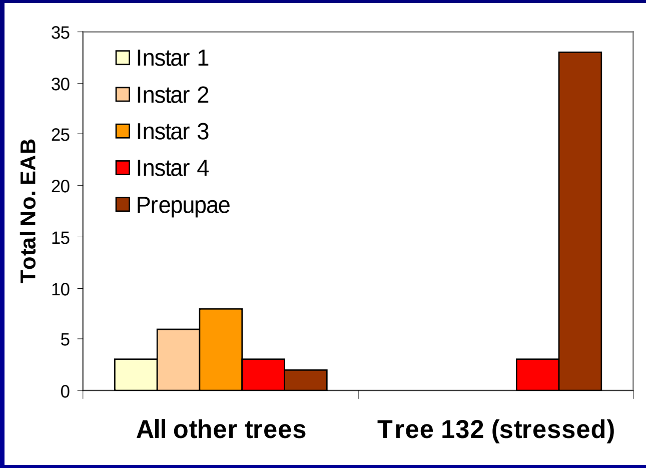
PP larva

Pupation

Note… In healthy ash with low EAB densities, 2-year life cycle dominates (early instars overwinter). In stressed trees, most or all EAB develop in 1 year.

1-year gallery; PP overwinters

Overwintering 2nd instar larvae



Siegert et al. 2010. Env. Entomol.
Tluczek et al. 2011. Env. Entomol.

Does EAB host preference or ash resistance vary among North American ash species?

Green Ash (*F. pennsylvanica)*

Grows in 44 states on a wide range of sites; often on heavy soils; common landscape & riparian species.

White Ash (*F. americana)*

Grows in 34 states, often in mixed stands on upland, fertile sites; timber valued; common landscape tree

EAB host preference: Green ash vs White ash

Street trees

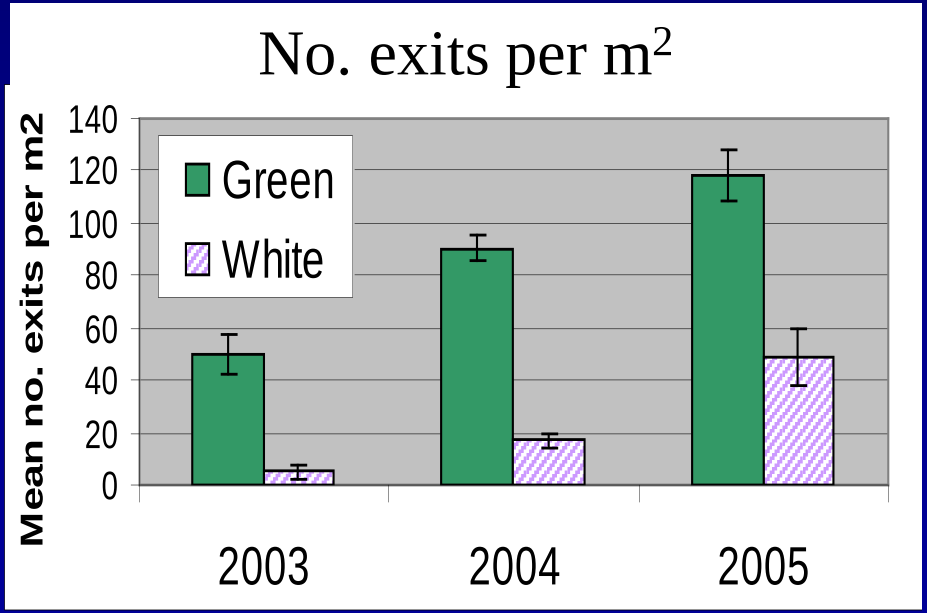
Plantation (2009-2011)

Small girdled ash

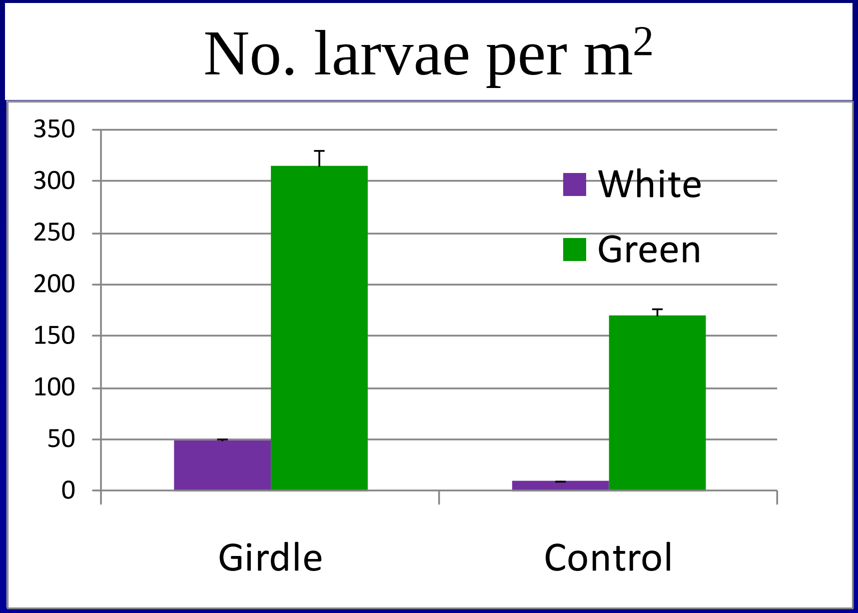
EAB host preference: green ash vs white ash

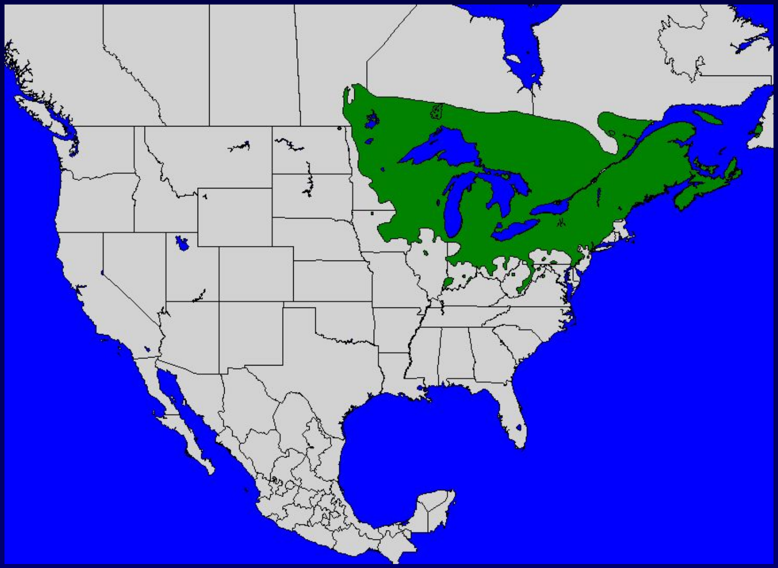
- Street trees: EAB preferentially attacks green ash over white ash trees when planted together.
- Plantation: EAB strongly prefers green ash over white ash trees; girdled white ash also colonized heavily.

