

# Dramatic impacts of Emerald Ash Borer Invasion on Ash Demographics

Andrew Liebhold<sup>1</sup>, Randall Morin<sup>2</sup>, Songlin Fei<sup>3</sup>, Samuel Fahrner Ward<sup>3</sup>

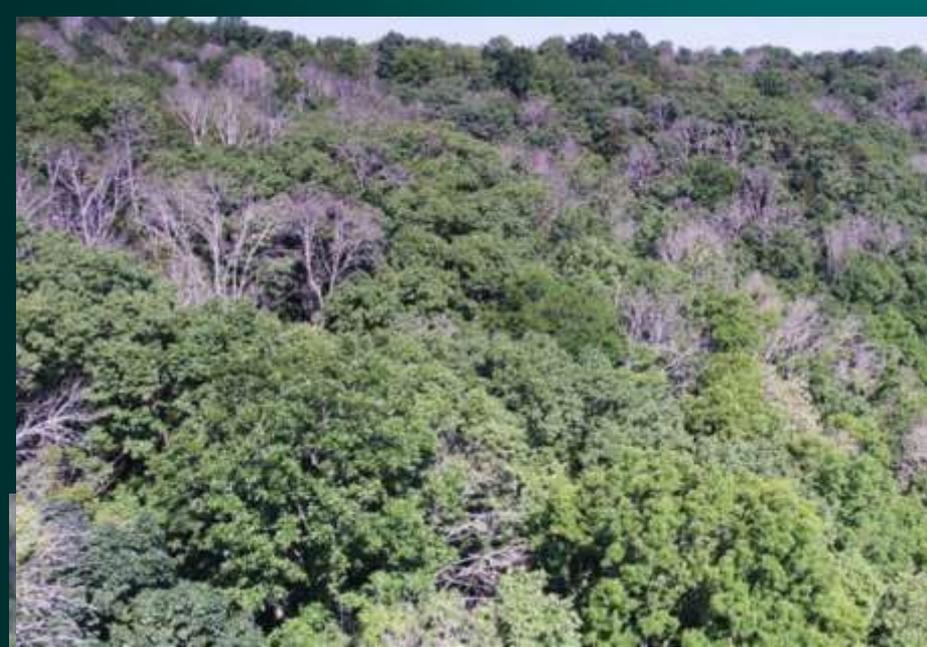
<sup>1</sup> Czech Univ. Life Sciences Prague, Czech Republic

<sup>2</sup> US Forest Service Northern Research Station, USA

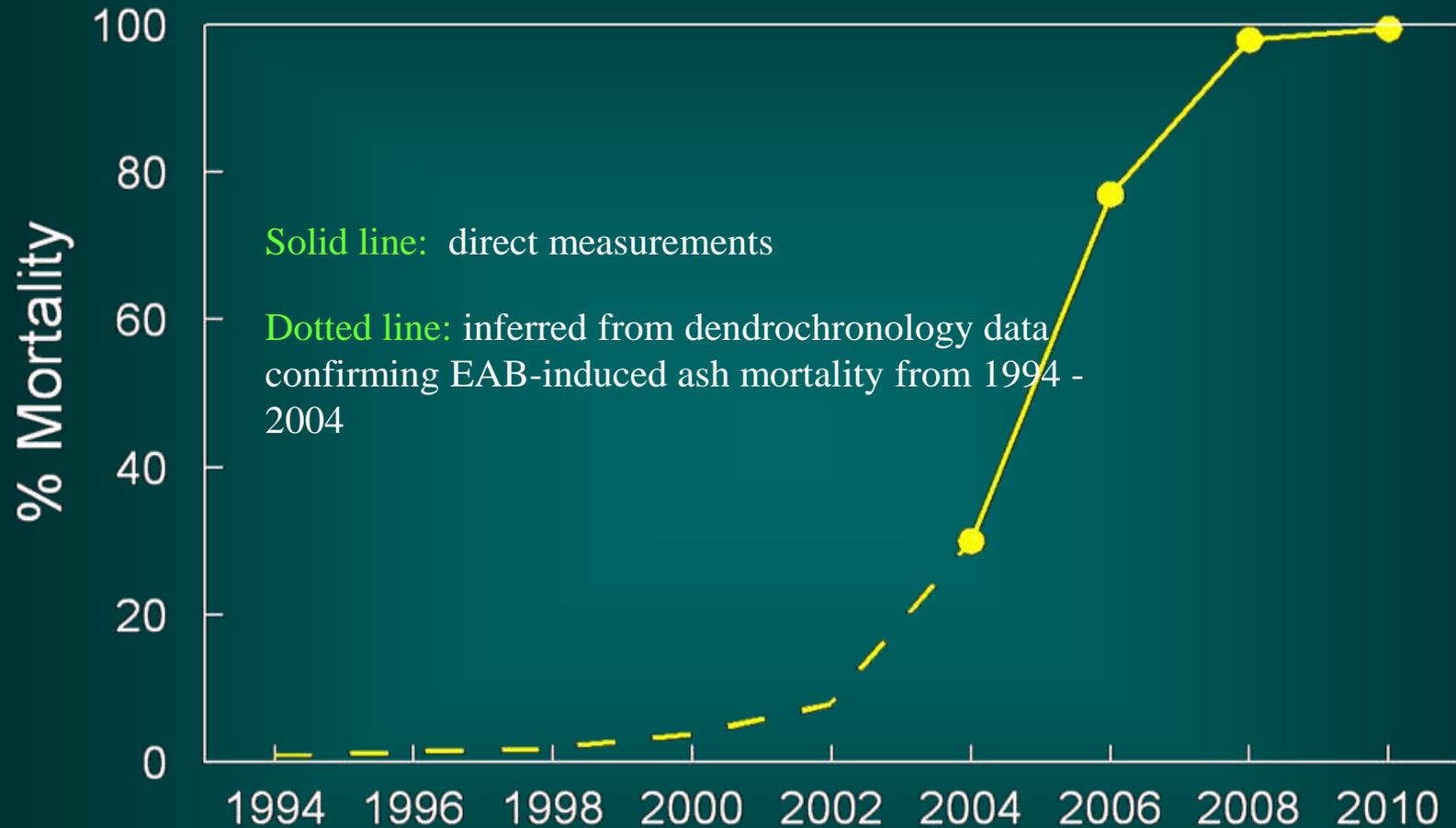
<sup>3</sup> Dept. Forestry and Natural Resources, Purdue University, USA



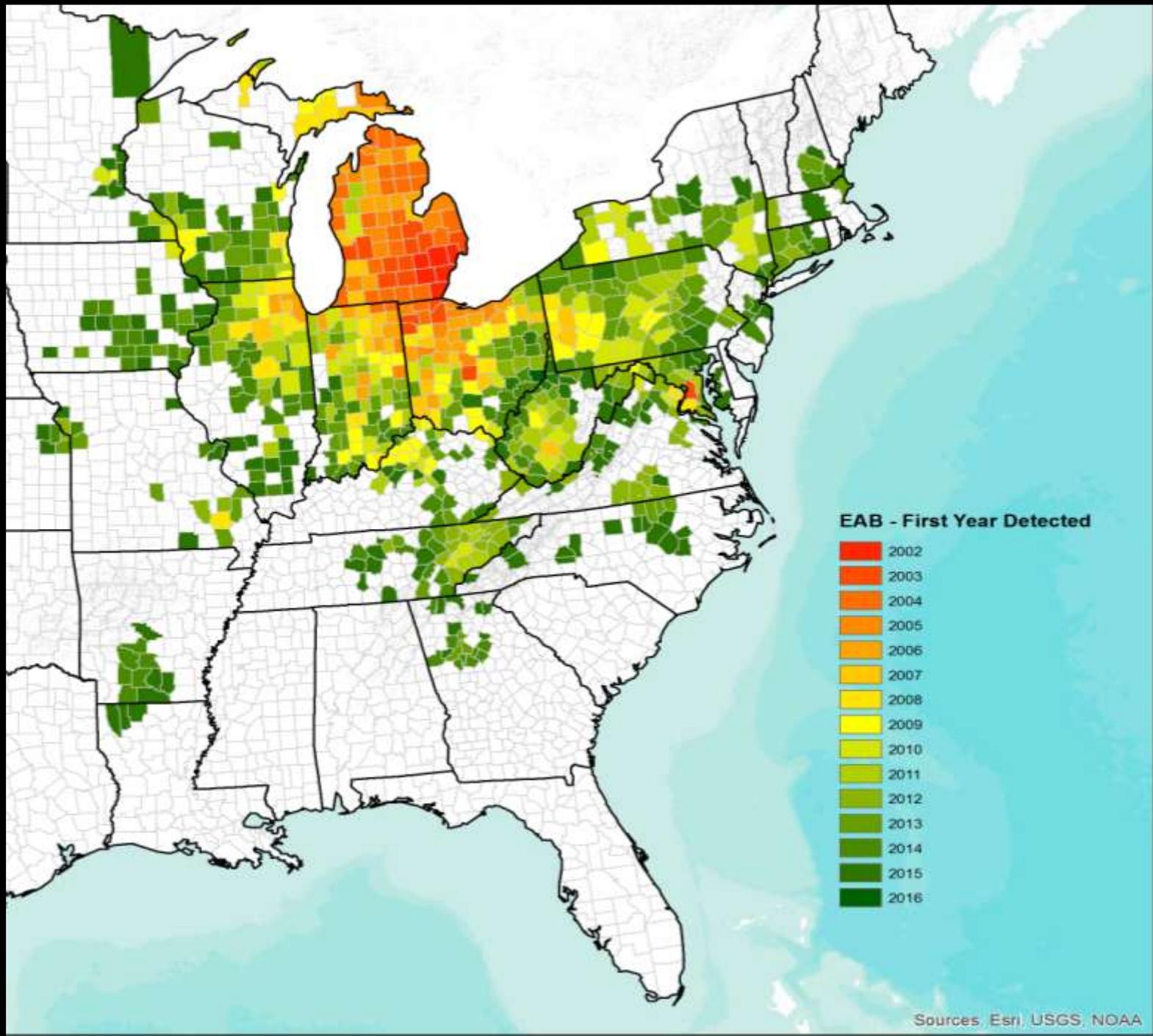
# Emerald ash borer has killed millions of trees in North America



