The First International Conference on Arboricultural Biosecurity

How global change abets insect invasions: Case studies of beetles and bugs from the US

Me and my friends are coming to visit. We thrive in urban forests and threaten their resiliency. Here's why.

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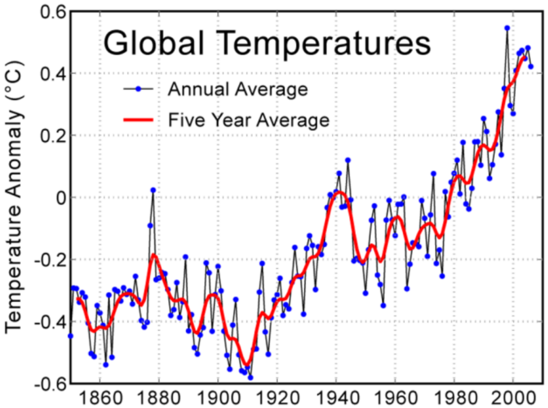
Ohio State University
www.bugoftheweek.com

Three forces of global change threatening arboricultural biosecurity

Invasive species
global economy = global biota



University of East Anglia and the Hadley Centre of the UK Meteorological Office

Climate change – range expansions, more generations of pests

Urbanization – loss and alteration of biodiversity

Is the rate of invasion increasing?

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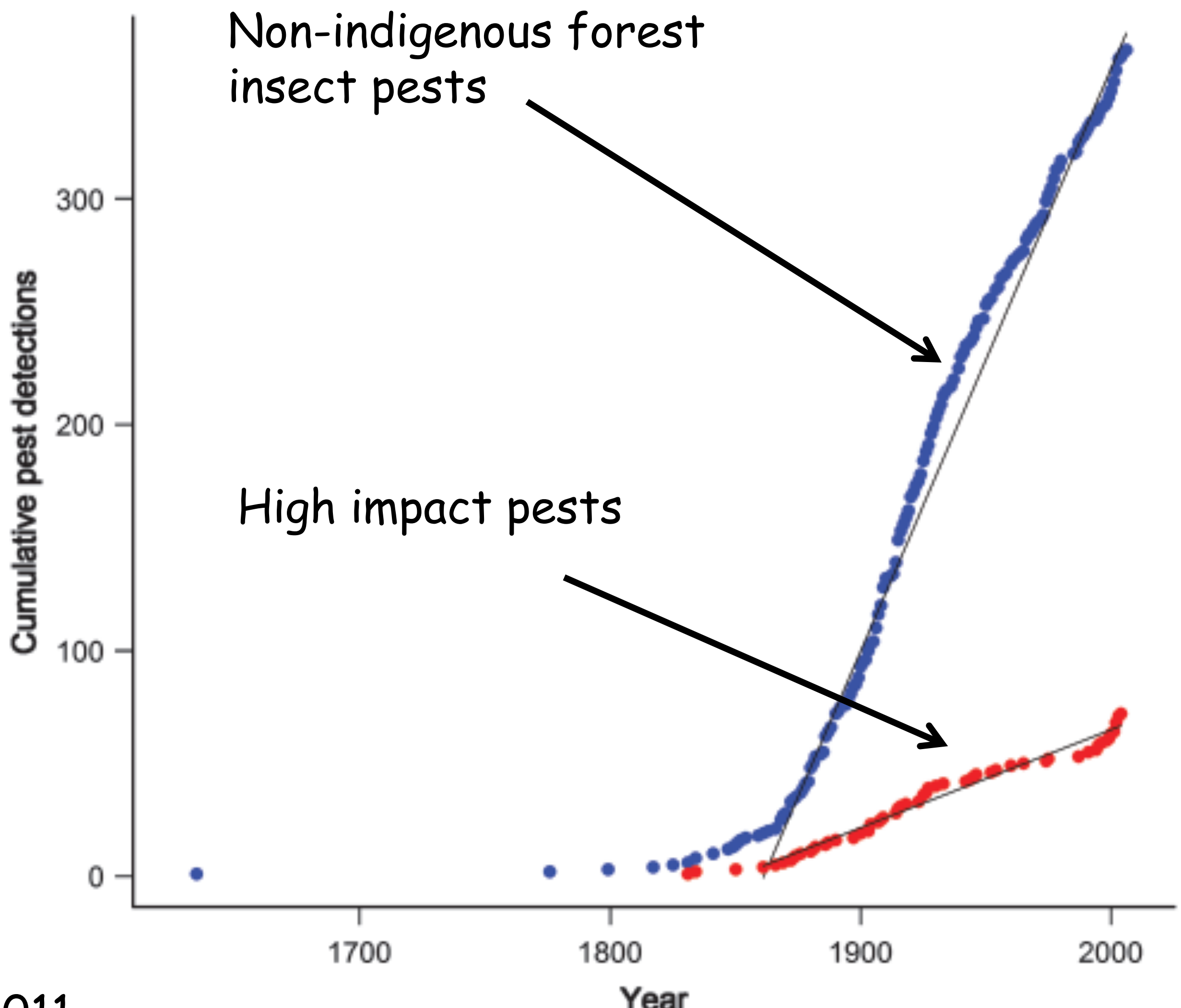


Aukema et al. 2011

Most of our non-native forest pests continue to arrive on shipments of live plants

AM Liebhold *et al.* Forest pest invasions via live plant imports

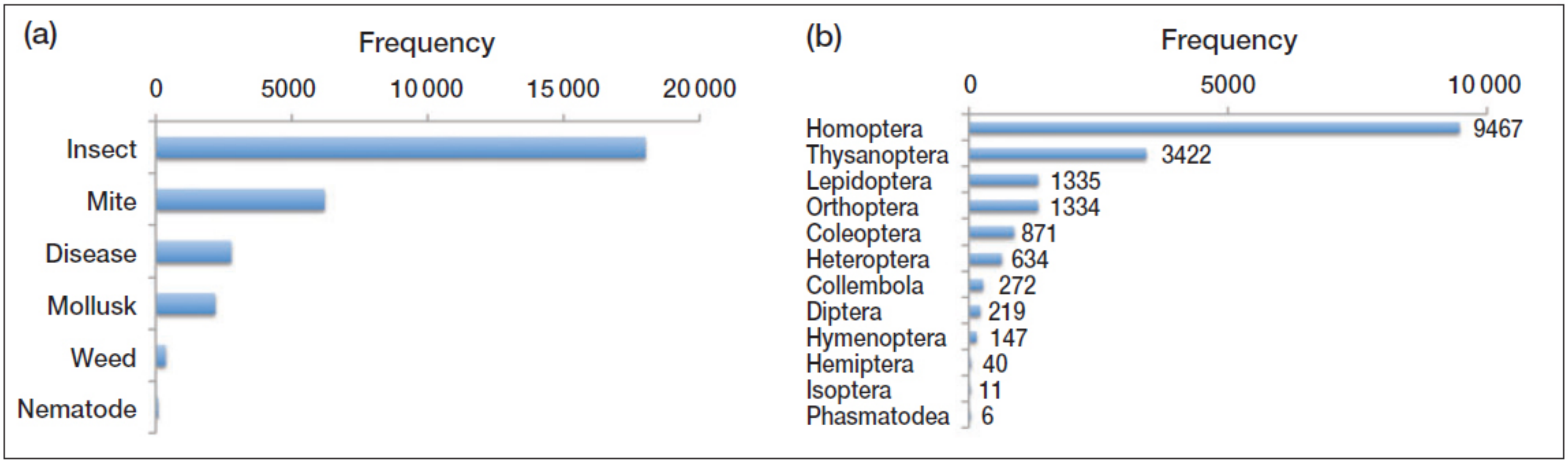


Figure 4. *Frequency (number of shipments infested) and taxonomic characterization of pests detected in shipments of live plants, fiscal years 2003–2010. (a) Types of pests detected. (b) Breakdown among insect Orders.*

Insect invasions in the US come in waves

- 1635 - first tree pest - codling moth – a pest of apples

- 1820 – 1860 - beetles in ballast

- 1860's – urban forest pest, gypsy moth – deliberately introduced

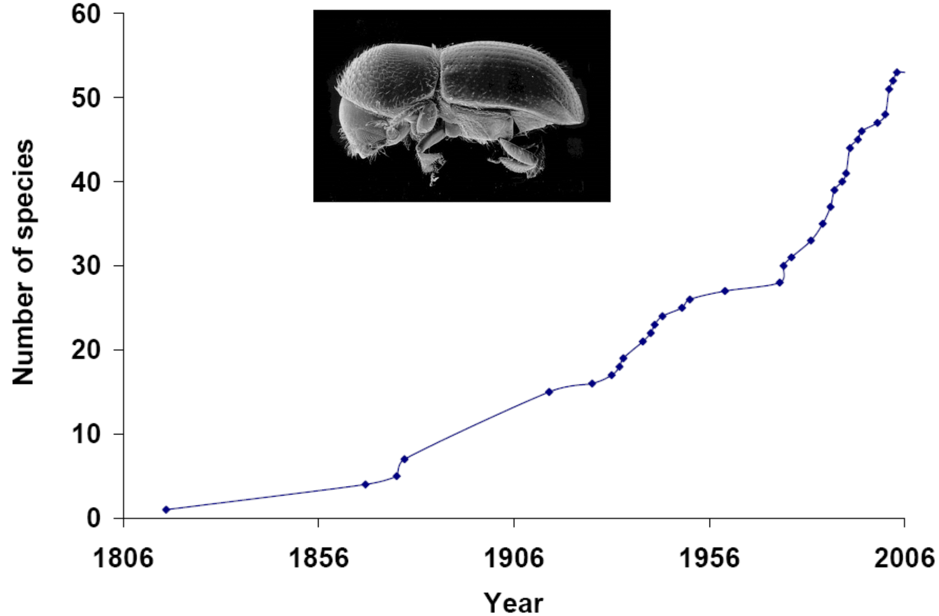
- 1890 - 1930 - many scales arrive

- 1900 – 1930 – aphids dominate

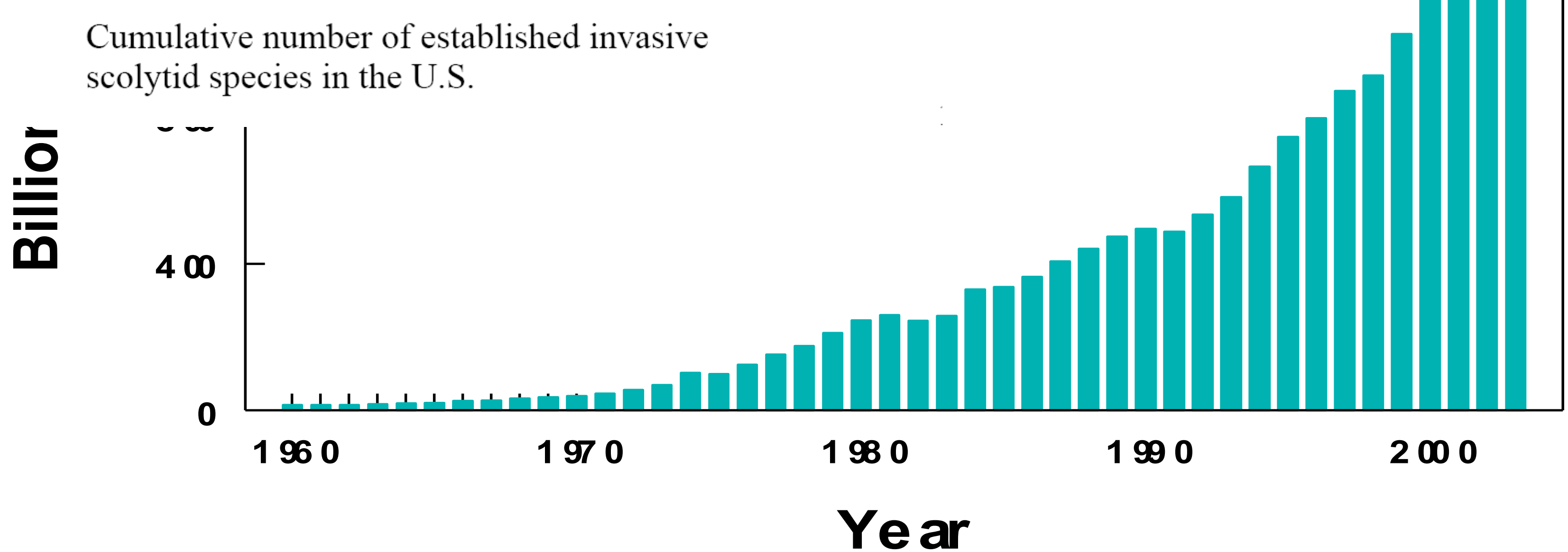
- 1900 – 1940 - foliage feeders including caterpillars, sawflies, and beetles

- 1980 – present - phloem feeding and wood boring beetles – e.g. emerald ash borer, Asian longhorned beetle

Payments - Imports



Cumulative number of established invasive scolytid species in the U.S.