Street trees



Plantation - 2010





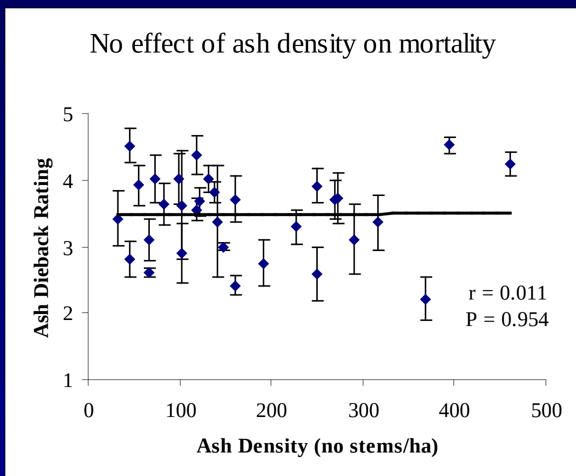
Black Ash
(*Fraxinus nigra*)

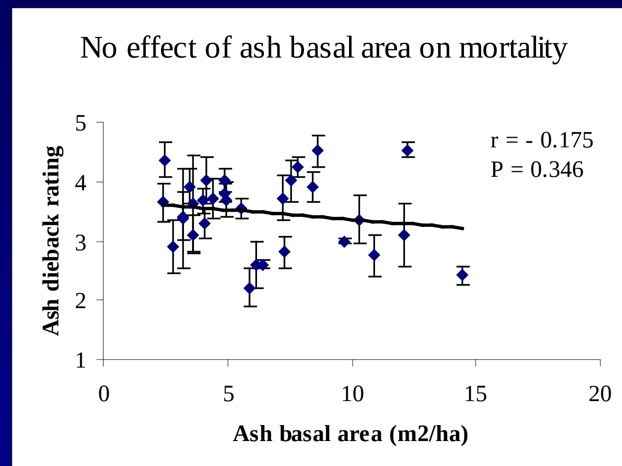
Common in northern bogs & swamps in 19 states; slow growth & infrequent seeding.

Cultural resource for Native American & 1st Nation tribes

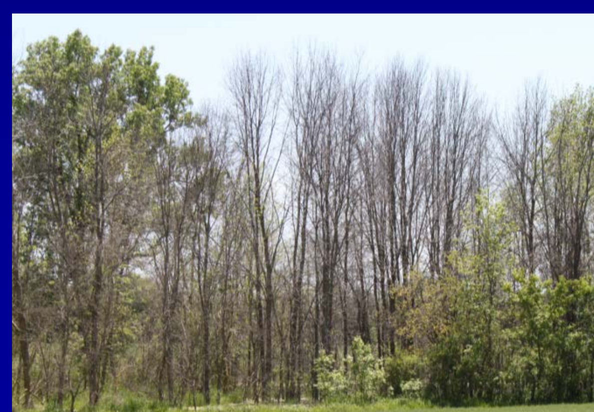
Black ash: Very suitable EAB host & highly vulnerable. Galleries extend further horizontally than on other ash species – each larva injures more area.

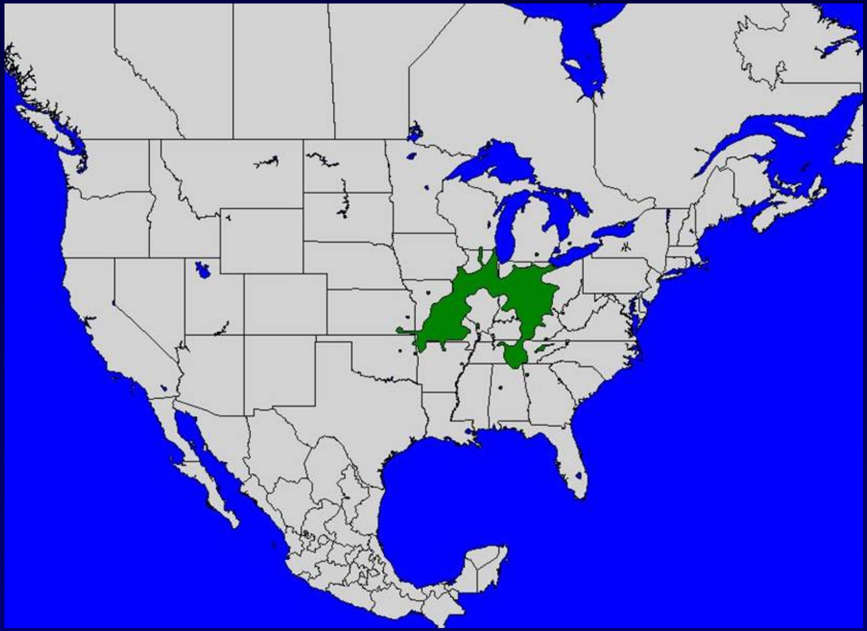
OSU data: EAB-caused mortality in green, white & black ash stands nearly 100%. Mortality not related to any site, stand or tree traits. No silvicultural options to “EAB-proof” a stand.





Data courtesy of Smith et al., OSU





Blue Ash

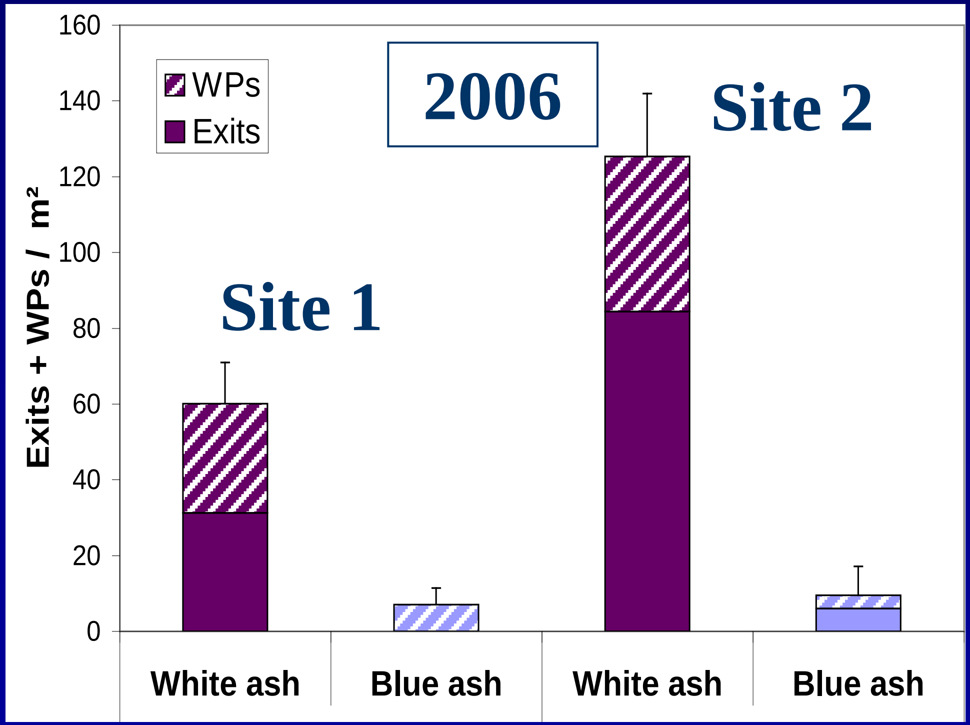
Fraxinus quadrangulata

Often found on fertile sites but tolerates wide range of soils; Native in at least 12 states; Monoecious; Distinct ridges on shoots.

EAB host preference: White ash vs Blue ash

In 2005-06, we sampled EAB larval density on trees in two SE MI woodlots. EAB preferentially attacked white ash over blue ash trees in both woodlots.

We expected EAB densities on blue ash would build as white ash died.



EAB host preference: White ash vs Blue ash

In 2010-2011, we inventoried 100% of the live & dead ash trees in the same 2 woodlots.

Superior	No. trees	% Live
Blue ash	210	63%
White ash	125	0
Plymouth		
Blue ash	381	71%
White ash*	186	16%

Most dominant blue ash are alive & healthy, despite evidence of previous EAB attacks.

The only live white ash are < 5 inches DBH.