# EAB-Induced Ash Mortality in the Upper Huron River Watershed, SE Michigan (Trees > 2.5 cm DBH)



Klooster WS, Herms DA, Knight KS, Herms CP, McCullough DG, et al. 2013. Ash (*Fraxinus* spp.) mortality, regeneration, and seed bank dynamics in mixed hardwood forests following invasion by emerald ash borer (*Agrilus planipennis*). *Biol. Invas.*



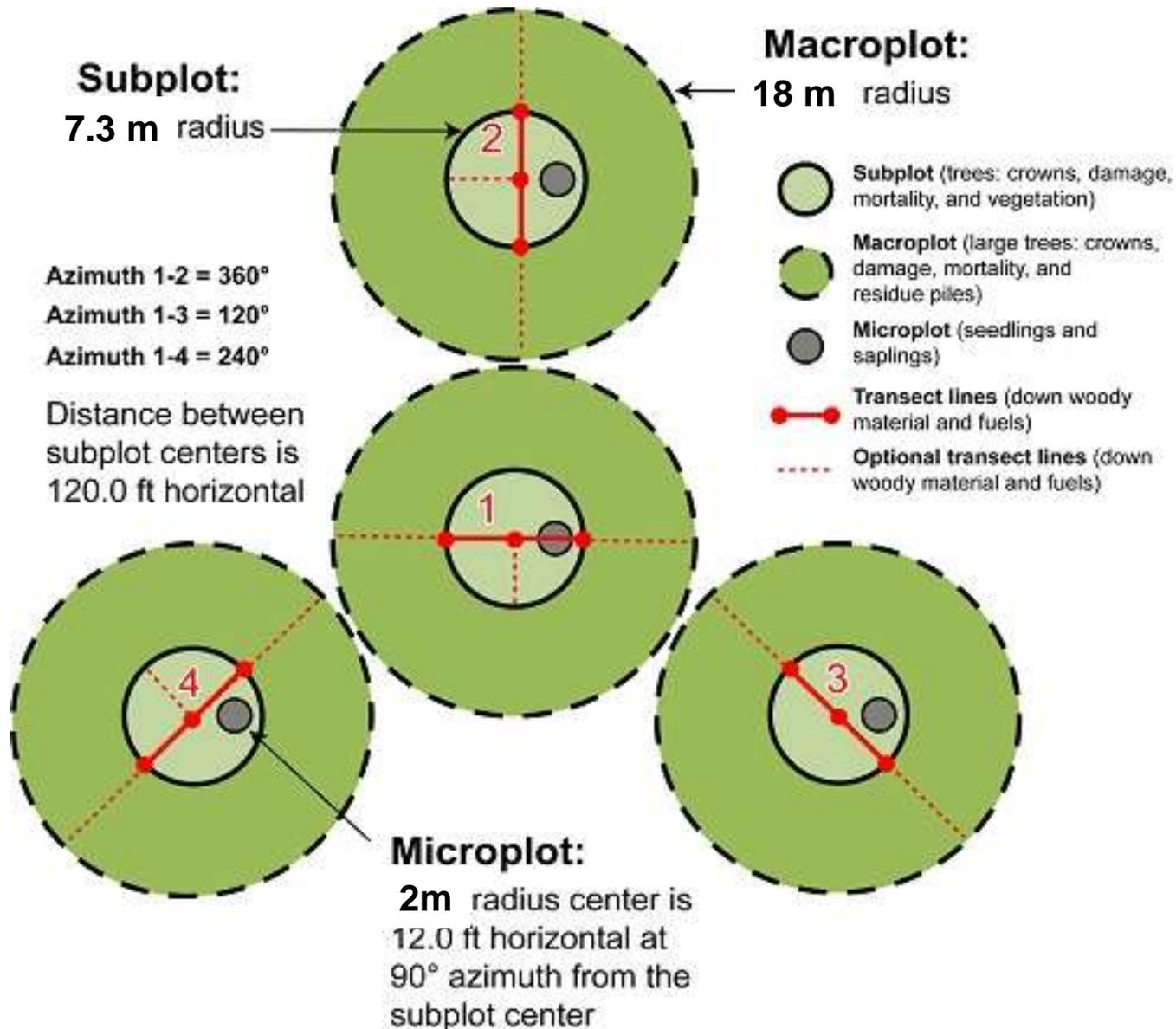
# US Forest Service Forest Inventory & Analysis (FIA)