Source, U.S. Census Bureau

- **How do rates of biological invasions by arthropods vary?**

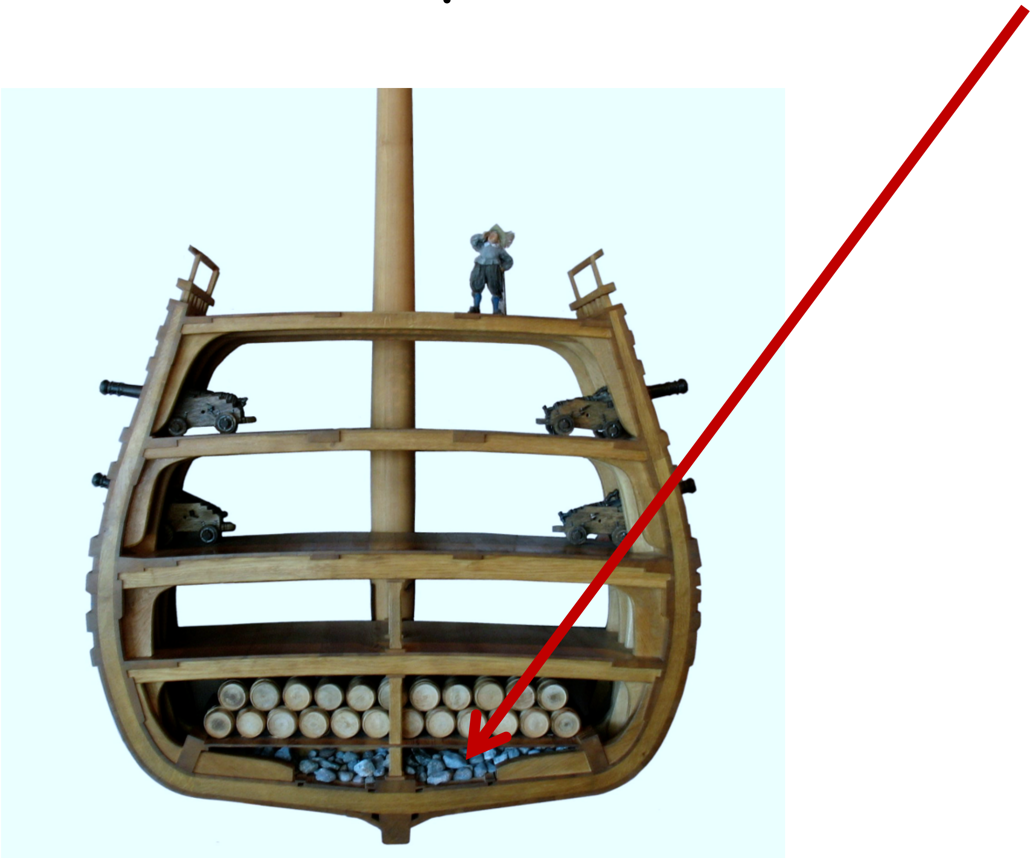
- **For great Britain 20,000 native species and 800 introduced species of insects. Introduced = 4%**
- **South Florida 24% introduced, Hawaiian Islands 25% introduced, Kerguelen Islands 38% introduced**
- **California acquires around 6 invasive species per year, Hawaii and Florida acquire new species at a rate of around 15 per year.**

Where do most invaders come from?

Most of the exchange has been from Eurasia to other parts of the world – biotic imperialism, humans and invasive species are biotic allies. i.e. humans live with and move other species

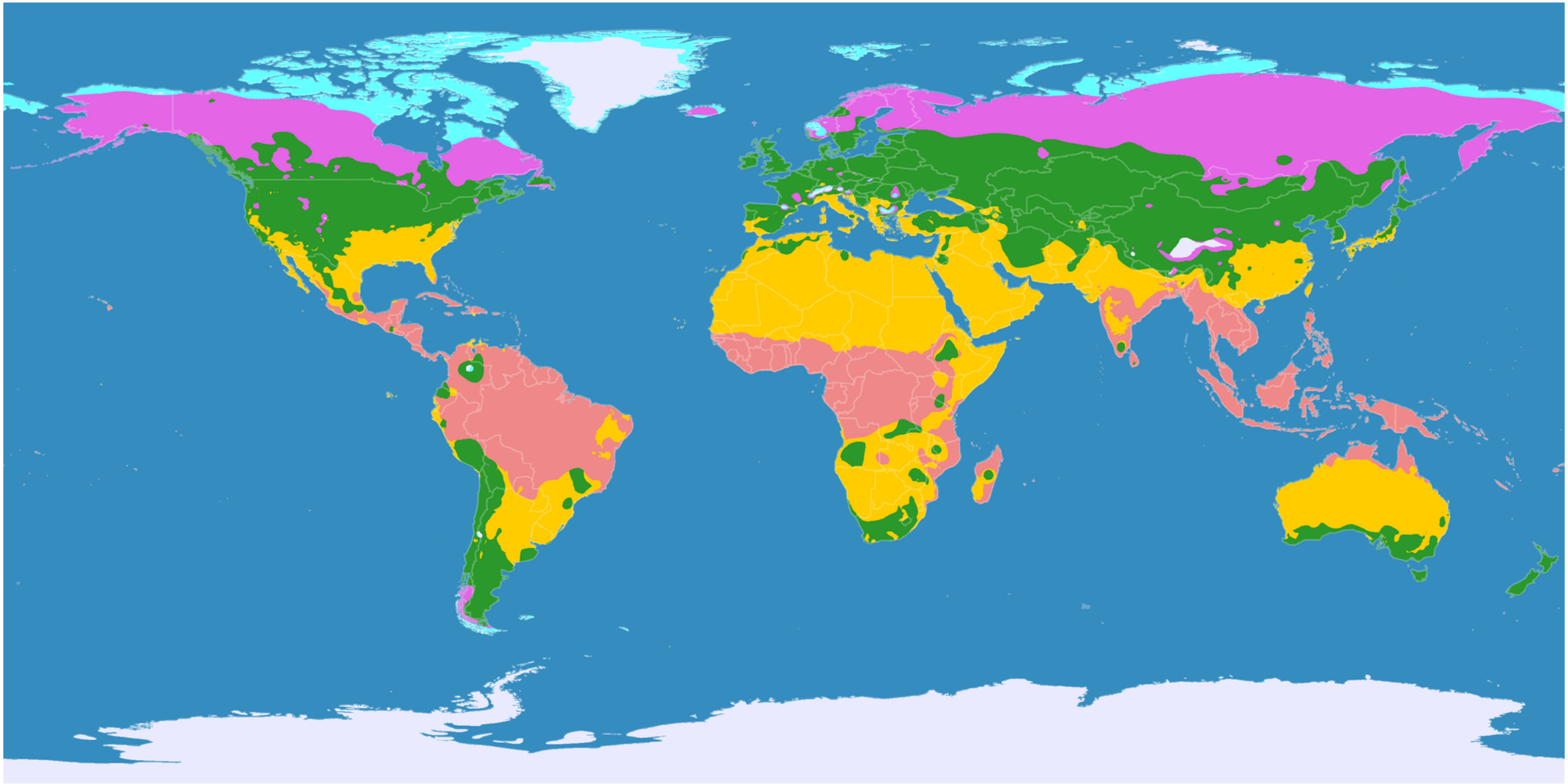
Example - Ground beetles
47 European species established in Canada
0 Canadian species established in Europe

- Propagule pressure – during early times of global trade Europe was the last stopover point before the new world. Ships supplied a steady stream of invaders to North America e.g. ground beetles and other epigeal insects in ballast (soil, stones) of ships



Why do most invaders come from Eurasia?

Many of the invaded regions of the world are temperate zones (in green) and share similar climates with Eurasia



Characteristics of Invader Species and Ecosystems Vulnerable to Invading Species

Characteristics of Successful Invader Species

- High reproductive rate, short generation time (r-selected species)
- Pioneer species
- Long lived
- High dispersal rate
- Generalists
- High genetic variability

Characteristics of Ecosystems Vulnerable to Invader Species

- Climate similar to habitat of invader
- Absence of predators on invading species
- Early successional systems
- Low diversity of native species
- Absence of fire
- Disturbed by human activities

Some but not all of our worst pests are generalists

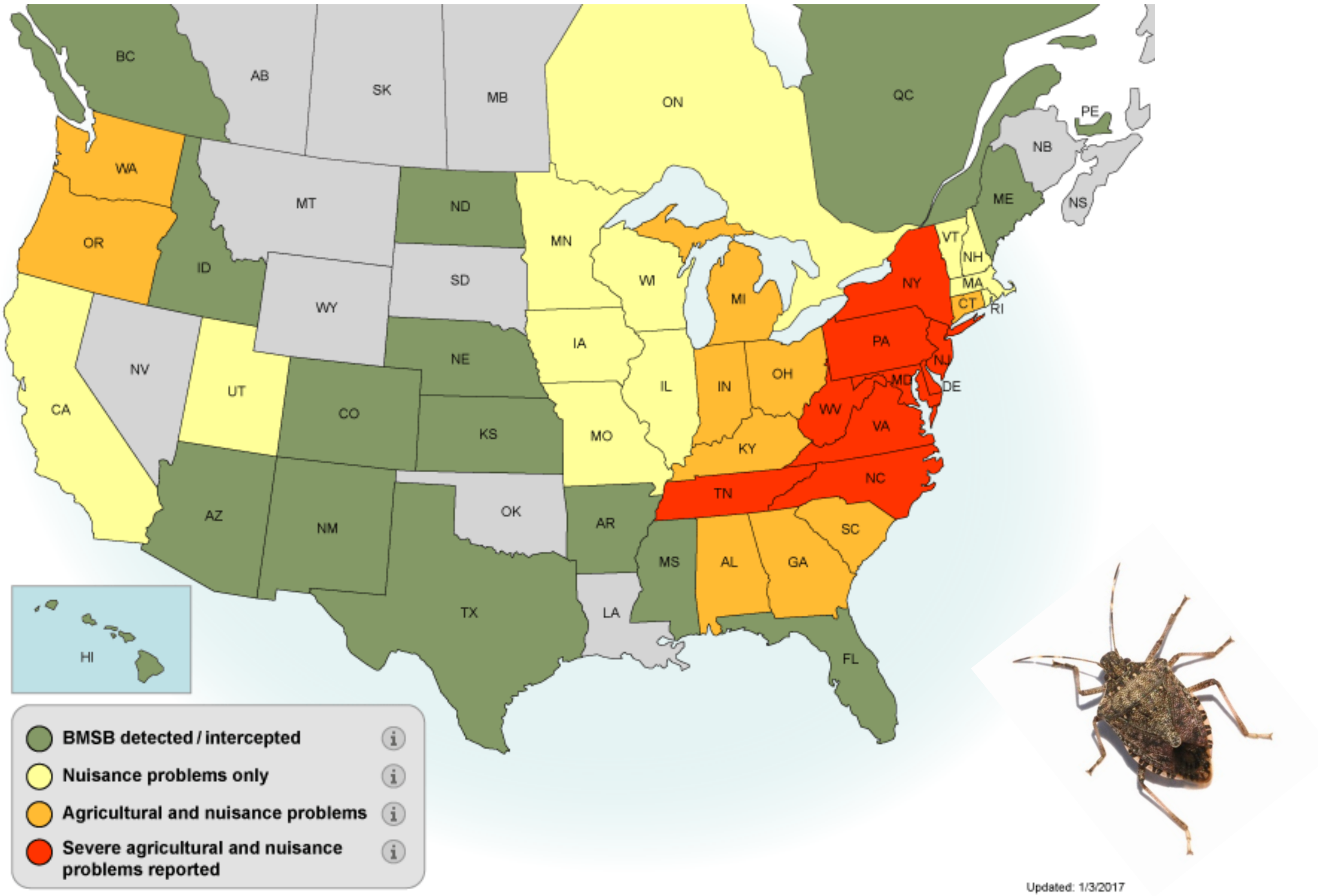








Brown Marmorated Stink Bug arrived in North America in mid-1990s, now in 43 states, 3 provinces