EAB Host Preference in North America

- EAB are strongly attracted to stressed trees (e.g. girdled)
- EAB preferentially attacks green ash over white ash when both species present (street trees, plantation).
- Black ash: highly preferred & most vulnerable host.
- Strong EAB preference for white ash over blue ash trees growing together.
- Blue ash is the most resistant host EAB has encountered in North America & likely to survive the EAB invasion.

Anulewicz et al. 2008. Env. Entomol 37:230-241.

------- *2007. J Arb & Urb For 33:338-49.*

------- *2008. Great Lakes Entomol. 39:99-112.*

Tanis & McCullough. 2012. Can. J. For. Res. In press.

Insecticides & Advances in EAB Control

Insecticides - Advances in EAB Control

1. Non-linear relation between tree DBH & surface area recognized; some products now adjust application rates for large trees.
2. TREE-äge (emamectin benzoate) provides 2-3 years of nearly 100% control with one injection.
3. Safari (dinotefuran) basal trunk spray is efficient & generally effective if applied annually in spring
4. Soil drenches – spring applications better than fall; 2x application rate better than 1x rate.
5. Economics favor insecticide treatment to protect mature urban trees.

Option 1. Do nothing

Pros: Cheap – at least in the short-term...

Cons: Must assume ash trees that are not protected with effective insecticides will be killed by EAB.

- Dead or dying landscape trees reduce property values.
- Dead ash decay & can be hazardous
- Tree removal is costly & unpleasant.

Ohio

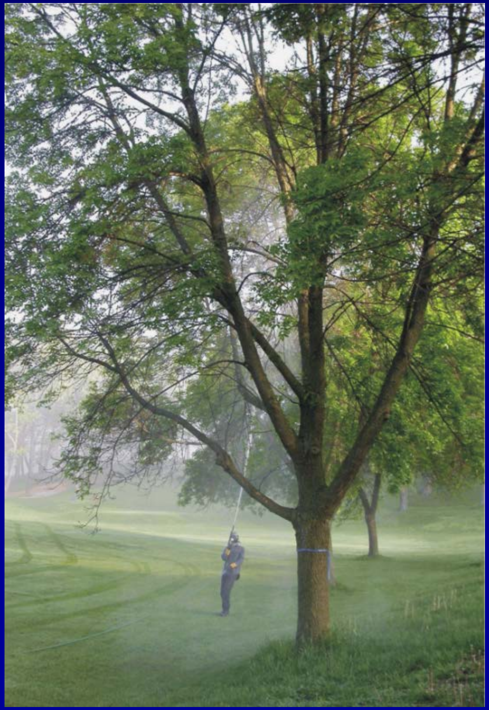
Michigan

Option 2. Cover spray with broad-spectrum insecticide

Pros: Can be effective, depending on product & timing.

Cons: Difficult to adequately cover large trees with spray.

- Insecticide drift can affect applicators, neighbors, non-target species like pollinators & beneficial predators.
- No effect on EAB larvae already under the bark.



Young EAB larva overwintering

Option 3. Systemic insecticides

Systemic products are transported by the tree from the base of the trunk (or roots) to the branches & leaves.

Pros: Several products & application methods are available; options include do-it-yourself soil drenches.

- No drift or negative impacts on non-target species.
- Minimizes exposure for applicator & residents.

Cons: Trees must be fairly healthy to transport the insecticides to branches & leaves.

- Effectiveness of products varies considerably.
- Proper application requires knowledge & skill.

Extensive canopy decline or obvious symptoms of EAB infestation on the trunk indicate trees are likely too infested to transport systemic insecticides.

Bark crack & WP hole

Severe canopy decline

Epicormic sprouts on trunk

Systemic insecticides for treating landscape ash trees

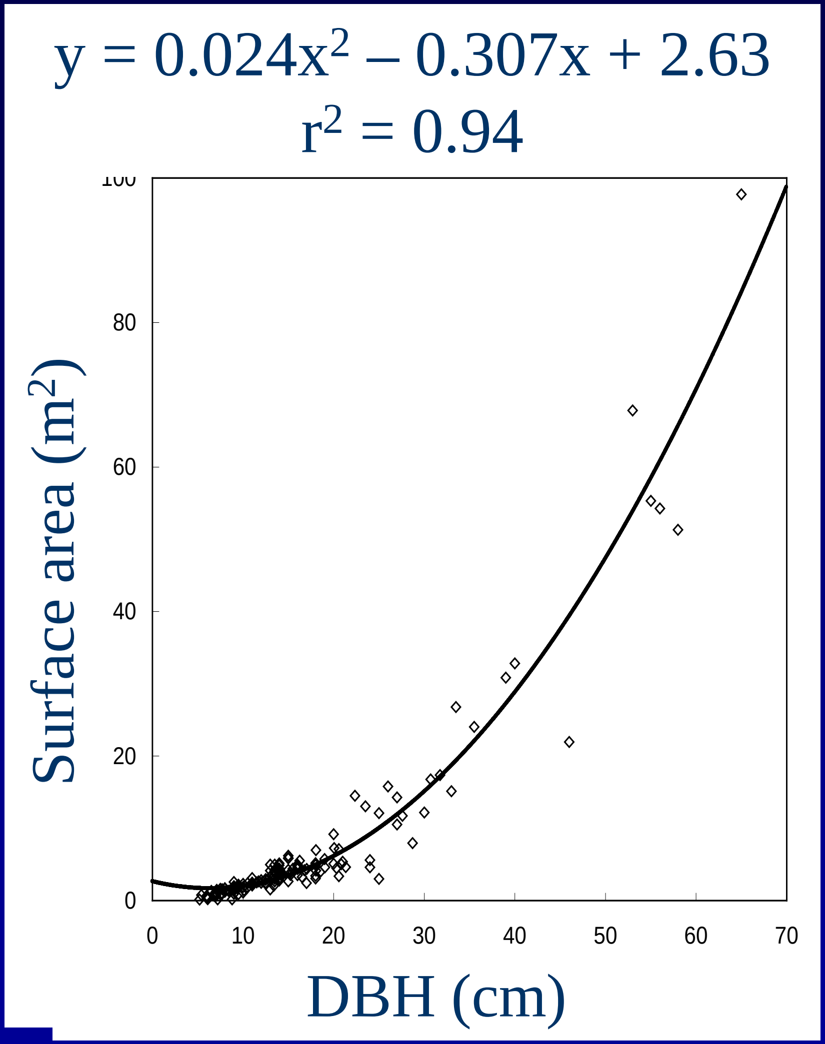
1. Imidacloprid (neonicotinoid)
Many products; Applied as soil drench or trunk injection

2. Dinotefuran (neonicotinoid)
Sold as Safari
Applied as a basal trunk spray or as soil drench

3. Emamectin benzoate (avermectin)
Sold as TREE-äge
Trunk injection (ArborJet QuikJet, Tree IV & Viper)

4. Azidirachtin (Neem derivative)
Sold as Tree-Azin - only product registered in Canada for EAB. Trunk injection (BioForest canisters)

DBH versus area is not linear!



- Application rates for systemic insecticides are based on tree DBH.
- But... surface area increases exponentially as DBH increases.
- Only a few products adjust application rates to account for area of larger trees.

McCullough & Siegert. 2007. J. Econ. Entomol. 100:1557-1586.