92,978 Forest Inventory plots

All trees in each 673 m<sup>2</sup> plot remeasured every 5 years



# FIA Plot Design

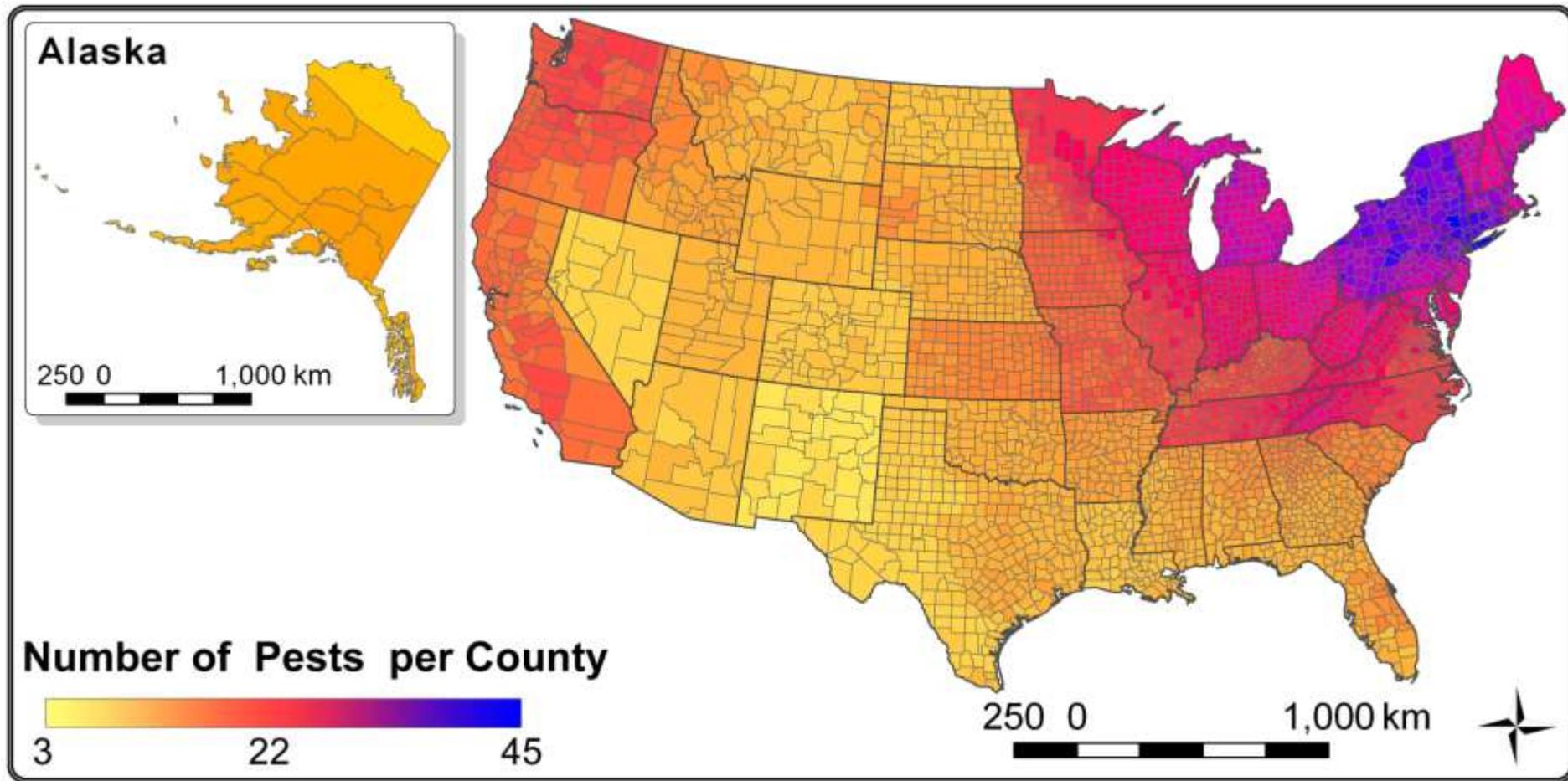


# Tree mortality is quantified by following the fate of individual trees in FIA plots over successive inventories

$t_1$		$t_2$		$t_3$
2003	→	2008	→	2013
2004	→	2009	→	2014
2005	→	2010	→	2015
2006	→	2011	→	2016
2007	→	2012	→	2017

$$\text{Percent ash mortality} = \frac{\text{m}^3 \text{ ash mortality}(t_2:t_3)}{\text{live ash m}^3 (t_2)}$$

# Numbers of damaging non-native forest pest species are concentrated in the northeastern US



Liebholt, A.M., D.G. McCullough, L.M. Blackburn, S.J. Frankel, B. Von Holle and J.E. Aukema. 2013. A highly aggregated geographical distribution of forest pest invasions in the USA. *Diversity and Distributions* 19, 1208-1216



$$\begin{aligned} \text{Alien pest impact} &= \text{mortality}_{\text{total}} - \text{mortality}_{\text{background}} \\ &= \text{mortality}_{\text{inside}} - \text{mortality}_{\text{outside}} \end{aligned}$$

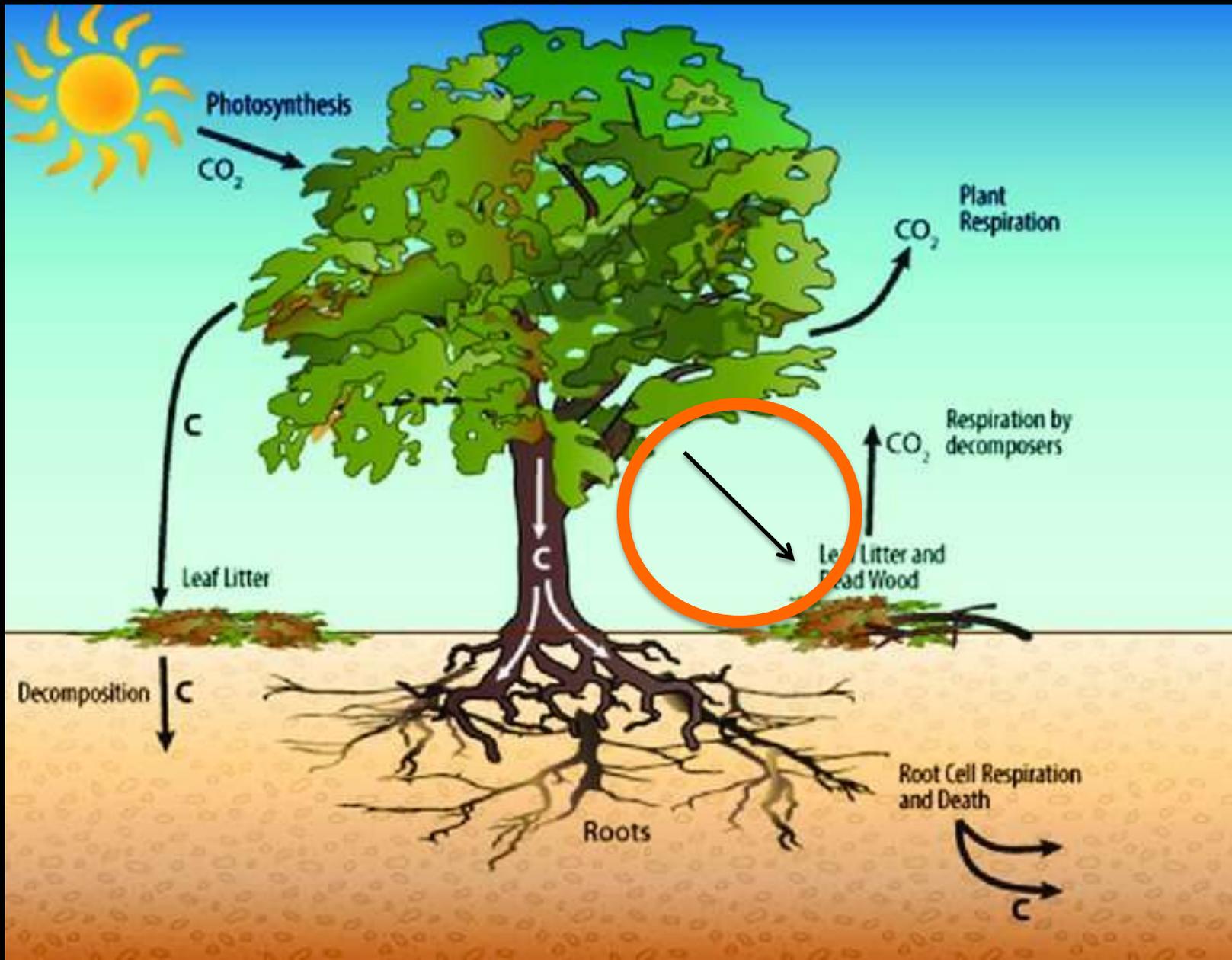
	% of biomass invaded	Annual Host Mortality Rate (% biomass killed / yr)	
		Invaded Range	Un-Invaded Range
<b>Dogwood Anthracnose</b>	<b>29</b>	<b>5.4</b>	<b>5.0</b>
<b>Laurel Wilt Disease</b>	<b>3</b>	<b>10.9</b>	<b>2.6</b>
Green Spruce Aphid	34	1.1	1.9
Balsam Woolly Adelgid	52	1.5	1.9
Gypsy Moth	29	1.2	1.4
<b>Emerald Ash Borer</b>	<b>28</b>	<b>4.1</b>	<b>1.3</b>
White Pine Blister Rust	93	1.0	1.2
Sudden Oak Death	12	1.0	1.1
<b>Beech Bark Disease</b>	<b>57</b>	<b>2.1</b>	<b>0.7</b>
<b>Port-Orford-Cedar Root Disease</b>	<b>91</b>	<b>0.8</b>	<b>0.6</b>
<b>Hemlock Woolly Adelgid</b>	<b>51</b>	<b>1.7</b>	<b>0.5</b>
<b>Red Pine Scale</b>	<b>1</b>	<b>3.2</b>	<b>0.4</b>
<b>Dutch Elm Disease</b>	<b>100</b>	<b>3.5</b>	<b>-</b>
<b>Butternut Canker</b>	<b>100</b>	<b>5.6</b>	<b>-</b>
<b>Chestnut Blight</b>	<b>100</b>	<b>7.0</b>	<b>-</b>
Annual mortality rate of all tree species			1.2%