BMSB – an extreme generalist based on dietary breadth

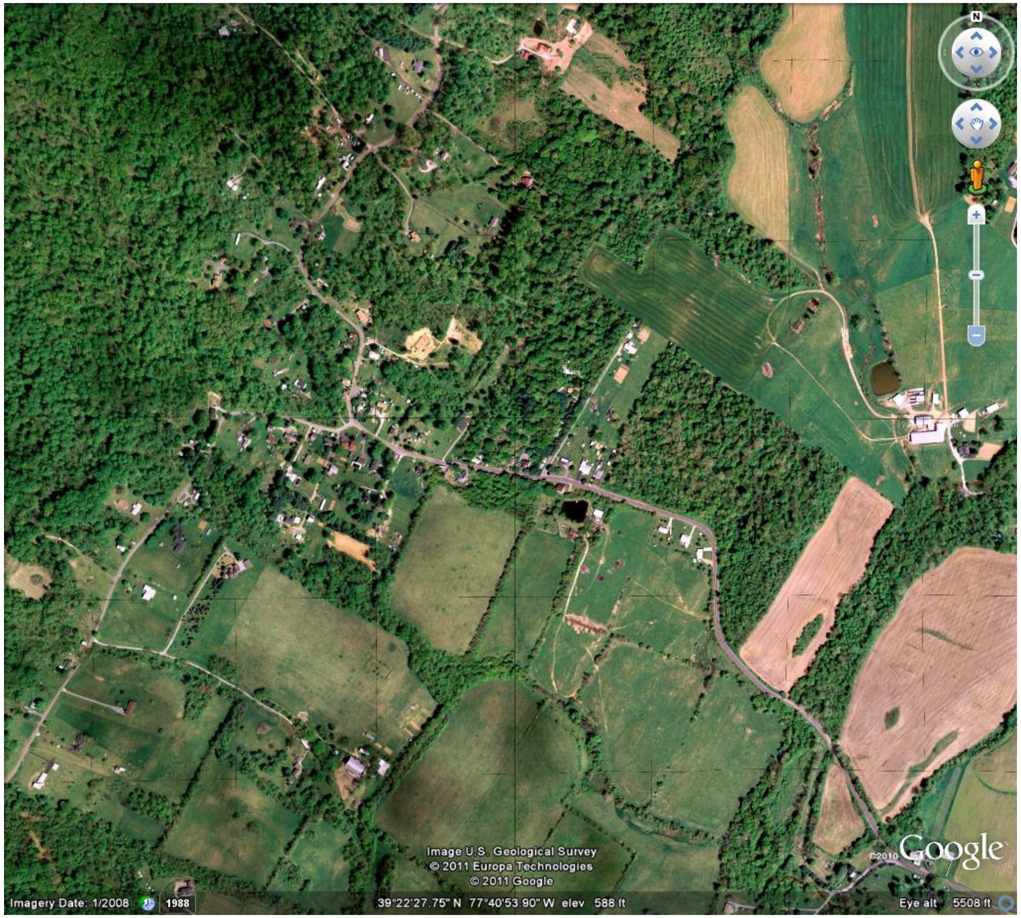
Asia – 106 hosts in 45 families (Lee et al. 2013)

Europe – 51 hosts in 32 families (Haye et al. 2014)

North America

- Virginia – 58 hosts in 33 families (Bakken et al.2015)
- Maryland -216 hosts in 31 families (Bergmann et al. 2016)

Highly vagal – moves miles



Females can lay hundreds of eggs

Photo Doug Inkley

Specialty Crops at Risk to BMSB Damage

HIGH RISK	apple, Asian pear, beans (green, pole, snap), bee-bee tree, edamame, eggplant, European pear, grape[1], hazelnut, Japanese pagoda tree, nectarine, okra, peach[2], Peking tree lilac, pepper, redbud, sweet corn, Swiss chard, tomato	
MODERATE RISK	apricot, asparagus, blueberries[1,3], broccoli, cauliflower, cherry[2], collard, cucumber, flowering dogwood, horseradish, lima bean, littleleaf linden, serviceberry, tomatillo	
LOW RISK	blackgum, carrot, cranberries, garlic, ginkgo, greens, Japanese maple, kohlrabi, kousa dogwood, leeks, lettuce, many gymnosperms, onion, potato, spinach, sweet potato, turnip	
UNKNOWN ?	almond, citrus, hops, kiwi, olive, pistachio, plum, strawberries, walnut	
HOSTS Non-Specialty Crop BMSB Hosts Contributing to Specialty Crops Risk	field corn, soybean	

1—Potential risk of taint/contamination. 2—Additional risk potential due to bark feeding. 3—Considered moderate-high risk.

About BMSB

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is a voracious eater that damages fruit, vegetable, and ornamental crops in North America. With funding from USDA's Specialty Crop Research Initiative, our team of more than 50 researchers is uncovering the pest's secrets to find management solutions that will protect our food, our environment, and our farms.

Learn more at **StopBMSB.org**.

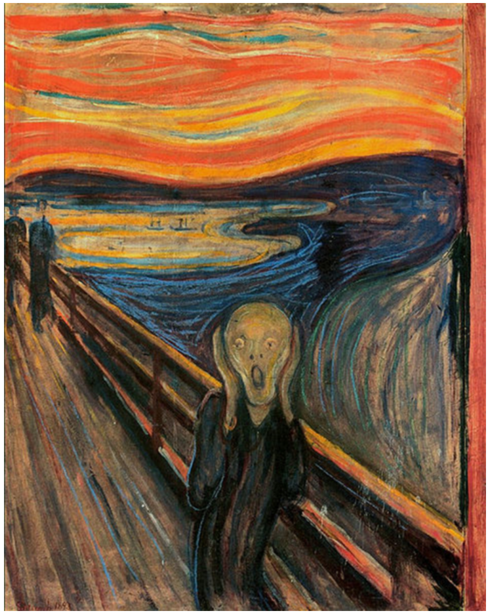
USDA

Funded by USDA-NIFA SCRI Coordinated Agricultural Project, grant #2011-51181-30937. Image credits—sweet corn: Joe Zlomek; eggplant: Howard F. Schwartz, Colorado State University, Bugwood.org; apple, carrots: morguefile.com/creative/bekahboo42; flowering dogwood: Richard Floyd, Creative Ideas LLC, Bugwood.org; blueberries, cauliflower: Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org; ginkgo: Jan Samanek, State Phytosanitary Administration, Bugwood.org; cranberries: Cjboffoli (CC-BY-3.0). Printed May 2015.