Two-Year Evaluation of Emamectin Benzoate & Neonicotinoid Products for EAB Control

McCullough et al. 2011. J. Econ. Entomol. 104: 1599-1612

D.G. McCullough, T.M. Poland, A.M. Anulewicz,
P. Lewis & D. Cappaert

MICHIGAN STATE
UNIVERSITY

Two-year MSU Evaluation of Treatments

1. Control (untreated)

2. Imidacloprid - trunk injection; Imicide (10%) in Mauget capsules; 0.15 g AI/inch DBH

3. Emamectin benzoate - trunk injection; TREE-äge (4%); Arborjet QuikJet micro-injector; 0.1-0.2 g AI/inch DBH

4. Imidacloprid + PB: basal bark spray; 2F formulation (21.4%) + 3 oz Pentra-Bark per gal.; 1.7 g AI/inch DBH.

5. Imidacloprid – no PB

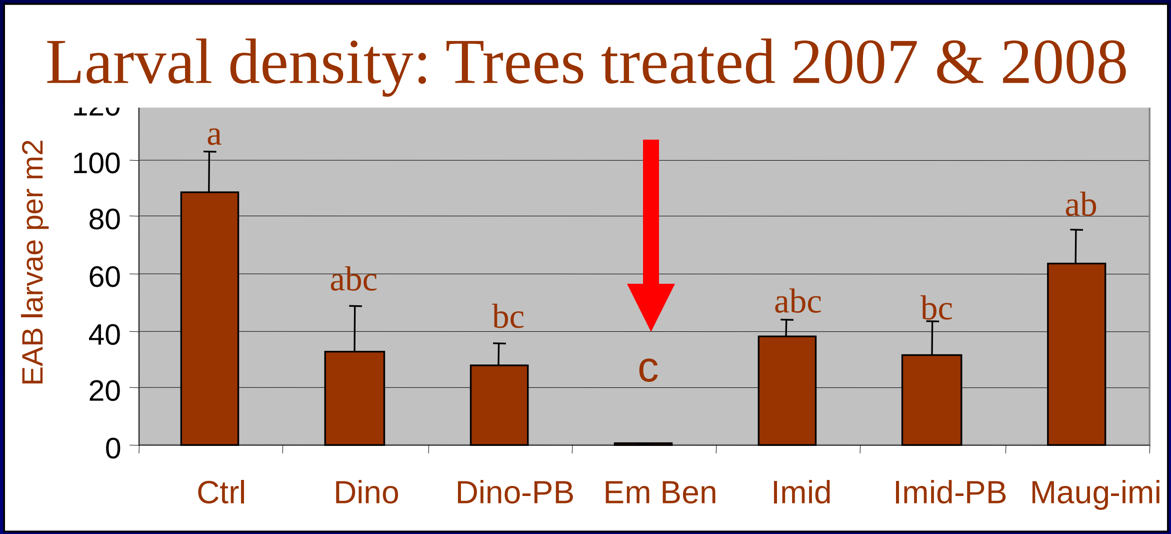
6. Dinotefuran + PB: basal bark spray; Safari (20%) + 3 oz Pentra-Bark per gal; 1.7 g AI/inch DBH.

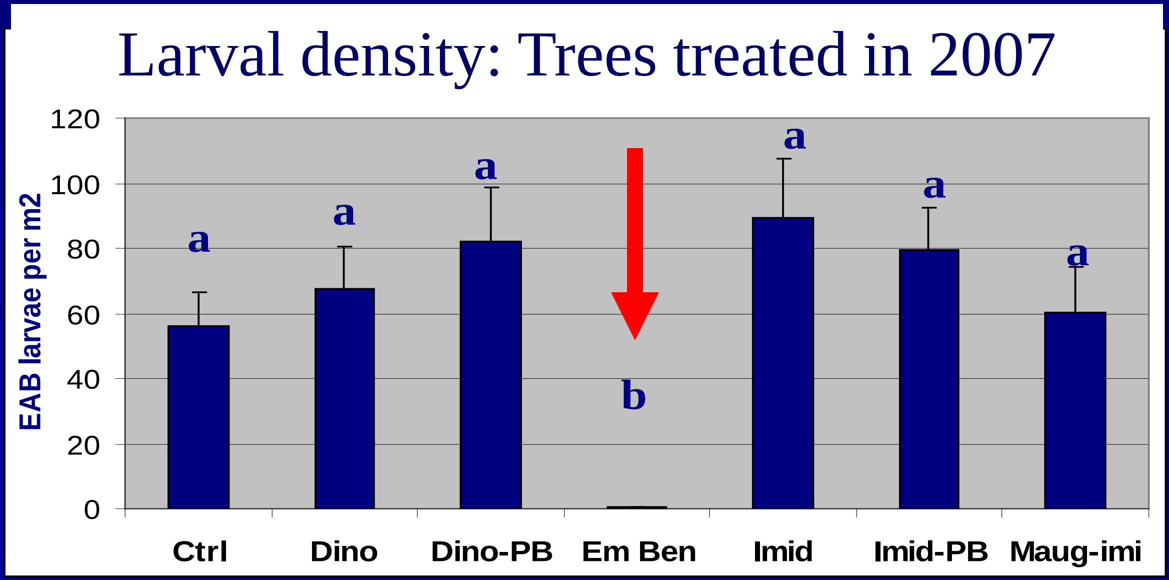
7. Dinotefuran – no PB

May 2007: 25 blocks of 7 trees selected across 3 sites

- All trees treated in spring 2007; Total of 175 trees; 25 trees per treatment. Tree DBH: 5 to 21 inches
- Half of the trees were re-treated in spring 2008.
- Adult EAB bioassays & foliar residue sampling conducted at 3-4 wk intervals each summer.
- Trees felled & debarked to quantify larval density in winter 2008-09.

Emamectin benzoate (TREE-äge) ≈ 99% EAB control for at least 2 years with a single injection.





Annual treatment:

Em Ben: >99% EAB control

Imi & Dino: 30-70% EAB control

2-year control

Em Ben: >99% EAB control

Imi & Dino: none

3 yr control - MSU study began in 2008

23 trees per block; 12 blocks (276 trees) at 3 sites

Product	Method	Timing
Dino+PB	Basal bark spray	Early June
TREE-äge Low (0.1 g ai)	Trunk injection (QuikJet)	Mid May
TREE-äge High (0.4 g ai)	Trunk injection (Tree IV)	Mid May
Imicide (10%)	Trunk injection	Mid May

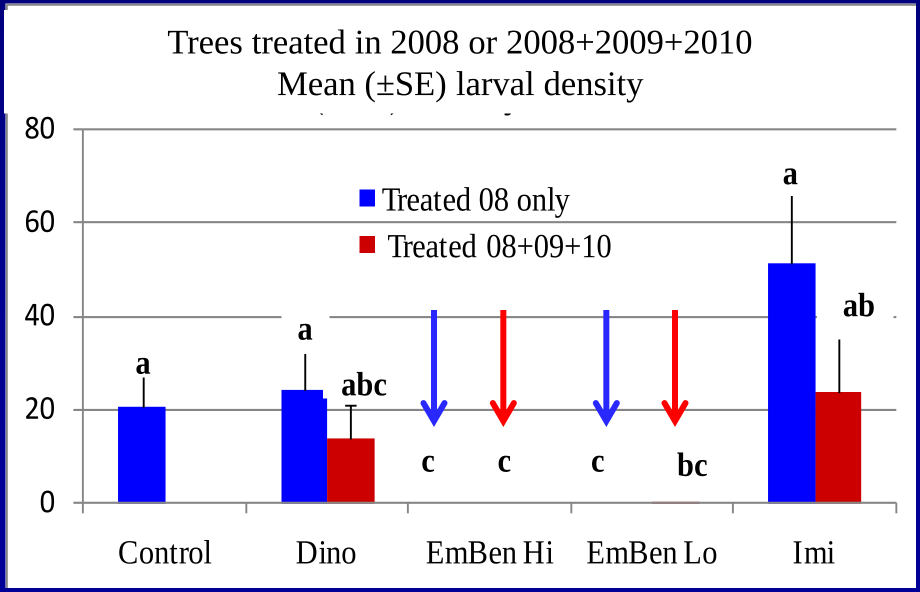
All trees treated in 2008. Some trees treated annually (2008+2009+2010), while others treated only in 2008. Tree DBH 6 to 17 inches. Foliar residues & adult EAB bioassays conducted each summer.