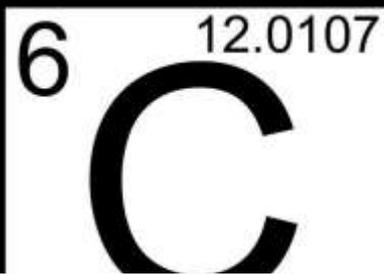
# Pest Induced mortality rate :

$$\text{mortality}_{\text{total}} - \text{mortality}_{\text{background}}$$

	Annual Host Mortality in Carbon (Tg/yr)	
	All US	Pest-Induced
<b>Emerald Ash Borer</b>	<b>6.315</b>	<b>2.323</b>
<b>Beech Bark Disease</b>	<b>2.324</b>	<b>1.301</b>
<b>Hemlock Woolly Adelgid</b>	<b>1.296</b>	<b>0.740</b>
Laurel Wilt Disease	0.564	0.045
Butternut Canker	0.061	0.047
Red Pine Scale	0.222	0.008
Port-Orford-Cedar Root Disease	0.023	0.005
Dogwood Anthracnose	0.166	0.004
Chestnut Blight	0.002	0.002
<b>Dutch Elm Disease</b>	<b>4.041</b>	<b>2.668</b>
<b>TOTAL</b>		<b>7.142</b>

# Forest Carbon Cycle





**5% of total national tree mortality rate**

**0.06% of total forest biomass in US**

**3.3% of annual net forest carbon sequestration**

**Alien pest induced annual mortality rate: 7.1 Tg/yr**

**Mortality rate of all forest species in US: 142.8 Tg/yr**

**Total live forest biomass in the US: 12,643.5 Tg**

**Total annual forest sequestration rate: 385.6 Tg/yr**

**Annual loss from wildfires in US: 107.2 Tg/yr**

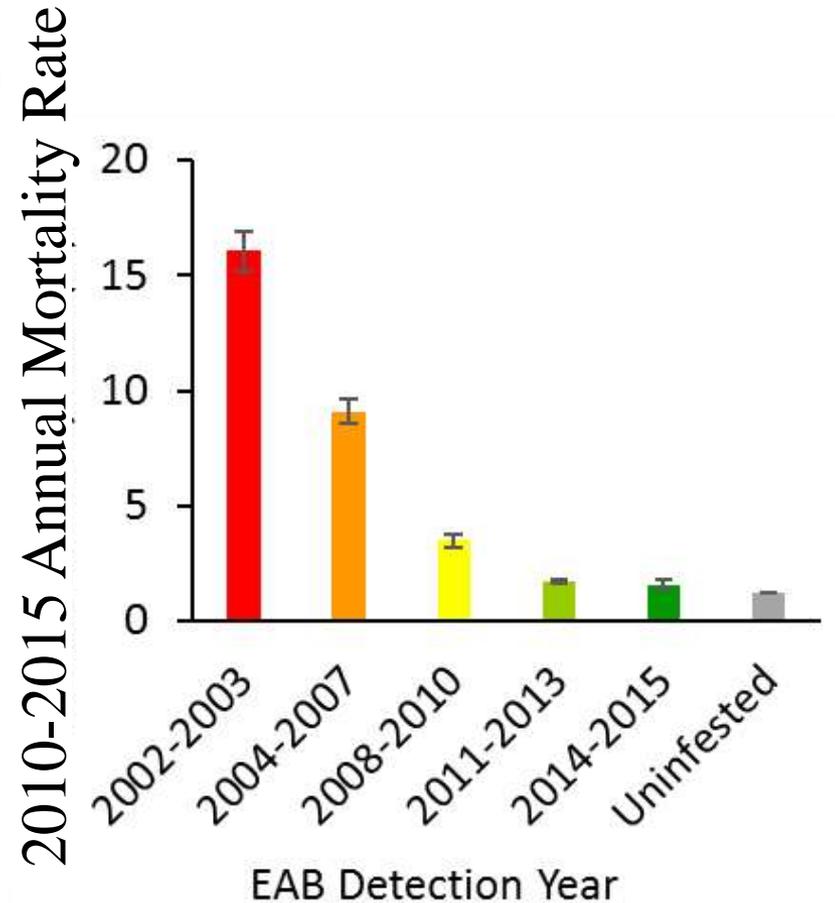
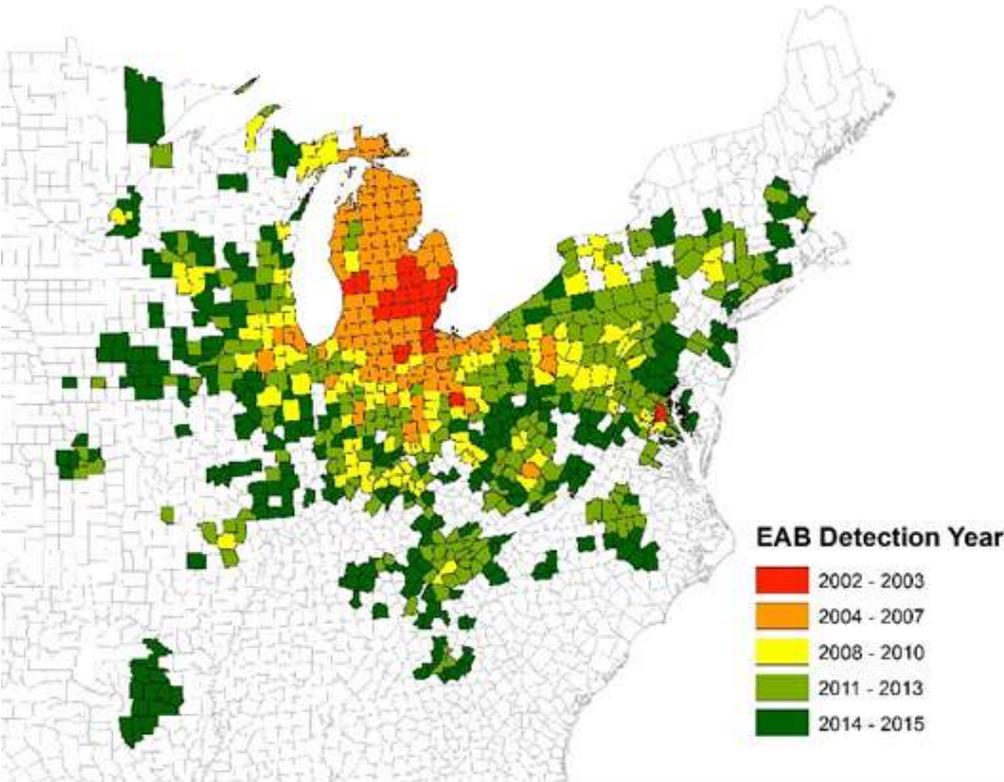
**5,200 Tg (41.1% of total live forest biomass) at risk**