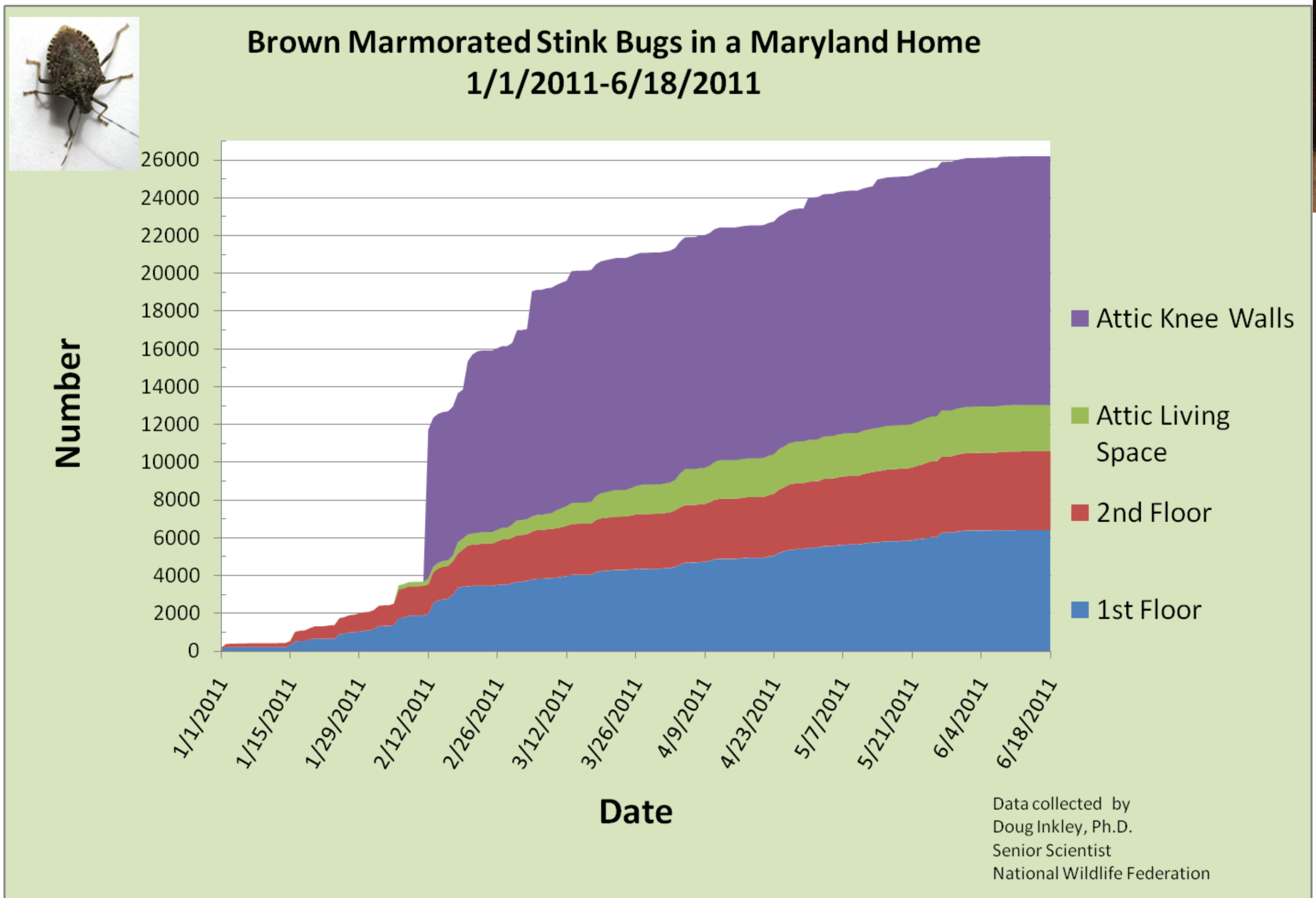
Stop BMSB

BMSB – a new pest of woody plants





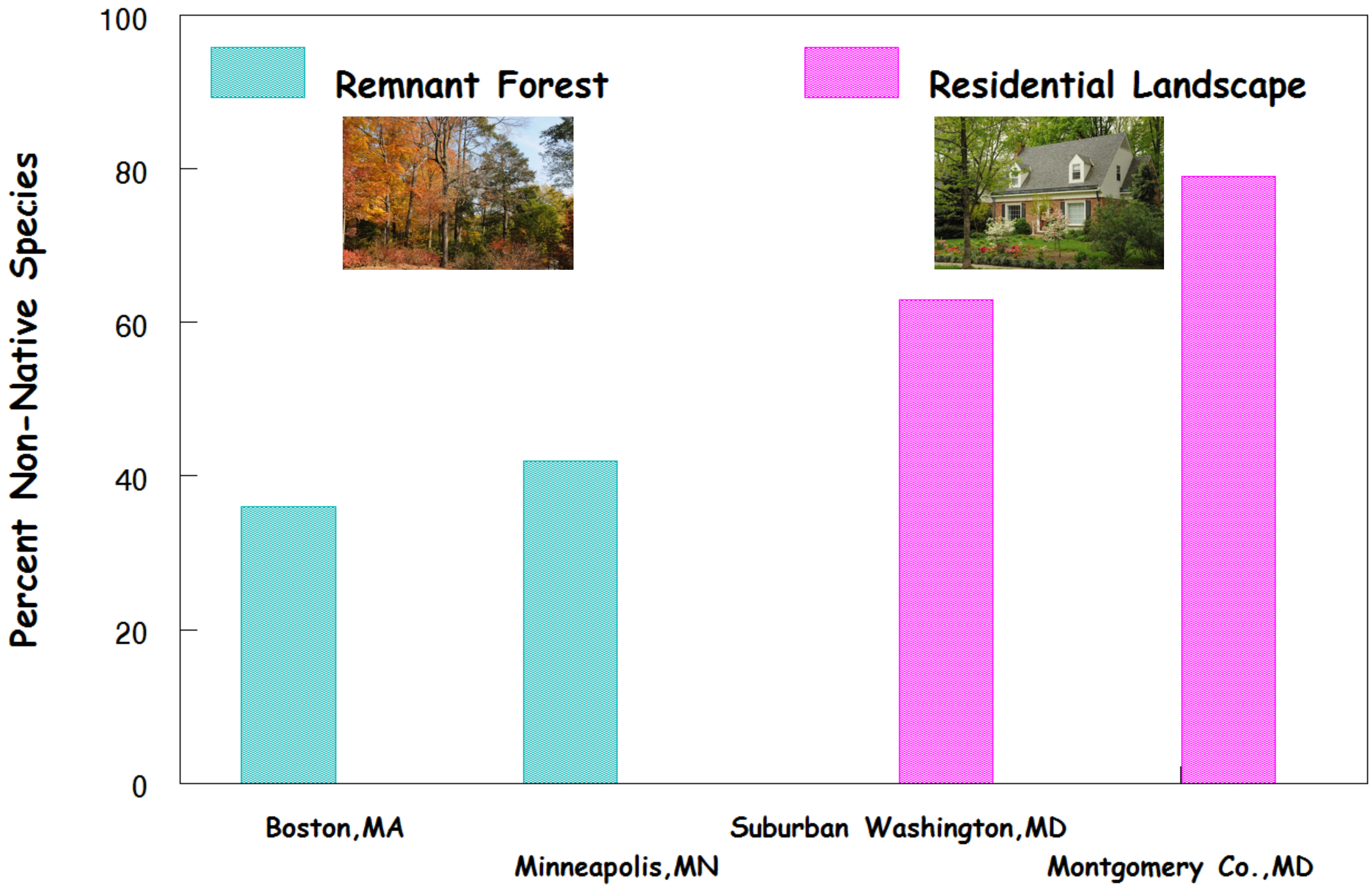
BMSB is a major pest as a home invader – this homeowner spent $ 10,000 on new windows and caulk to exclude stink bugs from his home



Changes that accompany urbanization and threaten resiliency of urban forests

1. Substitution of exotic plants for native plants
2. Lack of plant and animal biodiversity
3. Impervious surfaces – exacerbate climate change, reduce water infiltration, increase stress
4. Anthropogenic inputs of nutrients and pesticides can elevate pest populations

Non-Native Species in Remnant Forests and Residential Landscapes

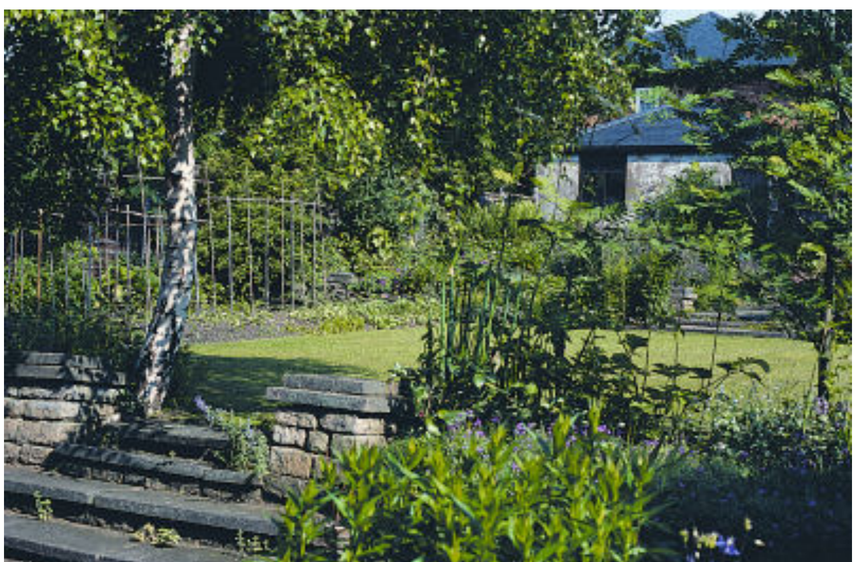


From Dunn and Heneghan (2011), Holmes (1984), Raupp and Riley (Unpublished)

Number of Native and Non-Native Plants found in Leicester Garden

Taxon	Native	Non-Native	Percent Non-Native
Compositae	17	30	68
Labitae	8	11	58
Rosaceae	10	9	47
Cruciferae	5	10	67
Leguminosae	6	8	57
Solanaceae	3	8	72
Onagraceae	2	5	71
Scrophularaceae	5	2	29
Umbelliferae	4	3	43
Grossulariaceae	3	14	82
Saxifragaceae	0	4	0
Salicaceae	3	0	0
Loganiaceae	0	1	0
Total	**66**	**104**	**61**

From Owen 1983



Natives and Exotics in the Coevolutionary Matrix

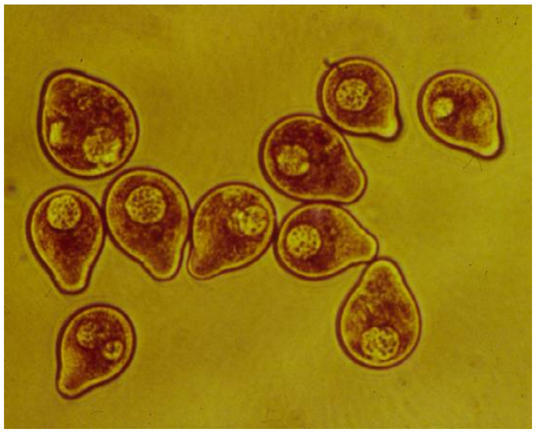
Coevolutionary matrix:

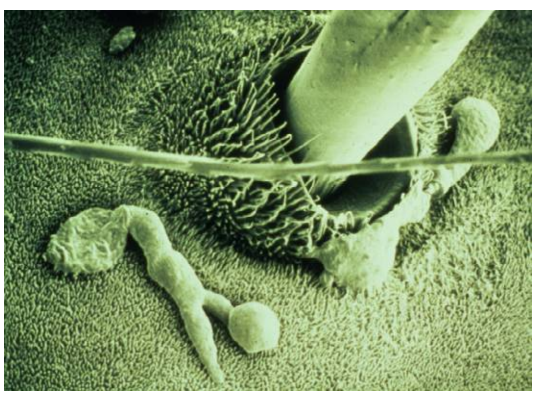
- Native plants / native insects (stable)
- Exotic plants / exotic insects (enemy release)
- Exotic plants / native insects (community simplification; defense free space)
- Native plants / exotic insects (enemy release; defense free space)

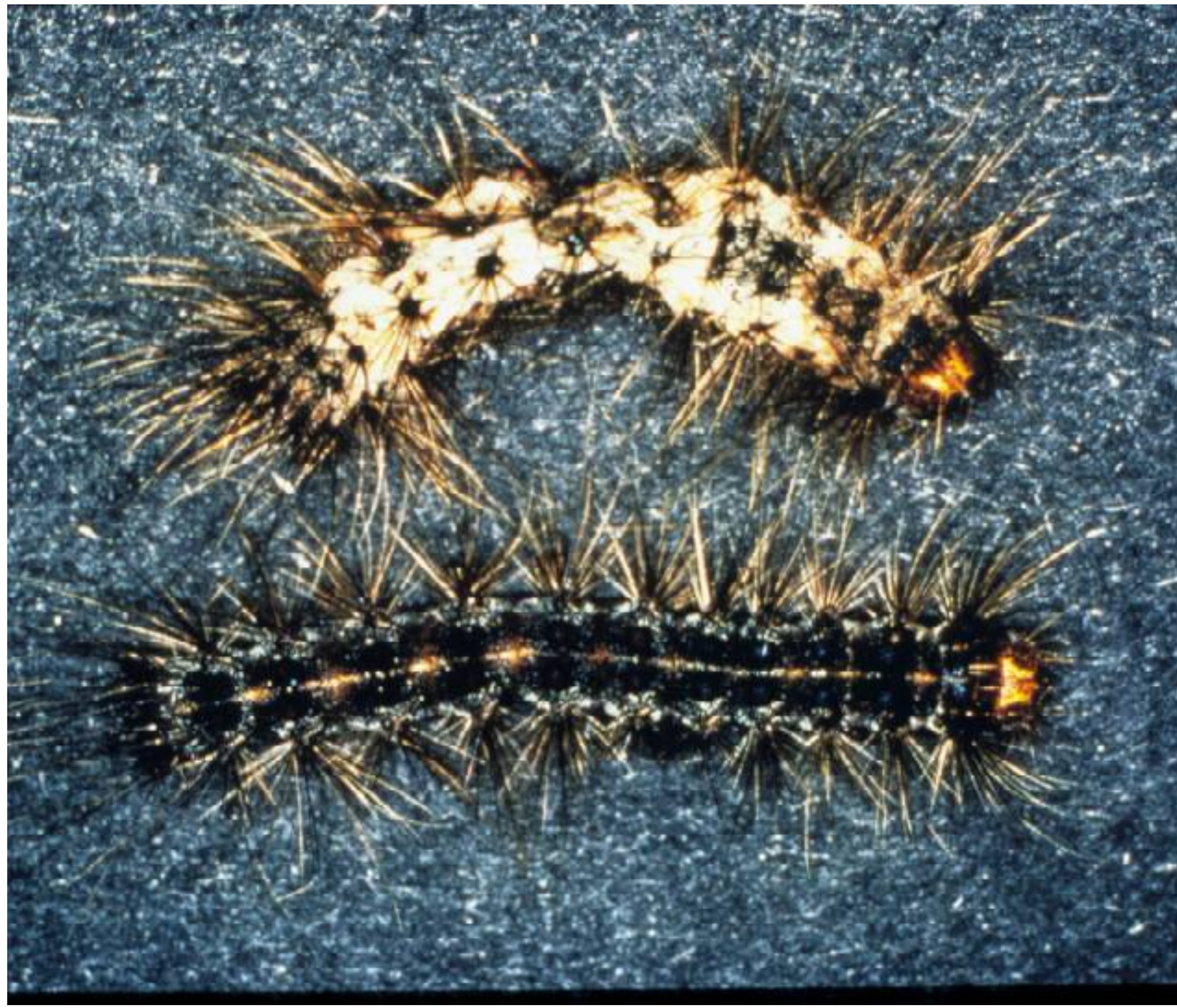
Exotic plants / exotic insects (enemy release)

How do we know it's enemy release?