Schedule of treatments & felling+debarking

	2008		**2009**		**2010**		**Total**
	Treat	Debark	Treat	Debark	Treat	Debark	12
Annual 1 year	**12**	**12**	**---**	**---**	**---**	**---**	**12**
Annual 2 years	**12**		**12**	**12**	**---**	**---**	**12**
Annual 3 years	**12**		**12**		**12**	**12**	**12**
2-year	**12**			**12**	**---**	**---**	**12**
3-year	**12**					**12**	**12**
Control		**12**		**12**		**12**	**36**

Em Ben (TREE-äge) remained highly effective for 3 years, even at the lowest rate (0.1 g ai per DBH inch).

Larval density on all Em Ben trees (low & high rates) was 99% lower than controls, even 3 years post-injection. Dino trees treated annually had 50% fewer larvae than controls in 2010. Imi applied annually was effective in 2008, less effective by 2010.

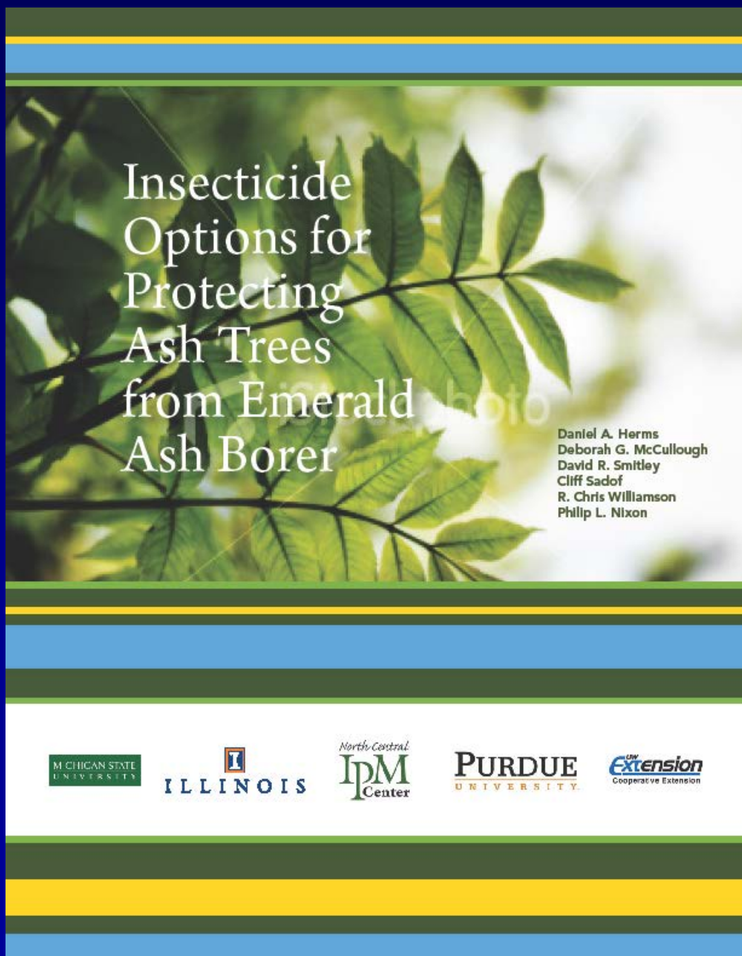


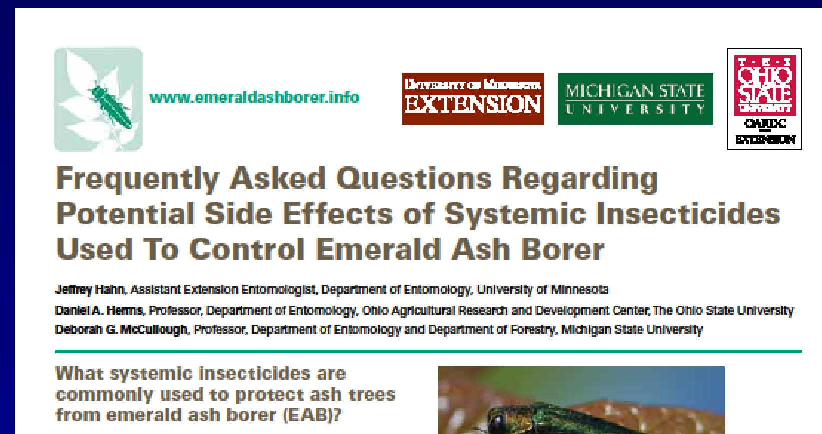
Imidacloprid - Soil Drenches

- Imi moves slowly within trees; requires at least 4-6 weeks to move into canopy. Apply to exposed soil right around tree base. Spring applications best.
- Do not apply when soil is very wet or dry.
- Avoid soil drenches on sandy soil, near open water or over a high water table. Labels have per acre restrictions.
- Efficacy varies with tree size.
- Labels on new products allow 2x rate; more effective but likely cost prohibitive for large trees.

Where can I find information on insecticides for EAB & ash protection? www.emeraldashborer.info

Multi-state extension bulletins





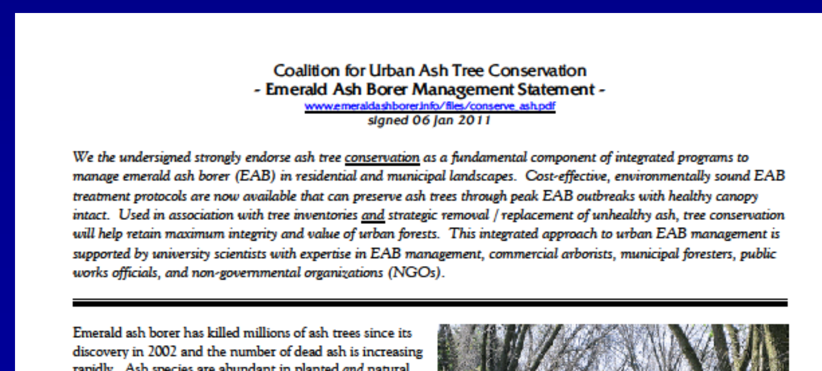
www.emeraldashborer.info

University of Minnesota EXTENSION | MICHIGAN STATE UNIVERSITY | THE OHIO STATE UNIVERSITY OARDC EXTENSION

Frequently Asked Questions Regarding Potential Side Effects of Systemic Insecticides Used To Control Emerald Ash Borer

Jeffrey Hahn, Assistant Extension Entomologist, Department of Entomology, University of Minnesota
Daniel A. Herms, Professor, Department of Entomology, Ohio Agricultural Research and Development Center, The Ohio State University
Deborah G. McCullough, Professor, Department of Entomology and Department of Forestry, Michigan State University

What systemic insecticides are commonly used to protect ash trees from emerald ash borer (EAB)?