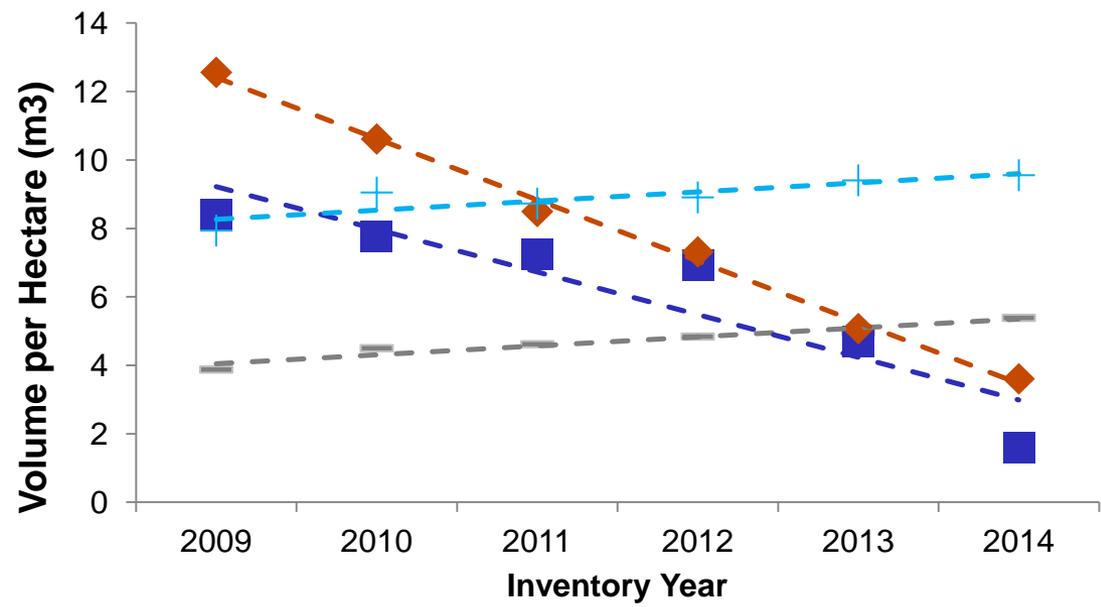
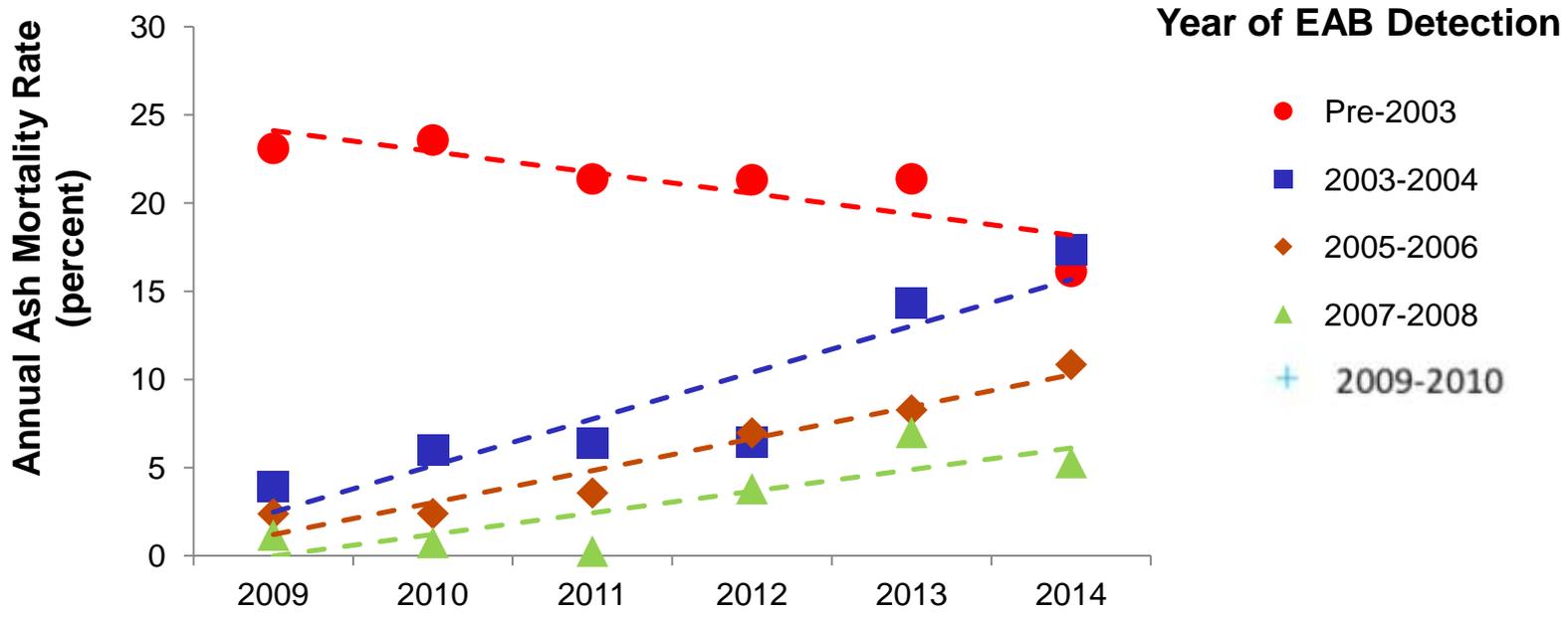
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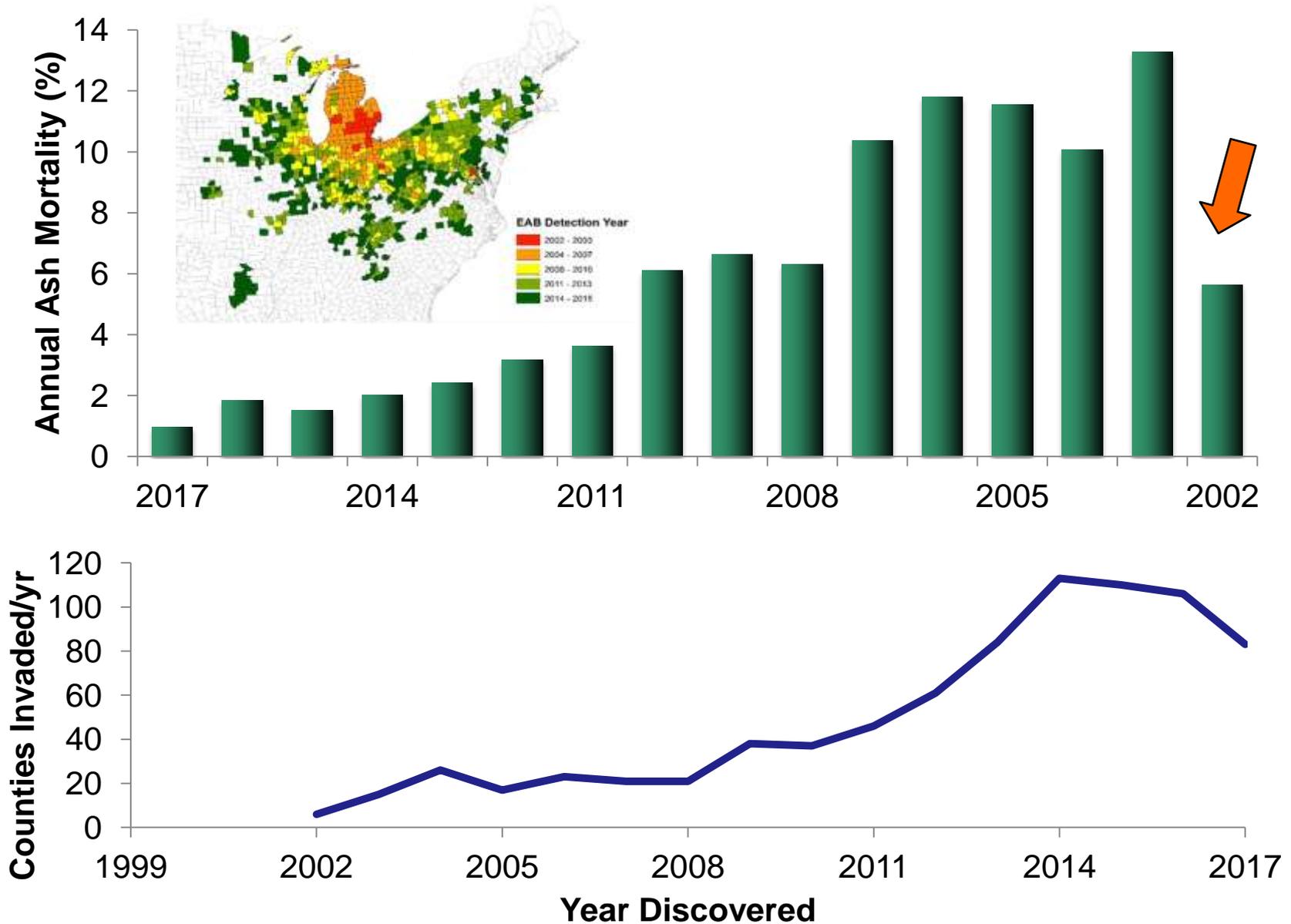
# Annual rate of ash mortality dramatically increases as the time since EAB increases