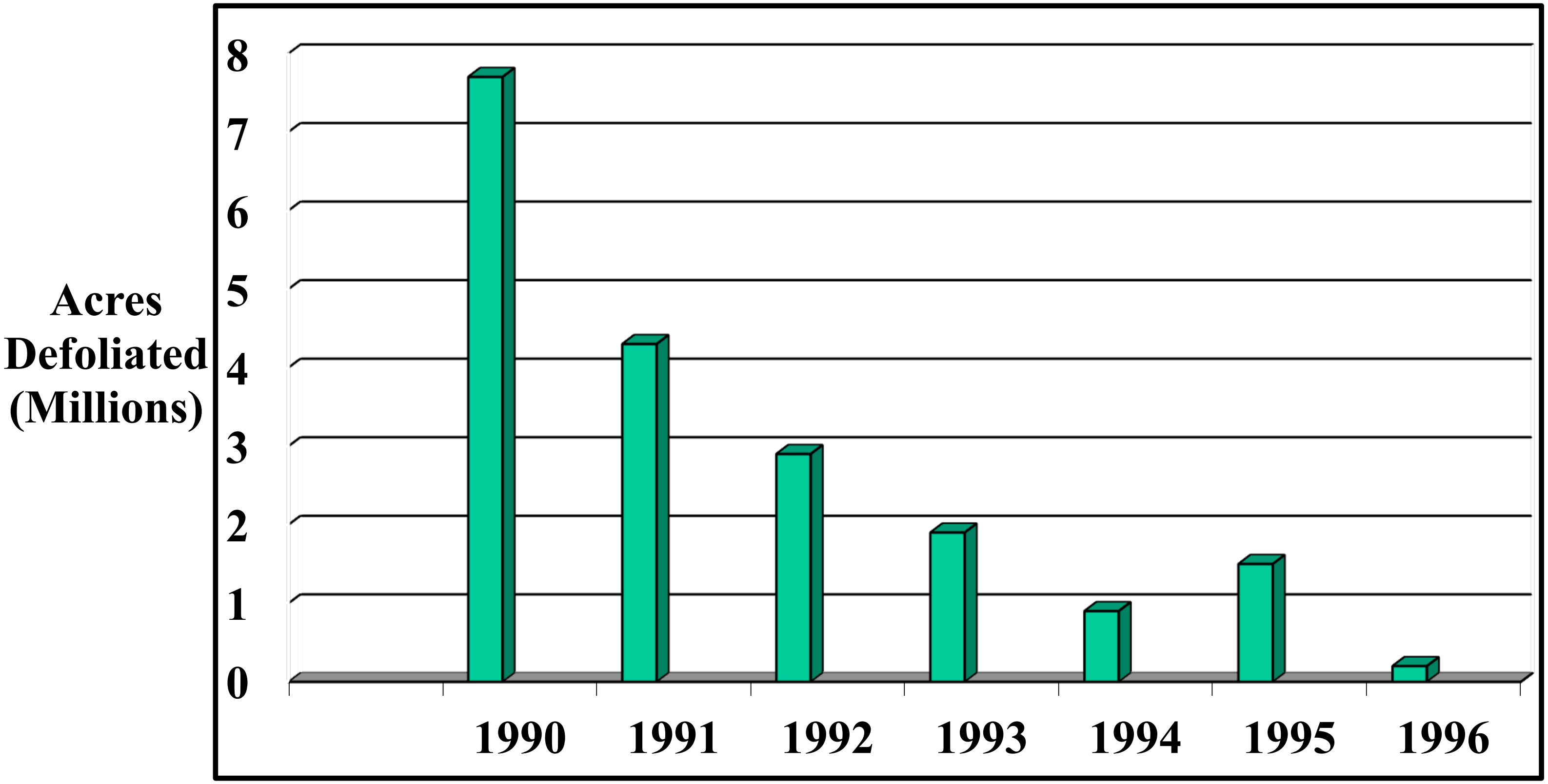
Entomophaga maimaiga – imported twice, once in early 1900's and again in 1980's







Moth Gypsy Defoliation



Coevolutionary matrix:

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- Native plants / exotic insects (enemy release; defense free space)

Elms in Urban Landscapes– Native elms killed by an exotic pathogen

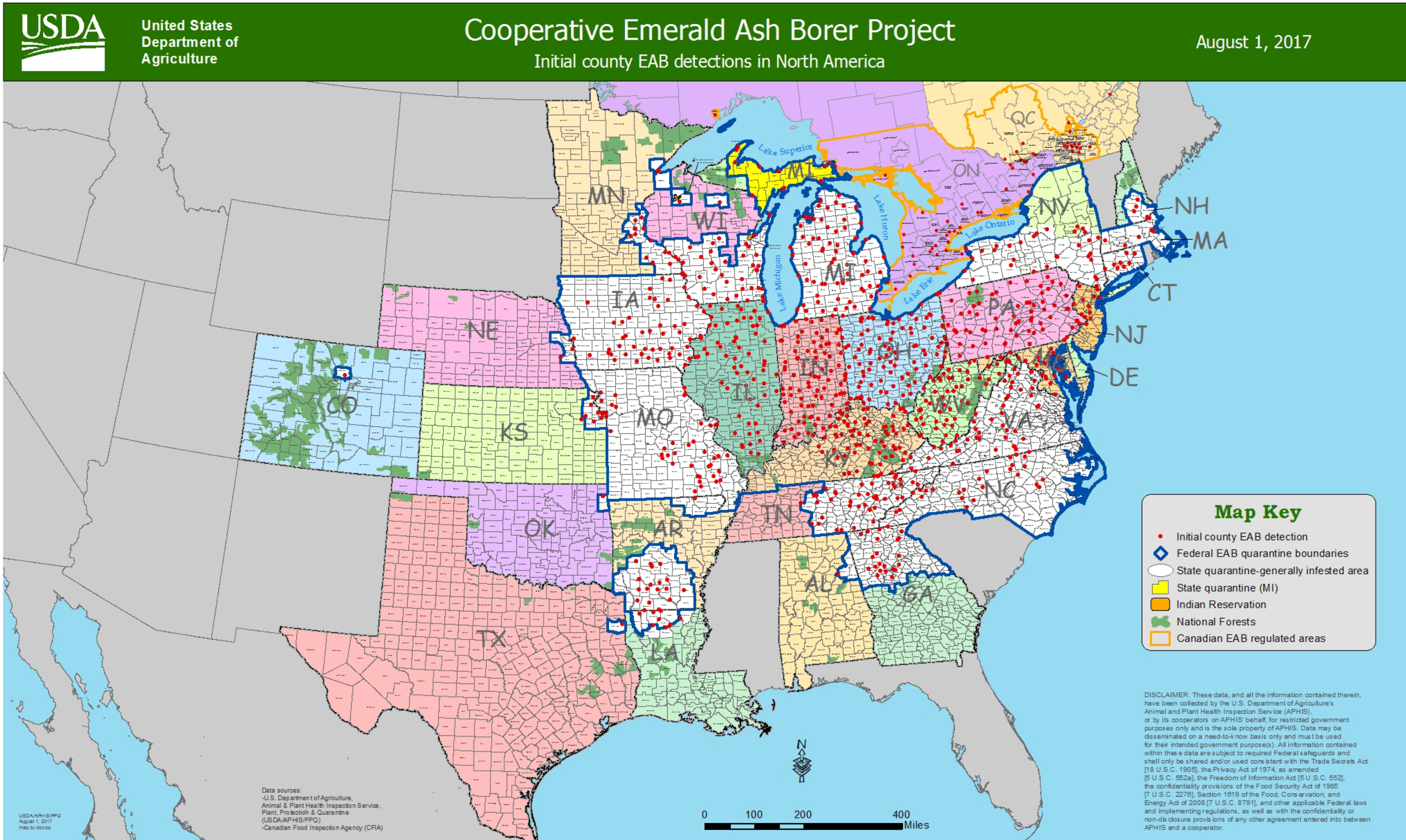
Arrival of two species of fungus *Ophiostoma ulmi* (1928) and *Ophiostoma novo-ulmi* (1940s) and a competent vector from Europe, the smaller European elm bark beetle in 1904

50 million elm trees were killed by 1989.

What the US faces now: Emerald ash borer hundreds of millions of dead ash trees (and counting)

Slide courtesy of Dan Herms

31 States, 2 Canadian Provinces



http://www.emeraldashborer.info

Resistant Plants for EAB Management
Exotic pest – Native and Exotic plants
Who lives? Who dies?

- Native ashes
  - *F. pennsylvanica* Patmore
  - *F. americana* Autumn Purple
  - *F. pennsylvanica* Marshall's Seedless
- Exotic ash
  - *F. mandshurica* Mancana

- Dead after 4 years (%)

  100

  75

  90

ASLA 2015 Annual Meeting and EXPO

Rebek et al 2008

AMERICAN SOCIETY OF LANDSCAPE ARCHITECTS

More is now known about ash resistance to EAB

F. quadrangulata and *F. mandshurica* - relatively resistant

F. americana - intermediate

F. nigra and *F. pennsylvanica* - susceptible

Sara R. Tanis and Deborah G. McCullough, 2015

Birch resistance to bronze birch borer

Interspecific Variation in Resistance of Asian, European, and North American Birches (*Betula* spp.) to Bronze Birch Borer (Coleoptera: Buprestidae)

DAVID G. NIELSEN, VANESSA L. MUILENBURG, AND DANIEL A. HERMS[1]

Department of Entomology, Ohio Agricultural Research and Development Center, The Ohio State University, 1680 Madison Avenue, Wooster, OH 44691

Environ. Entomol. 40(3): 648–653 (2011); DOI: 10.1603/EN10227

When native pest meets exotic plant, who wins, who dies?

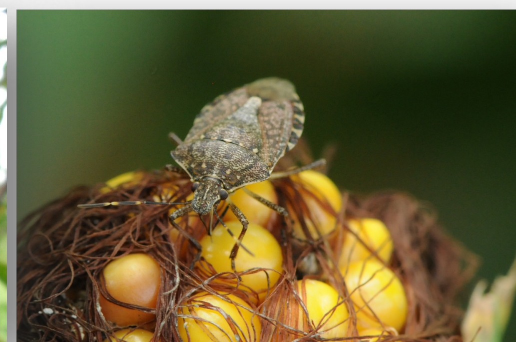
Birch survival after 20 years of exposure to bronze birch borer:

North American species:
- *B. nigra* 97%
- *B. papyrifera* 73%
- *B. populifolia* 75%