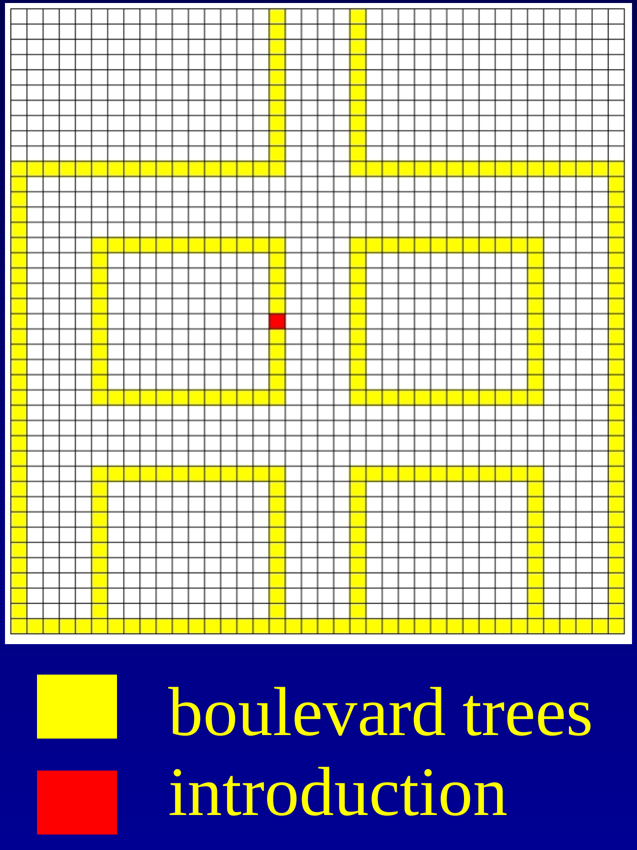
Coalition for Urban Ash Tree Conservation
- Emerald Ash Borer Management Statement -
www.emeraldashborer.info/files/conserve_ash.pdf
signed 06 Jan 2011

We the undersigned strongly endorse ash tree conservation as a fundamental component of integrated programs to manage emerald ash borer (EAB) in residential and municipal landscapes. Cost-effective, environmentally sound EAB treatment protocols are now available that can preserve ash trees through peak EAB outbreaks with healthy canopy intact. Used in association with tree inventories and strategic removal / replacement of unhealthy ash, tree conservation will help retain maximum integrity and value of urban forests. This integrated approach to urban EAB management is supported by university scientists with expertise in EAB management, commercial arborists, municipal foresters, public works officials, and non-governmental organizations (NGOs).

Emerald ash borer has killed millions of ash trees since its discovery in 2002 and the number of dead ash is increasing rapidly. Ash species are abundant in planted and natural

Can we optimize resources & use of insecticides to protect urban ash trees in a neighborhood?

- Created an urban "environment" to represent a subdivision.
- Assumed EAB introduction.
- Applied EAB population models to project EAB density, distribution & ash condition over time.



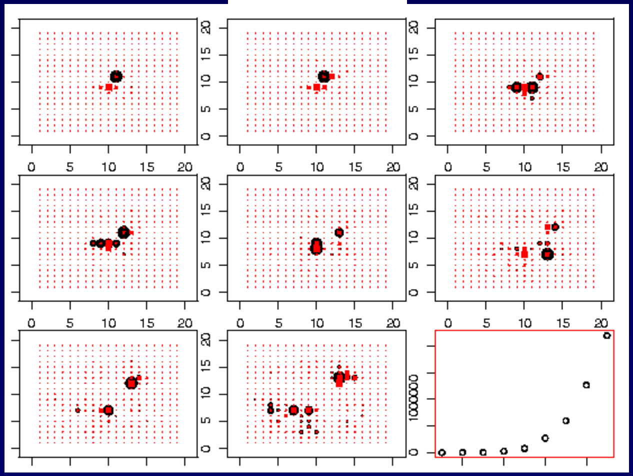
Coupled Map Lattice Model for EAB

Stage 1: Adult emergence (1-yr & 2-yr cohorts tracked)
(Cappaert et al. 2005; Siegert et al. 2010; Tluczek et al. 2011)

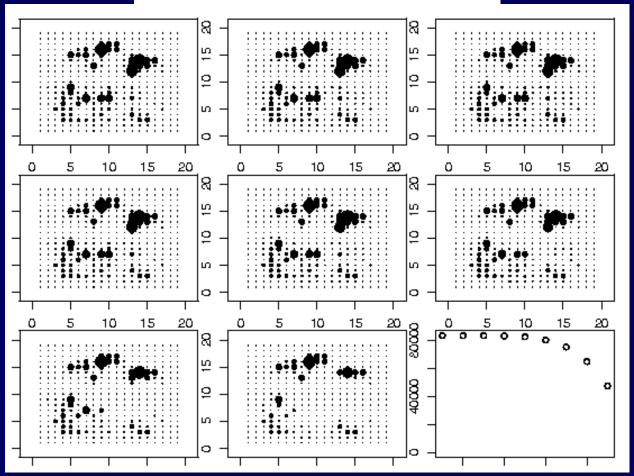
Stage 2: Dispersal of adults
(McCullough et al. 2009a, 2009b; Mercader et al. 2009, 2011a; Siegert et al. 2010)

Stage 3: Population growth & phloem consumption
(McCullough & Siegert 2007; Mercader et al. 2011a, 2011b)

EAB



Ash phloem



Simulated Environments

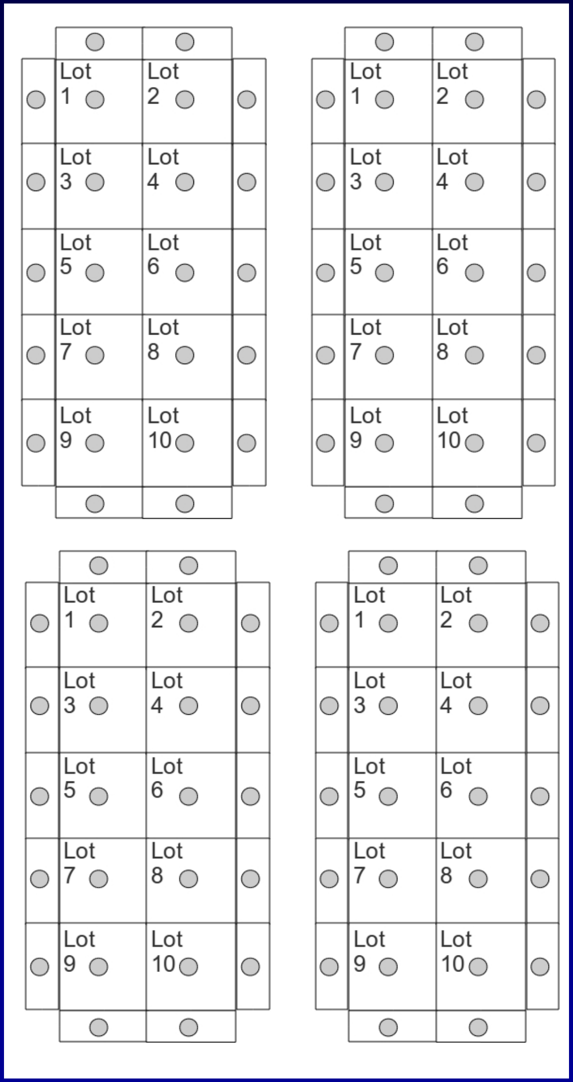
320 blocks, 20 x 16 grid; 10 m streets.
Ten lots (20 x 20 m) per block;

Trees: 1 in front (public) & 1 in back.

Ash tree distribution: Bernoulli trial; probability of 0.3. *(≈2300 ash trees)*.

Ash tree size: 6 to 30 inches; median DBH of 16 inches; 1% annual growth.

Created 200 environments; means presented for each scenario.



McCullough & Mercader. 2012. Int. J. Pest Manage. 58: 9-23.