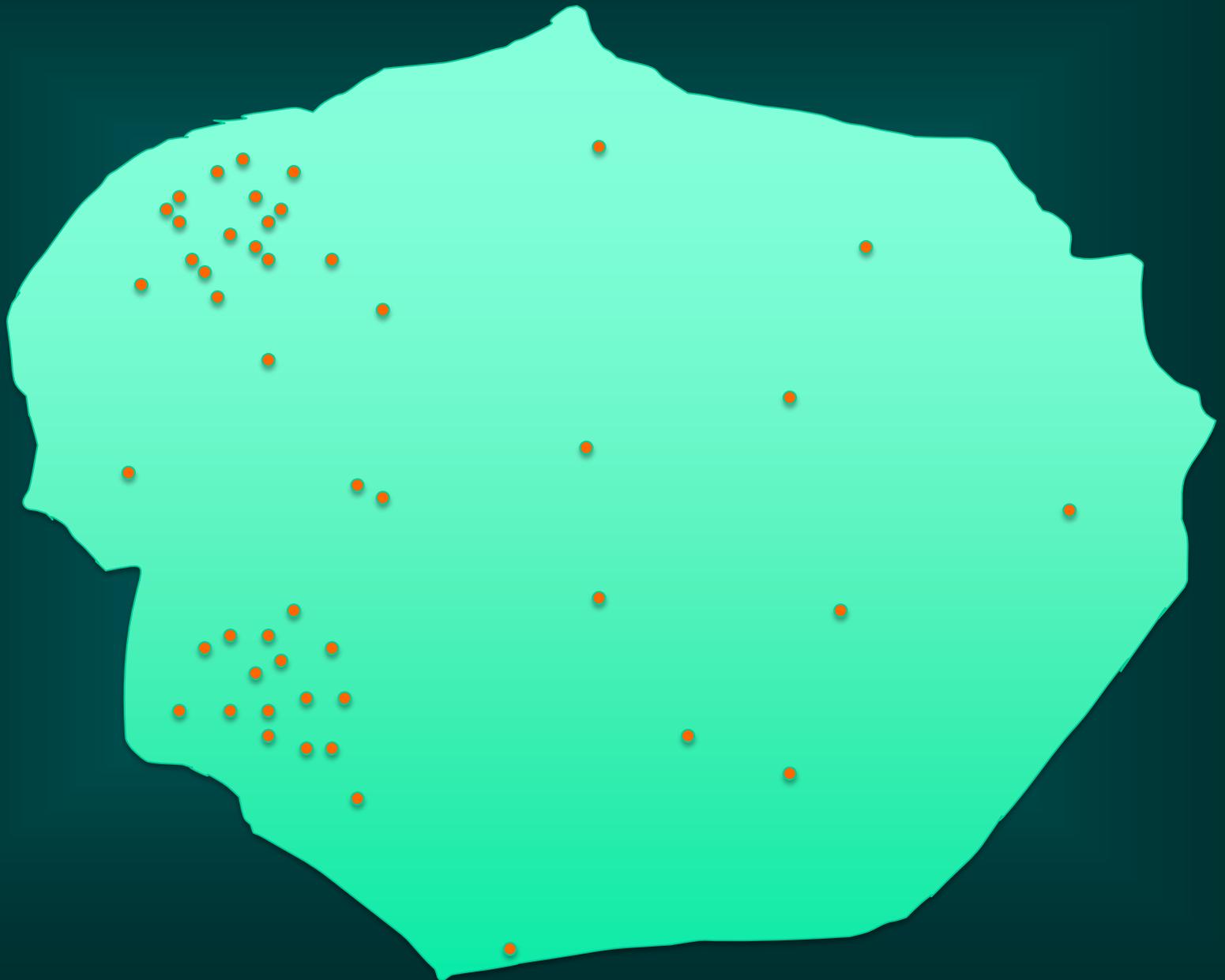


Morin, R.S., A.M. Liebhold, S.A. Pugh and S.J. Crocker. 2017. Regional assessment of emerald ash borer, *Agrilus planipennis*, impacts in forests of the Eastern United States. *Biological Invasions* 19:703-711

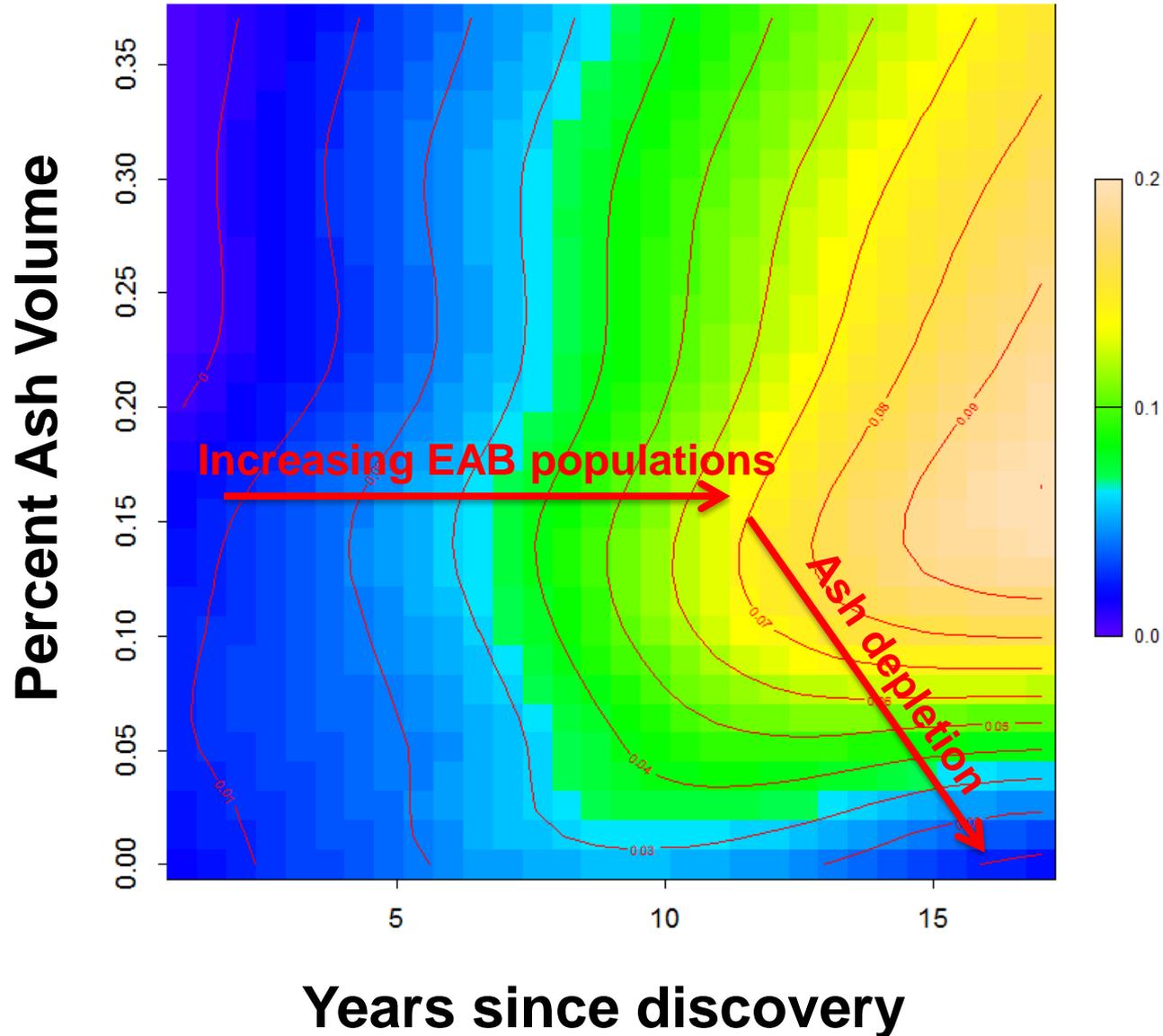
# 2015-2017 mortality rates show decline in annual ash mortality rate as invasion progresses