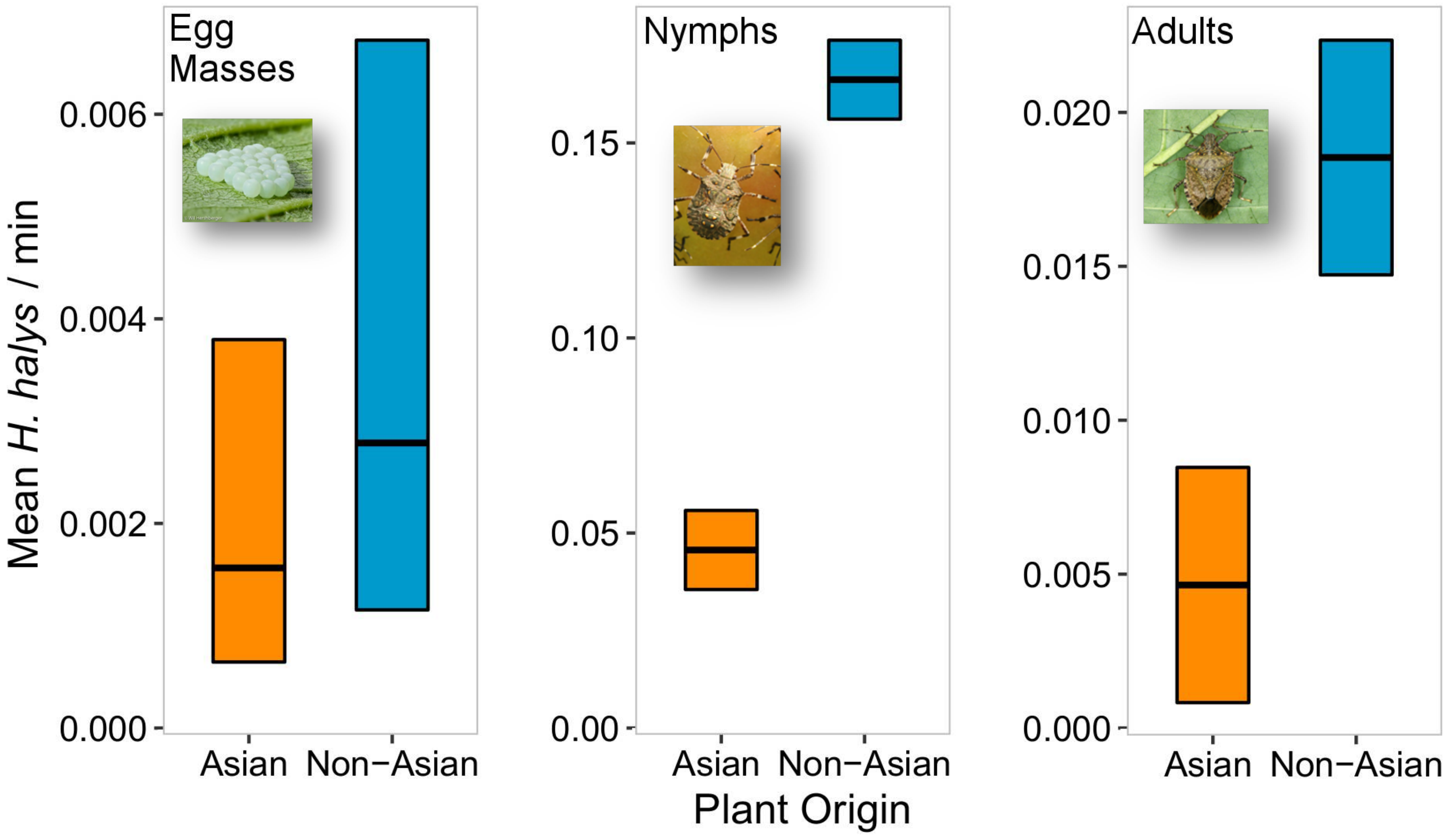
Exotic species:
- *B. pendula* 0%
- *B. pubescens* 0%
- *B. platyphylla* 0%
- *B. maximowicziana* 0%

Please don't bring bronze birch borer infested trees into the UK

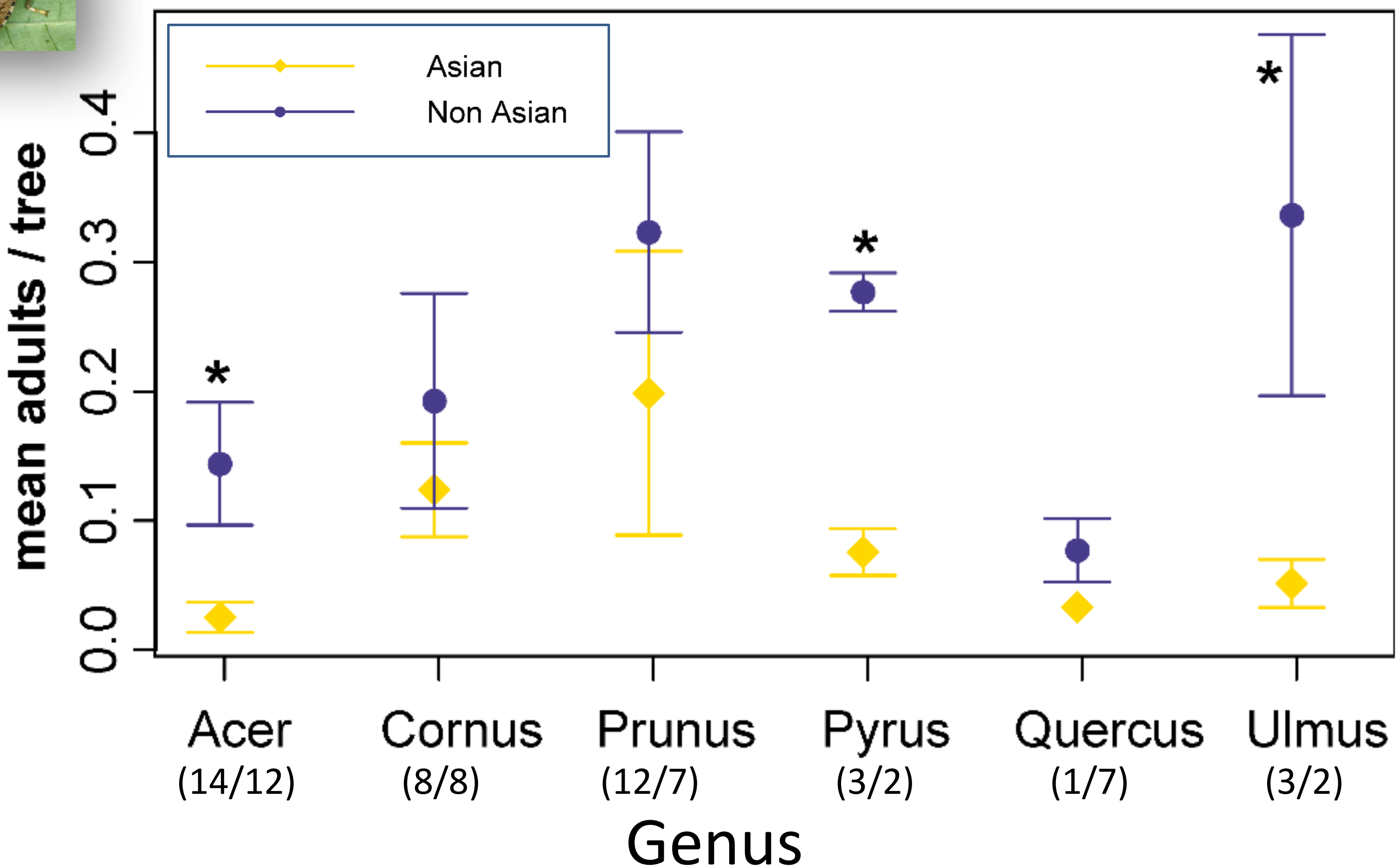
How does BMSB utilize plants native to US vs Eurasian hosts?



Abundance of BMSB Greater on Non-Asian Plants



Effect of Plant Origin is Consistent Across Common Genera



Defense free space and biological invasions:

Documented examples of low host resistance where coevolutionary history is lacking

- Bronze birch borer and Eurasian birches
- Emerald ash borer and N.A. ashes
- Pine needle scale and Eurasian pines
- Hemlock wooly adelgid and eastern N.A. hemlocks
- Balsam wooly adelgid and N.A. firs
- Beech bark scale and N.A. beech
- Viburnum leaf beetle and N.A. viburnums
- Redbay ambrosia beetle and N.A. redbay
- American chestnut and chestnut blight
- Dutch elm disease and N.A. elms
- Thousand canker disease and eastern walnut
- Brown marmorated stink bug and N.A. hosts

Slide courtesy of Dan Herms

Conclusion: No evolutionary history, no resistance. Exotic insect pests and diseases arriving in the US and the UK often enjoy defense free space and devastate native plants.

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How does "natural" become the suburbs and urban forest?
Eastern Deciduous Forest – Subtraction Experiment

How do plant diversity and density differ along the urbanization gradient?

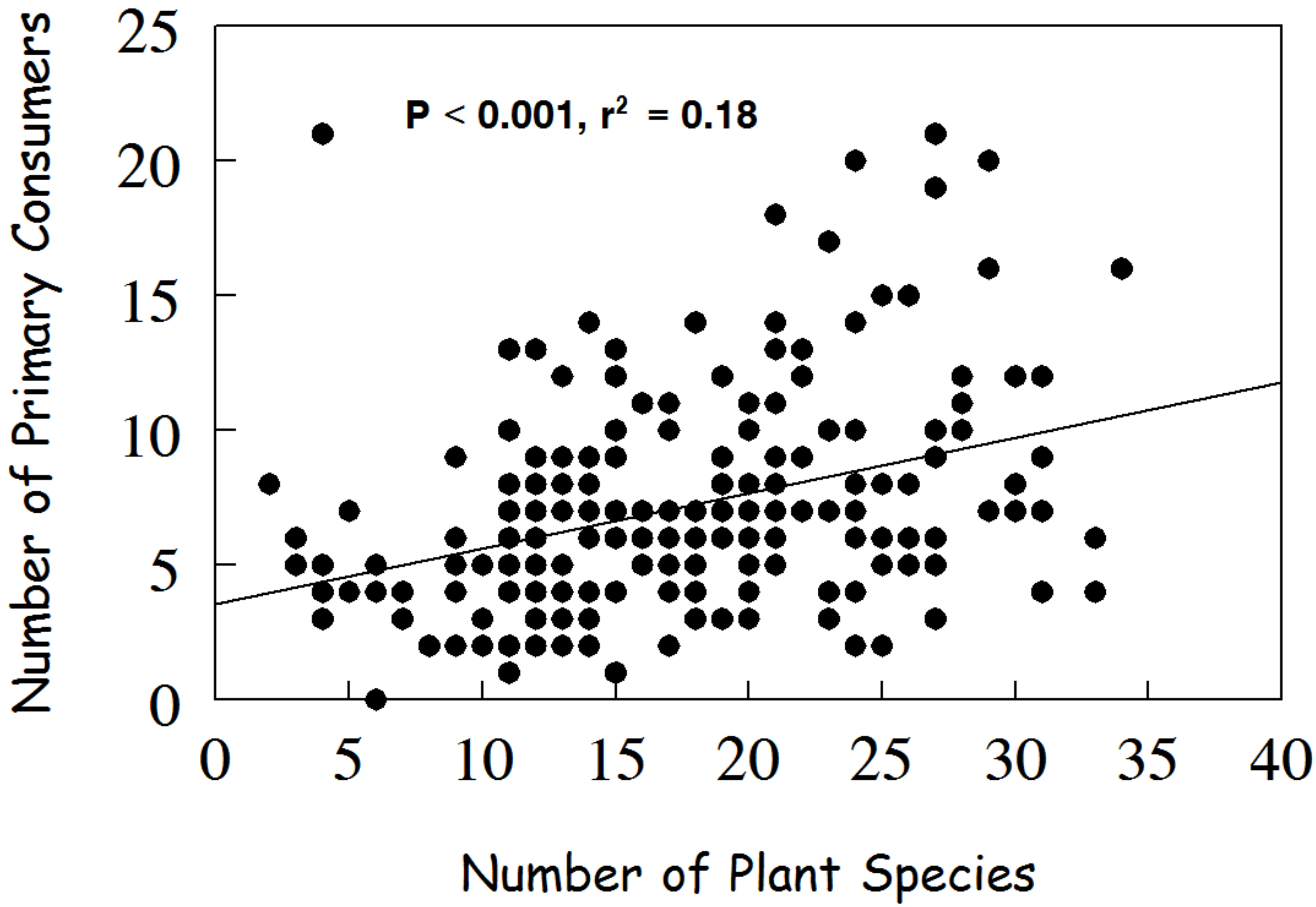
Plant density - 69,000 plants per km2
Plant diversity - > 100 species