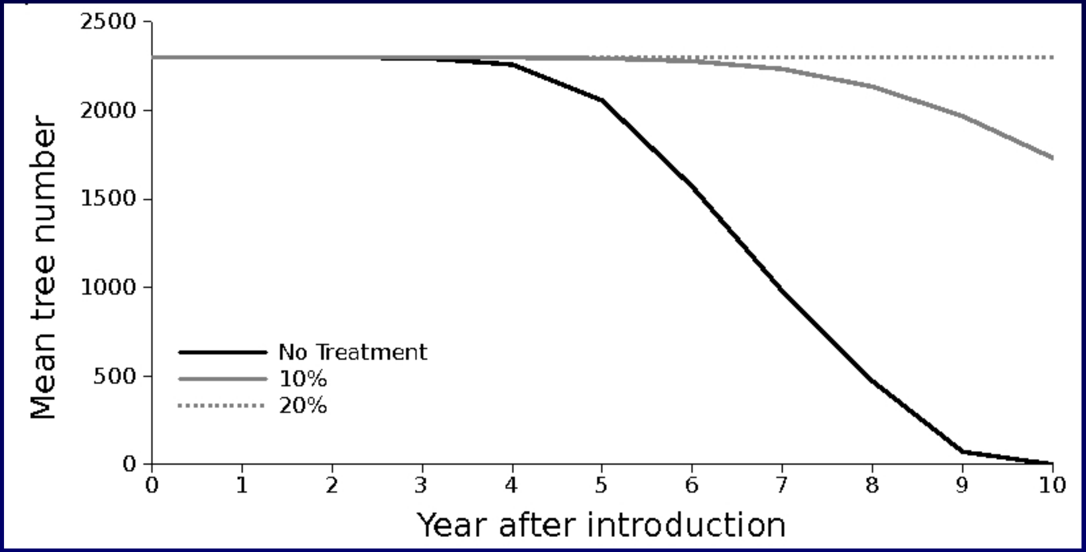
- Assumed 400 EAB emerged from from Billy Bob's firewood.
- Each female EAB could visit up to 10 trees; most likely to visit trees near origin (Billy Bob's house).
- Potentially 20 offspring per female
- EAB models account for 1-year & 2-year larval development.
- Trees treated with Em Ben would kill female EAB & larvae for 2 years.
- Trees "removed" if >60% of phloem consumed.

- Used a modified version of our coupled map lattice model to project EAB distribution, population growth & phloem consumption over 10 years.

- Compared effects of treating up to 50% of ash trees every 2 years.

- Compared effects of beginning 1 year versus 4 years post-introduction.

- Compared “targeted” versus random selection of trees for treatment.



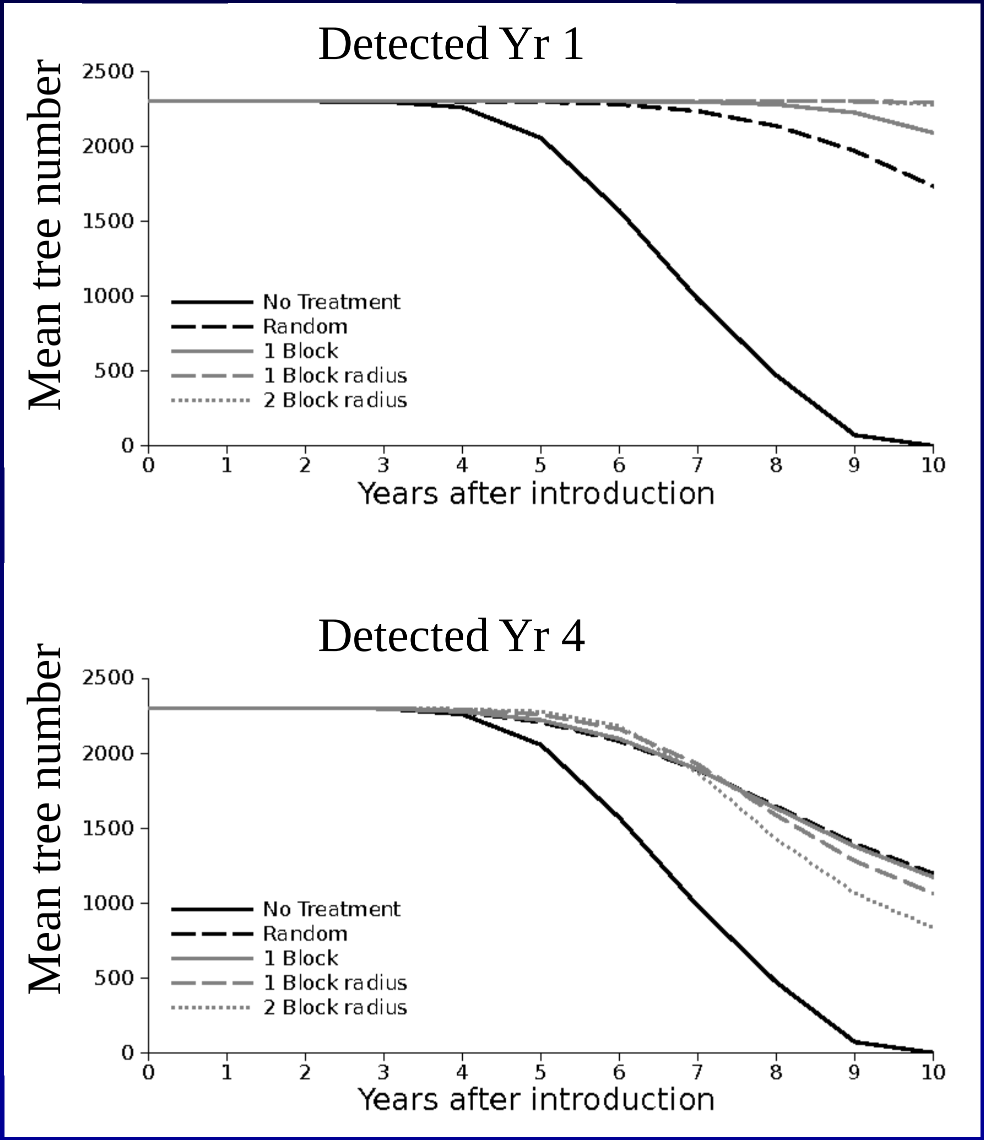
No treatment: Ash removal begins Year 4; Ash gone by Year 10.

Very consistent with real-life patterns.

If treatment began 1 year after EAB introduced:

Treating 10% of randomly selected ash trees annually protected ≈ 80% of trees for 10 years.

Treating 20% of trees annually protected 99% of trees over the 10 year time period.



If 20% of trees treated: When treatment began 1 yr post-introduction, targeting the origin was more effective than random tree selection.

If treatment began 4 yrs post-introduction, randomly selecting trees for treatment was better than targeting treatment.

No treatment: Ash gone by Year 10.

Cost estimates: Acquired 2010 or 2011 estimated costs from municipal foresters in 6 cities (IL, MI, WI).