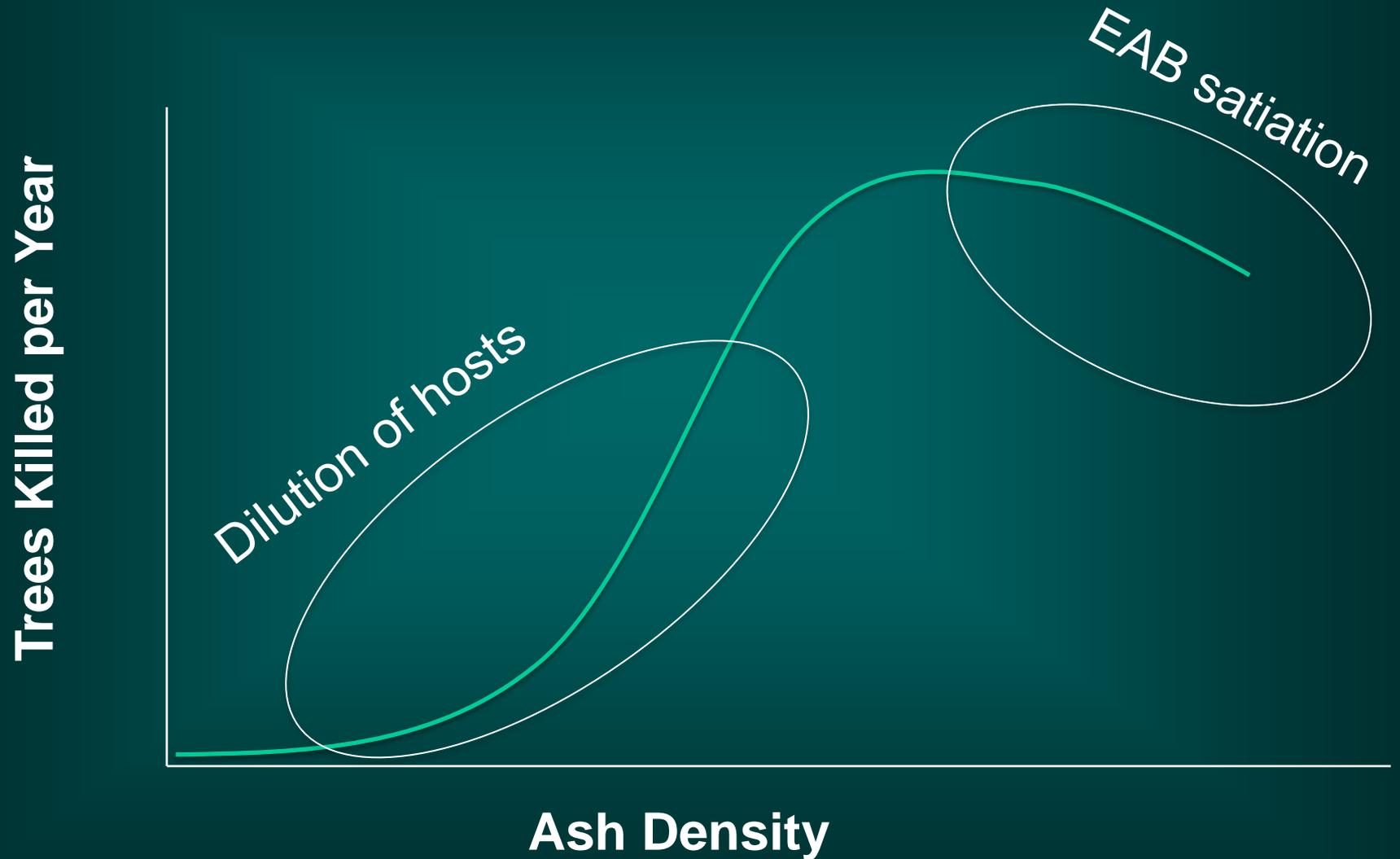
# Regional Variation in ash density



# Annual ash mortality (%) as a function of initial ash density and years since initial detection



# Functional Response of Emerald Ash Borer to Host Ash Density



# Conceptual model of combined numerical and functional Response of Emerald Ash Borer to Host Ash Density



**invasion**

**epidemic**

**equilibrium**

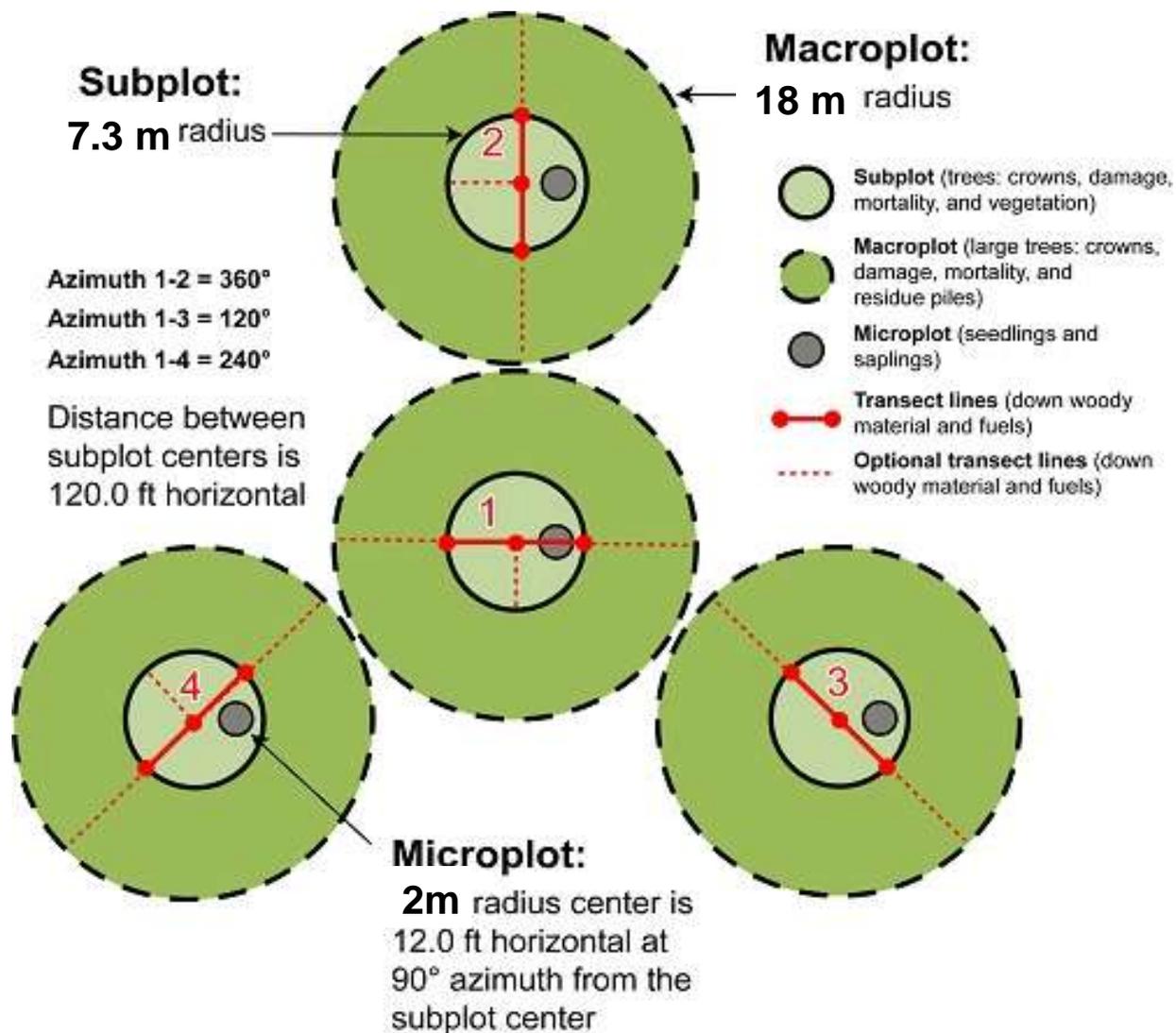


## The “orphaned cohort” of ash and the trajectory of the EAB invasion

### What is the future of N. American Ash?

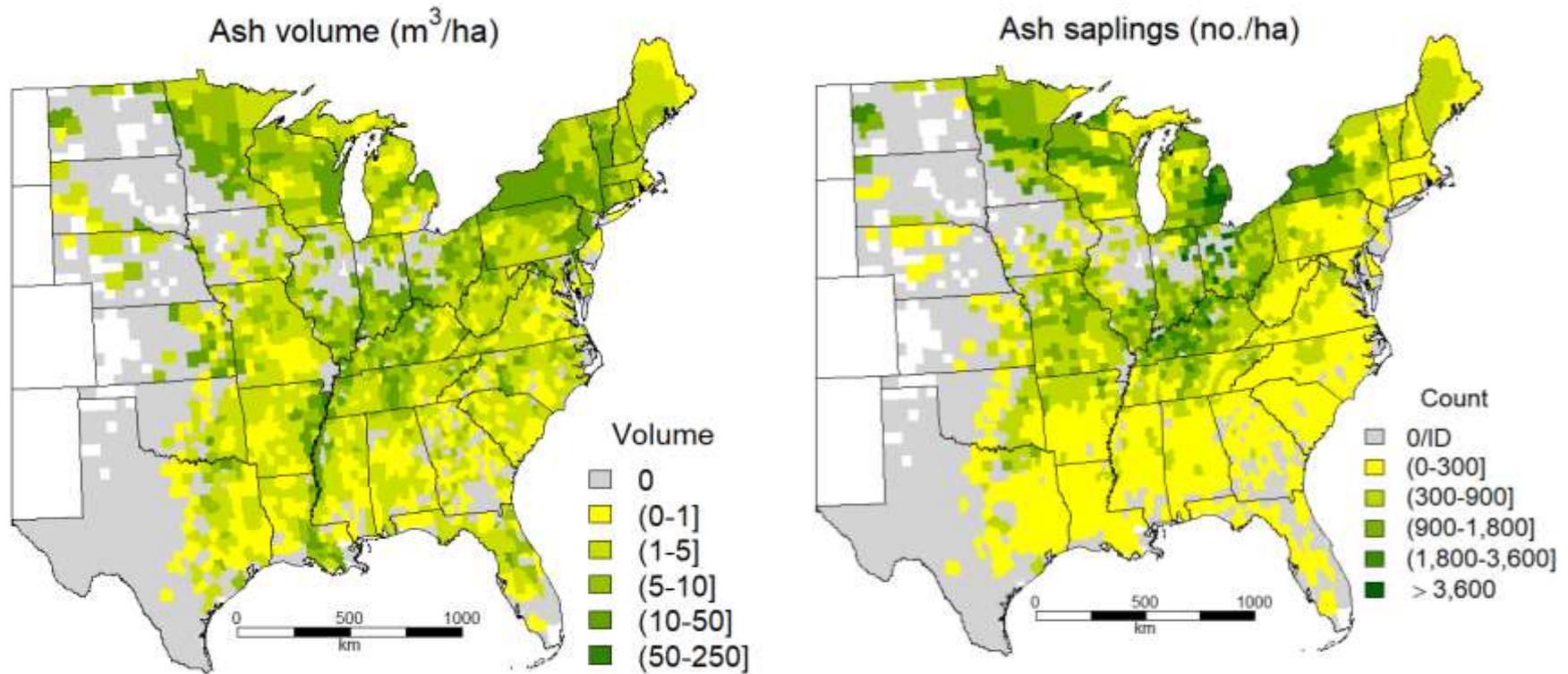
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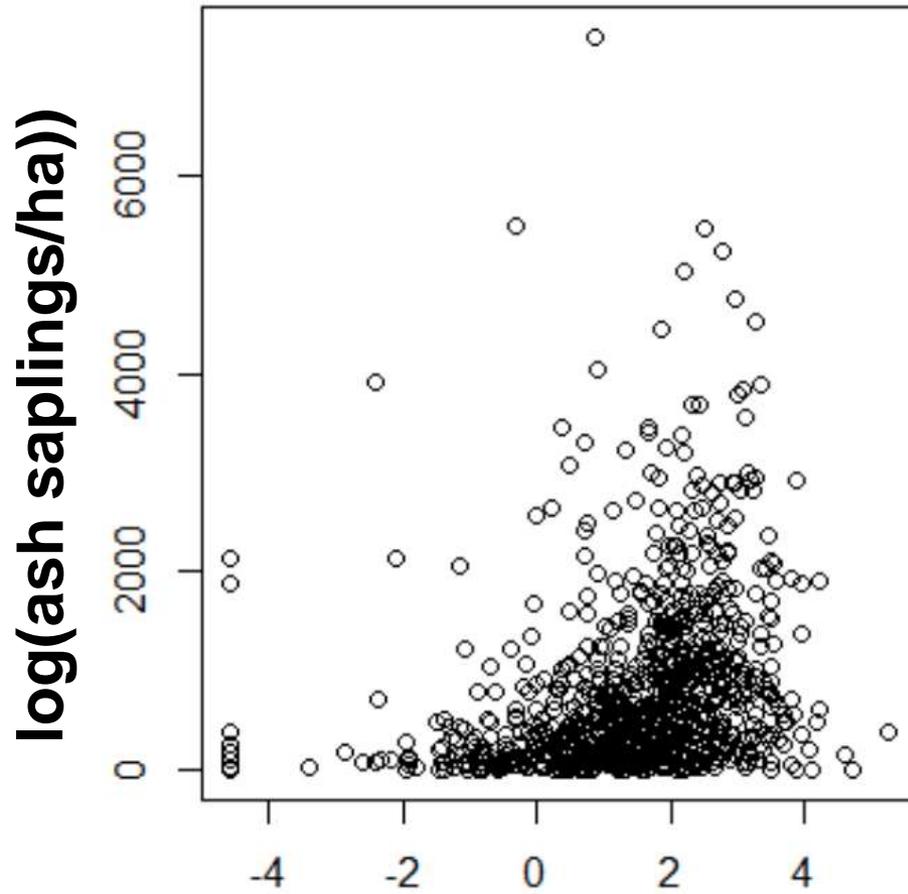
- EAB will persist on a dwindling population of saplings
- Will saplings survive to reproductive maturity?