Diversity Dilemma

Plant density - 48 plants per km2
Plant diversity - 30 species

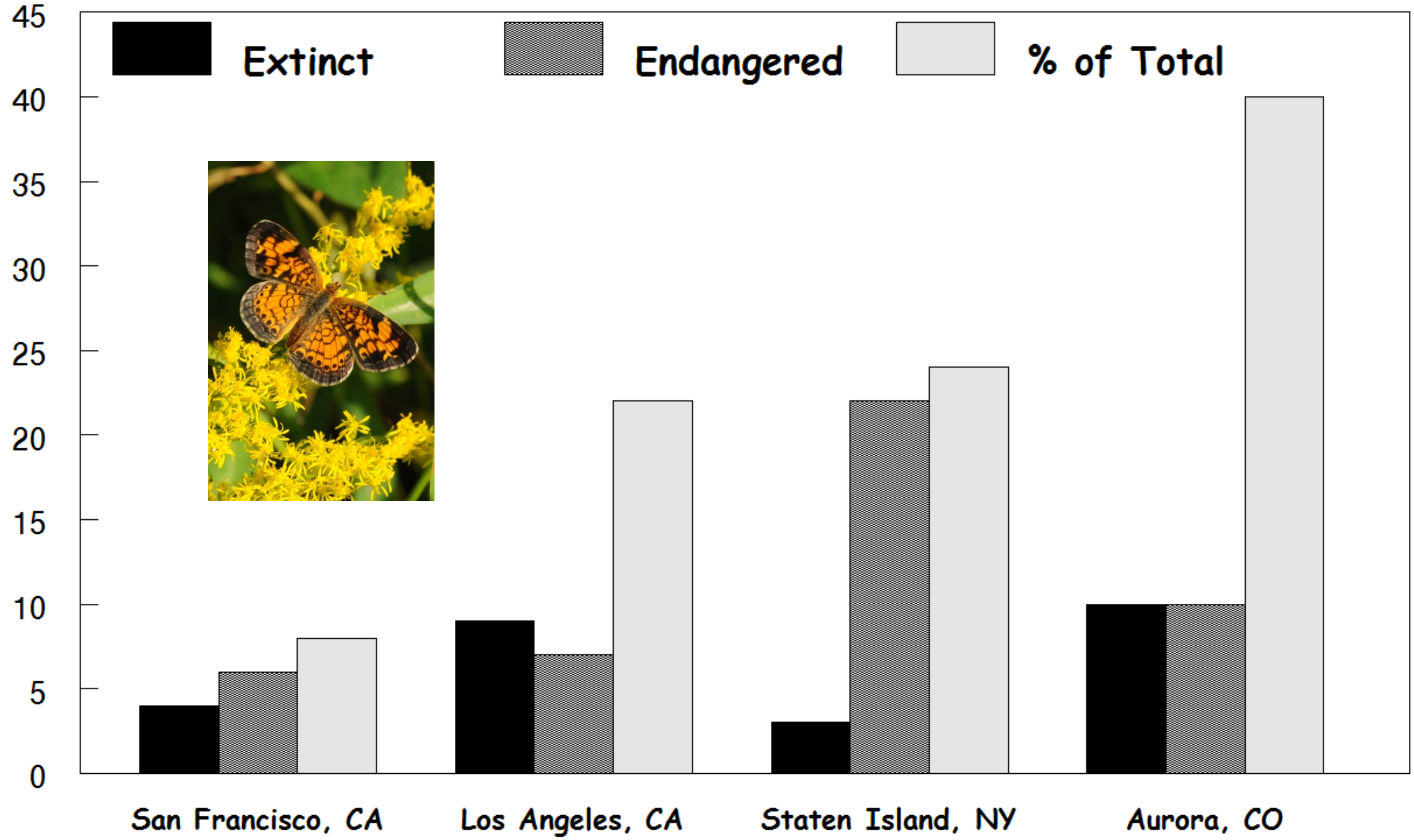
Raupp et al. 2010

Relationship Between Plant Species Richness and Richness of Primary Consumers



Loss of 1^0 Consumers

Extinct and Endangered Butterflies in Four Urban Areas



From Pyle 1983

Loss and gain of Ground Beetles (Carabidae)

esa ECOSPHERE

SYNTHESIS & INTEGRATION

A meta-analysis of the effects of urbanization on ground beetle communities

Holly M. Martinson† and Michael J. Raupp

Department of Entomology, University of Maryland, College Park, Maryland 20742 USA

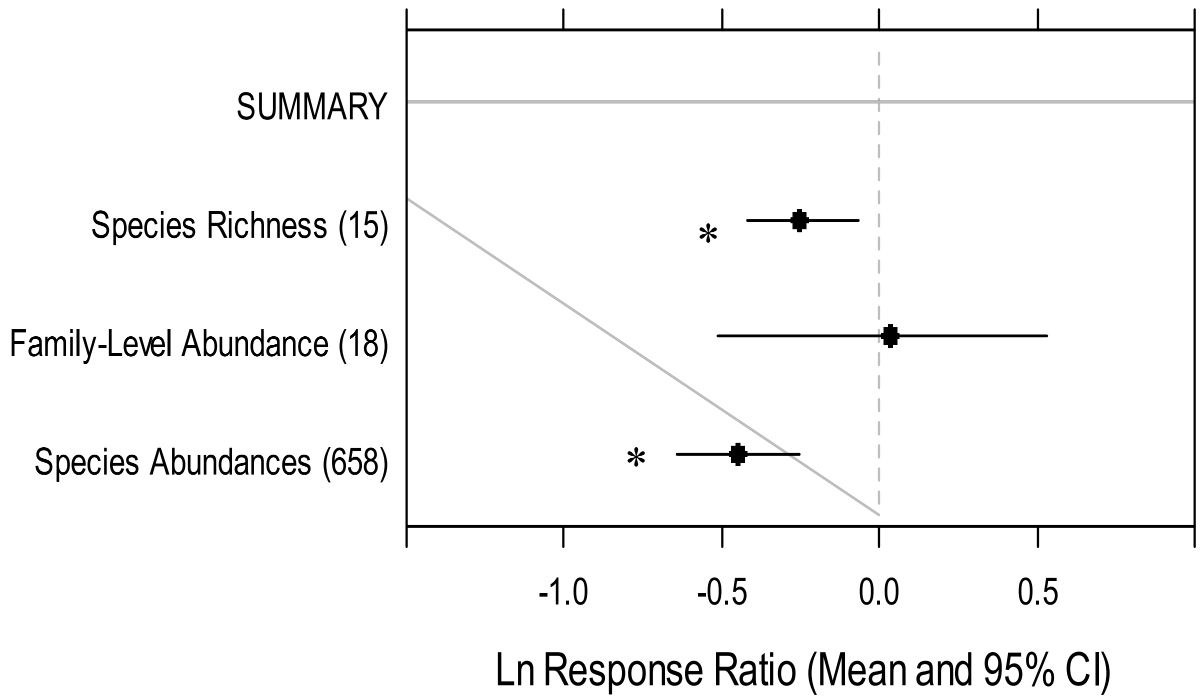
Citation: Martinson, H. M., and M. J. Raupp. 2013. A meta-analysis of the effects of urbanization on ground beetle communities. Ecosphere 4(5):60. http://dx.doi.org/10.1890/ES12-00262.1

Motivation

- **Indicator taxon, environmentally sensitive**
- **Well-studied (GlobeNet, additional studies)**



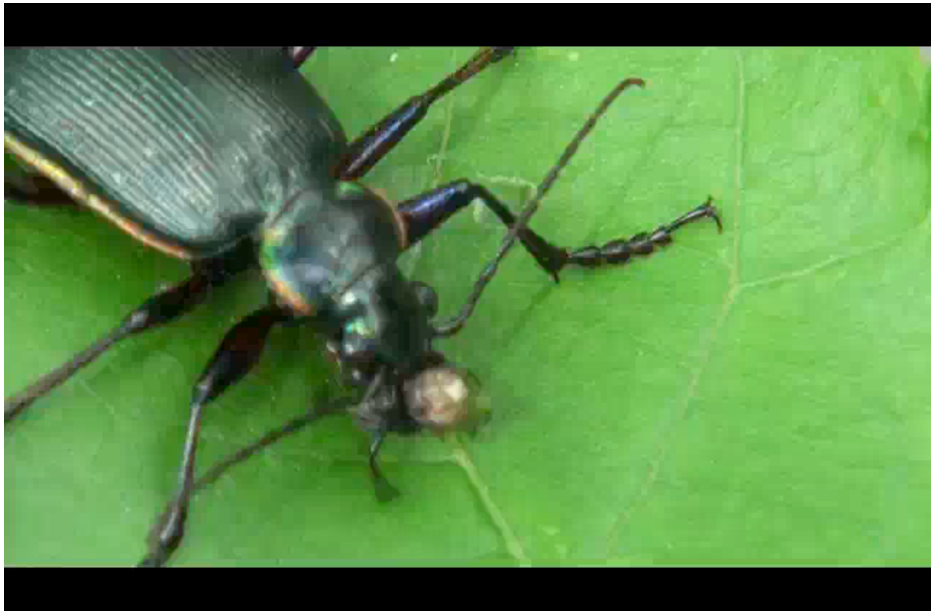

Overall Effects of Urbanization on Carabids



Urban species richness: 77.6% of rural richness
Urban species abundances: 63.7% of rural abundances

Martinson & Raupp (2013) *Ecosphere*

Large forest-dwelling ground beetles were rare in cities. They murder caterpillars.



Does this explain outbreaks of oak processionary moth and fall cankerworms in cities in the UK and US?

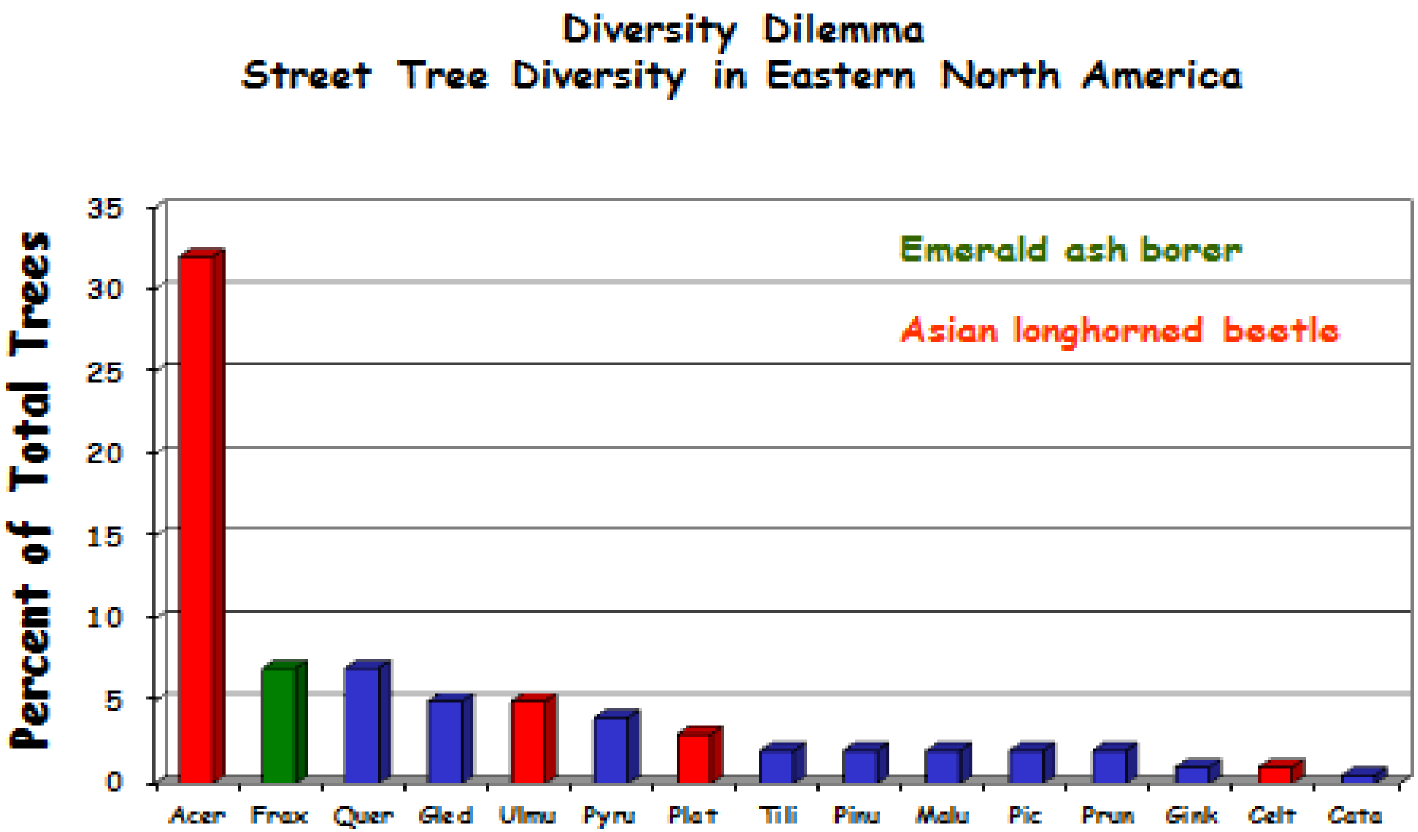
What was learned from Dutch Elm Disease?