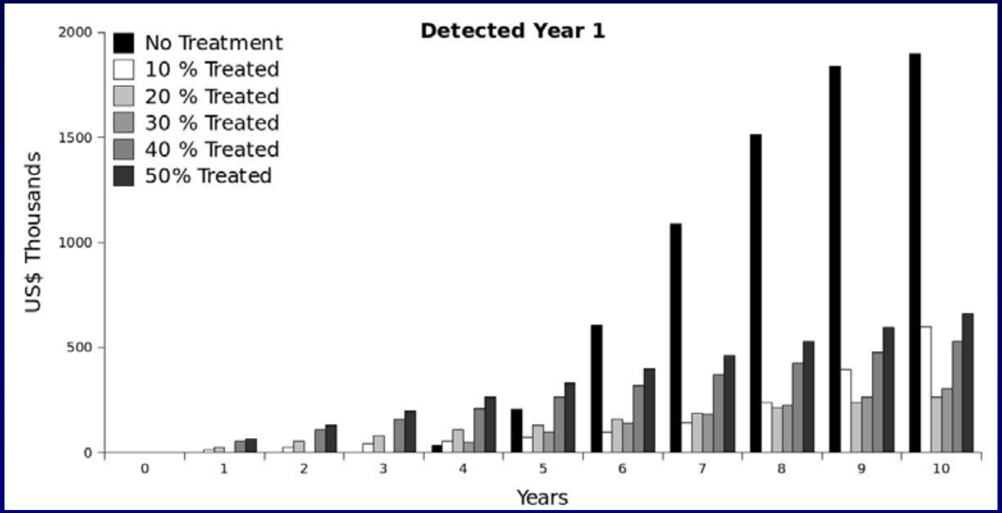
Costs: labor, fuel, administrative, insecticide, stump grinding, replacement trees & mulch

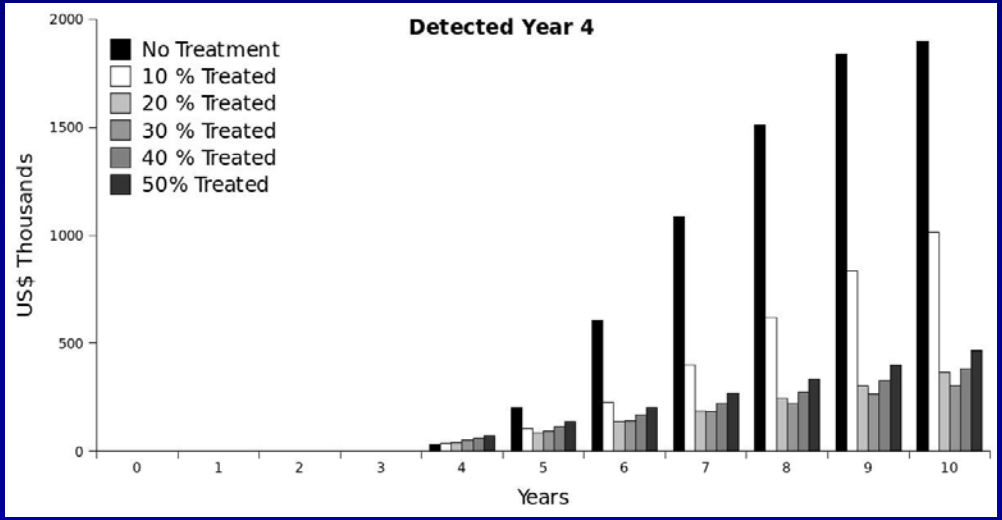
Tree removal & replacement ranged from \$750 to \$1172 per tree; averaged \$888 ± \$54.13.

Em Ben treatment: \$3.03 to \$3.62 per DBH inch

We used \$818 per tree & \$3.62 per DBH inch for simulations (conservative cost estimates).

Cost estimates for treatment + removals





Cumulative Costs

No treatment: removals cost $1.9 million

Treatment + removals Optimal: treat 20% of trees annually

Begin Yr 1: $265,271

Begin Yr 4: $364,554

Ash canopy remains nearly intact 10 years after EAB introduction.

Benefits to consider:

- Treating 20% of trees annually retained nearly all trees & associated values (e.g., aesthetics, shade, stormwater capture) over 10 year time frame.
- Treatment costs are predictable; Allows for long-term planning & staging.
- Recent data shows Em Ben (TREE-äge) can provide 3 years of control, further decreasing costs.

Insecticides for EAB control - issues & challenges

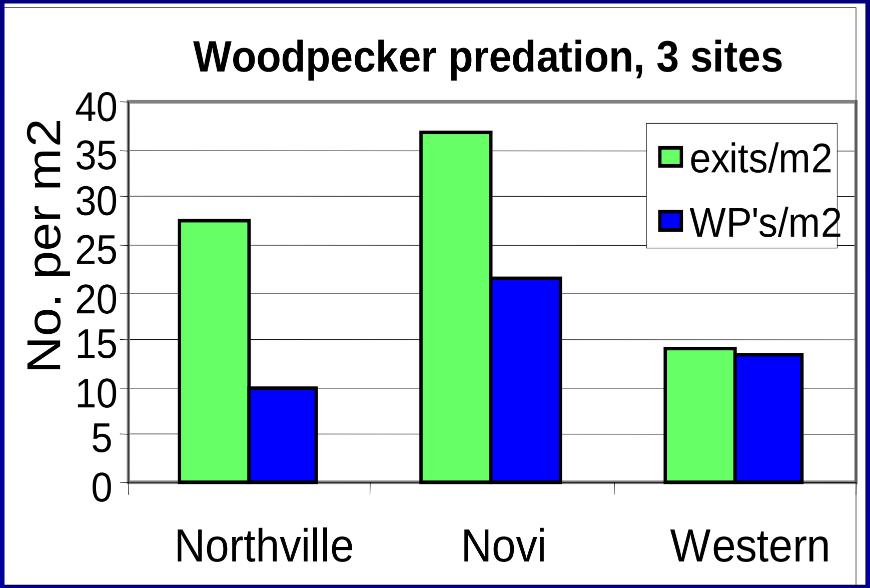
1. Out-of-touch arborists who insist that insecticides are not effective or not economically justifiable.
2. Inaccurate, misleading & confusing claims by some pesticide distributors.
3. Rapid rate of ash decline & mortality: decisions about tree protection cannot be delayed.
4. Inconsistent interpretation of label restrictions for imidacloprid soil drenches among states.
5. US Forest Service policies: help fund urban tree replacement but not protection.

Other options – natural enemies & biocontrol?

Woodpecker Predation

WP predation highly variable but remains the most important source of EAB mortality. WP attacks are often the 1st sign of EAB.

WPs usually prey on late instar EAB larvae & PP in winter & early spring.



Lindell et al. 2008. Am Midl Nat

Asian parasitoids - Classical biocontrol for EAB

USDA APHIS, USFS & ARS have invested $ millions

3 Chinese parasitoids;
1st released Aug. 2007; Releases & evaluation are continuing.

Egg parasitoid

Oobius agrili

Larval parasitoids

Tetrastichus planipennisi

Spathius agrili

Native Parasitoids

- Parasitism by *Atanycolus cappaerti* increasingly common & sometimes abundant.
- Native parasitoids may be learning to search ash trees.
- High parasitism rates usually in heavily infested, dying trees.
- Potentially important behind the EAB invasion wave?

- Biocontrol especially important for ash in forests where insecticides are not an option.
- Production of Asian parasitoids improved.
- Successful establishment in many sites.
- *Tetrastichus* appears to be a good disperser.
- Interest in additional species for introductions?
- Research underway on VOCs to attract Asian wasps.
- Native parasitoids, especially *Atanycolus cappaerti*, becoming more common – learning to find EAB?

Atanycolus cappaerti

- Federal agencies – interest in native parasitoids is generally minimal.
- Whether parasitoids can slow EAB population growth & ash mortality unknown.
- No examples of phloem-feeders regulated by parasitoids or other natural enemies.

Atanycolus cappaerti

EAB – Is the glass half-full or half-empty?

- TREE-äge (emamectin benzoate) provides 2-3 years of highly effective control. Some other products can also be effective if applied annually.
- Blue ash is relatively resistant & likely to survive.
- Asian & native parasitoids may become more important.
- EAB detection remains very difficult.
- We can save some ash trees - but can we save the forest?