**Saplings 0.30 – 1.4 m height measured in FIA microplots**

# Geographical distribution of ash saplings similar to that of overstory ash



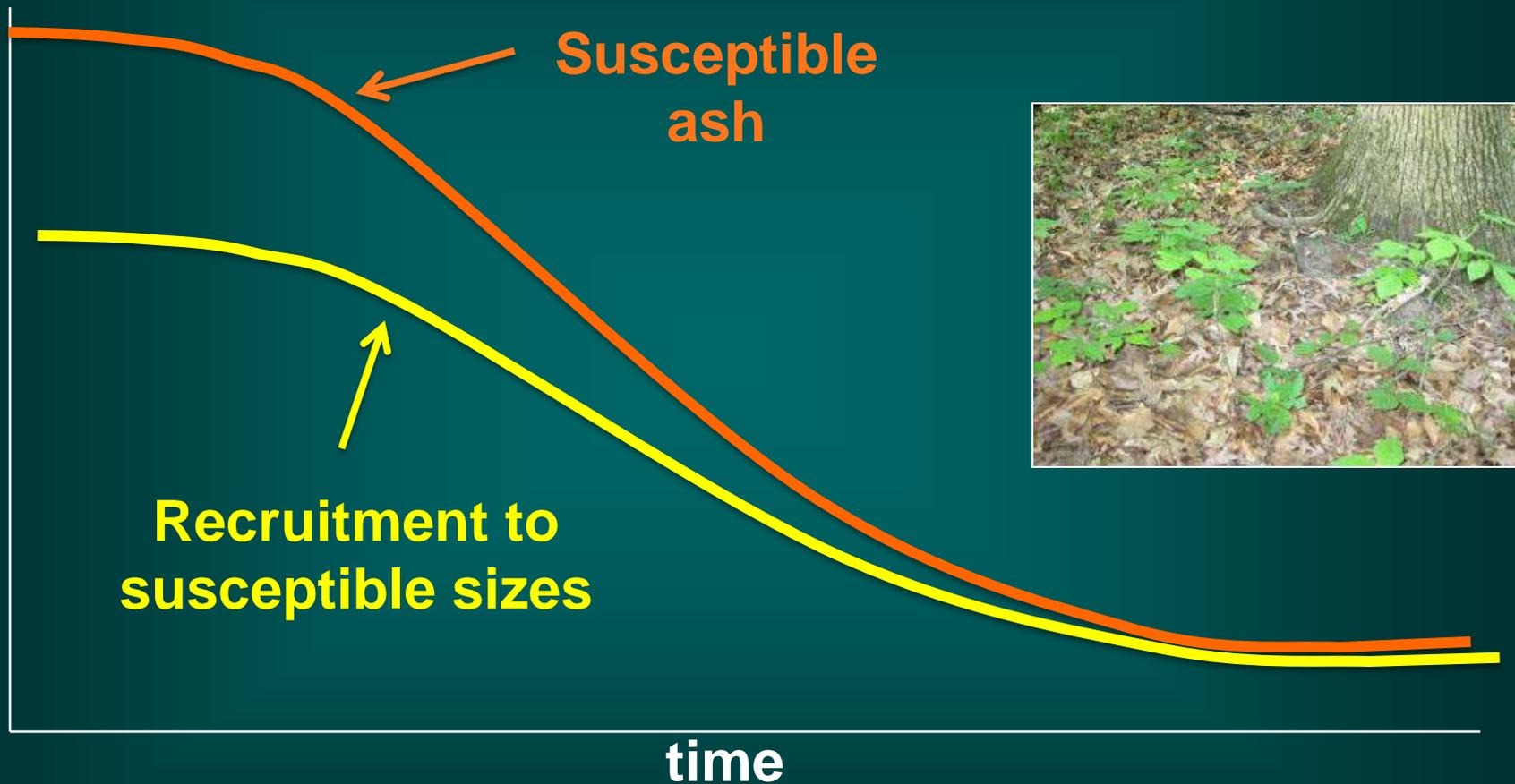


**log(ash volume) (log(m<sup>3</sup>/ha))**

## Model of Ash Density by County

Predictor	Estimate	SE	$ Z $	$P$
Intercept	6.6121	0.5258	12.58	<0.0001
Years since detection	0.0628	0.0150	4.18	<0.0001
Ash density $t_3$	0.1297	0.0306	4.24	0.0014
Max temperature	0.0767	0.0334	2.30	0.0215
Precipitation	-0.0022	0.0005	4.64	<0.0001

# Ash density reaches equilibrium when mortality loss equals sum of growth and recruitment



# Conceptual model of combined numerical and functional Response of Emerald Ash Borer to Host Ash Density



**invasion**

**epidemic**

**equilibrium**