Avoid monocultures in urban forests to avoid catastrophic loss of street trees.

10-20-30 Rule

How diverse is the urban forest in eastern North America?

Unfortunately the important lesson to diversify the urban forest was not learned and large numbers of maple and ash were planted to replace elm setting the stage for invasions by Asian longhorned beetle and Emerald ash borer



Ann Arbor, Chicago, Florence, Gastonia, Kansas City, Lincolnshire, Marion, Mt. Ranier, New York, Toledo, Toronto, Wilmington – Raupp et al. 2006

Conclusions

- Cities face the loss or need for insecticide protection of 29% to 70% of their street trees
- The average percentage of trees at risk was 49.7% (4.0% s.e.)
- No more Acer or Fraxinus
- Diversify now or face catastrophic loss

Raupp et al. 2006

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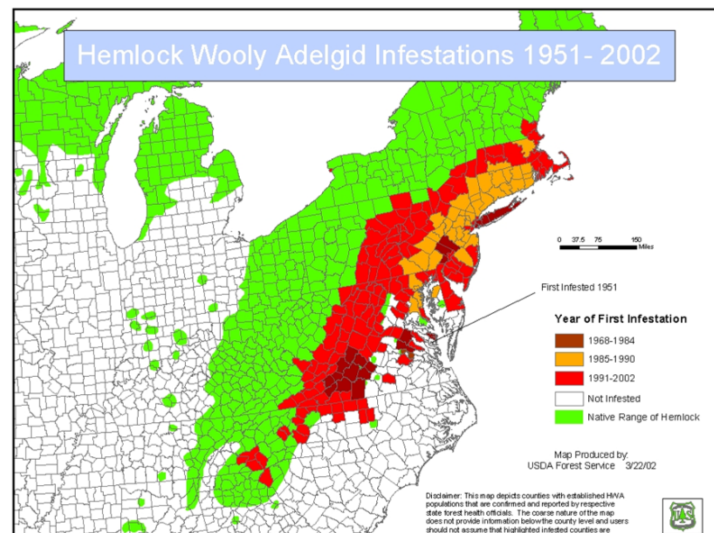
How climate change may facilitate spread of an invader

Hemlock woolly adelgid was introduced from Asia to Virginia in the 1950's

It spread slowly at first throughout the eastern United Sates but the rate has increased and it has killed millions of hemlock trees

It's rate of spread is expected to increase with warming temperatures – here's why.



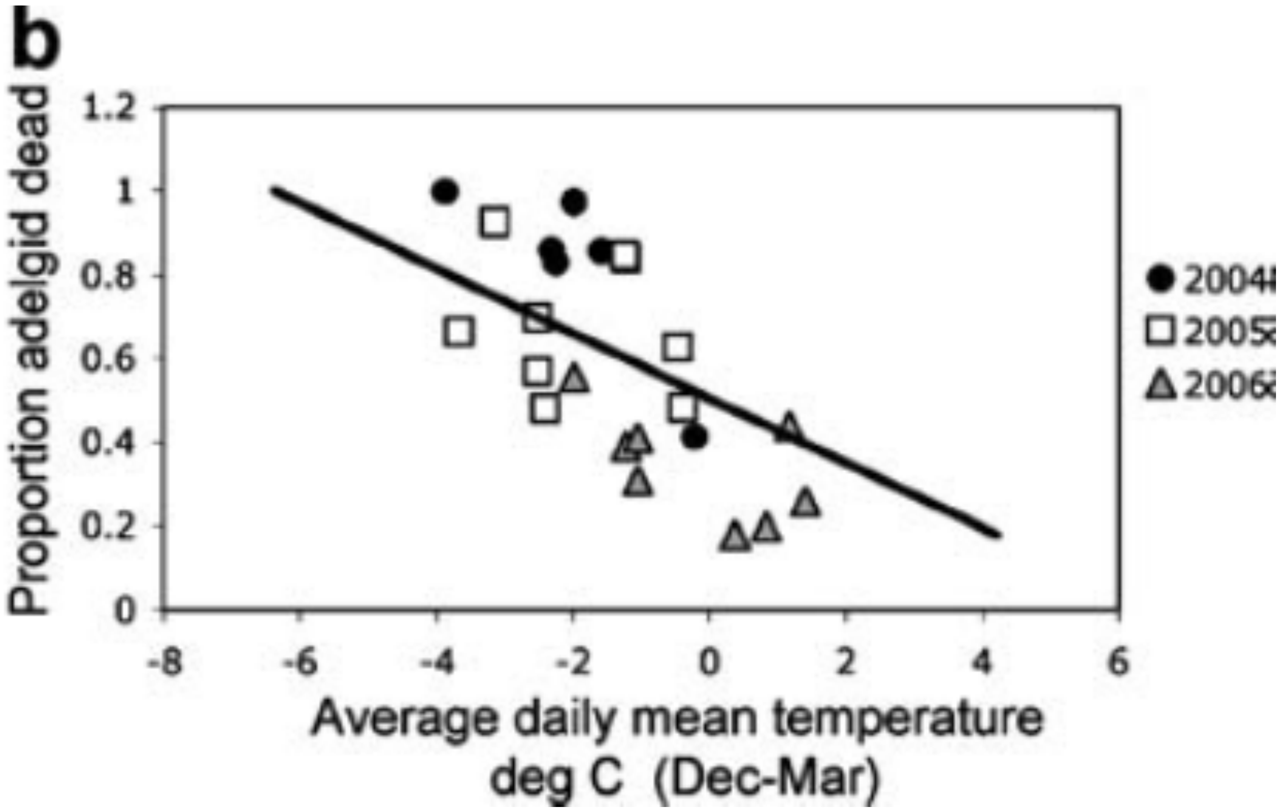
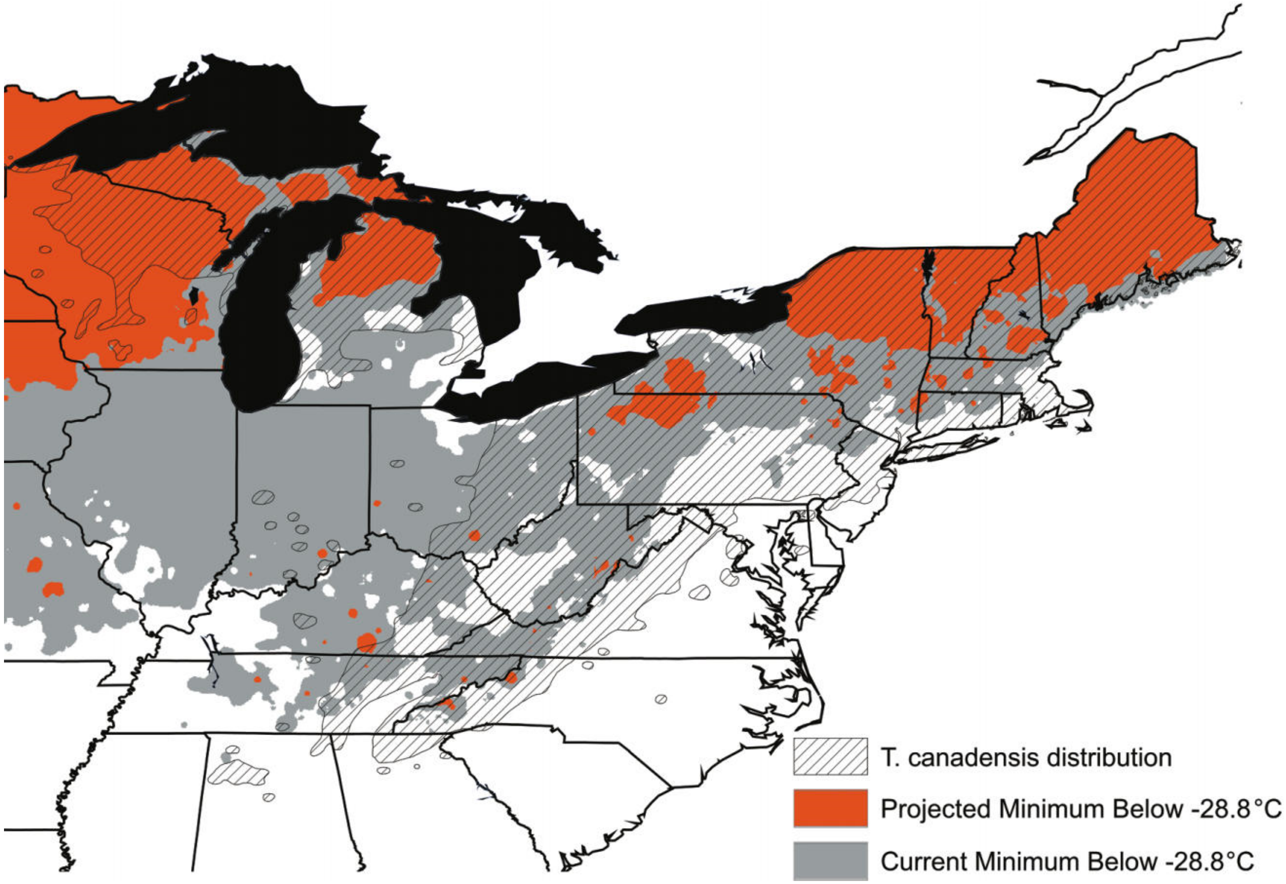


Fig. 3 Relationship between adelgid overwintering mortality the average daily mean temperature for December through March (P=0.008; R2=0.430).

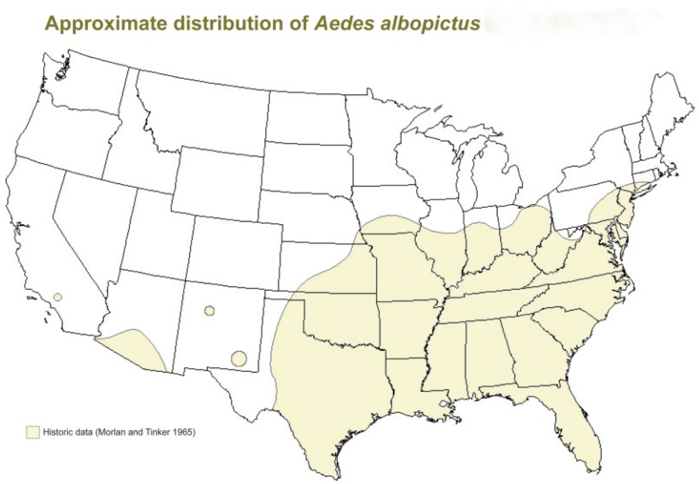
Populations cannot expand when mean winter temperature is 23 Fahrenheit or if there are 79 days with a minimum temperature of 14.



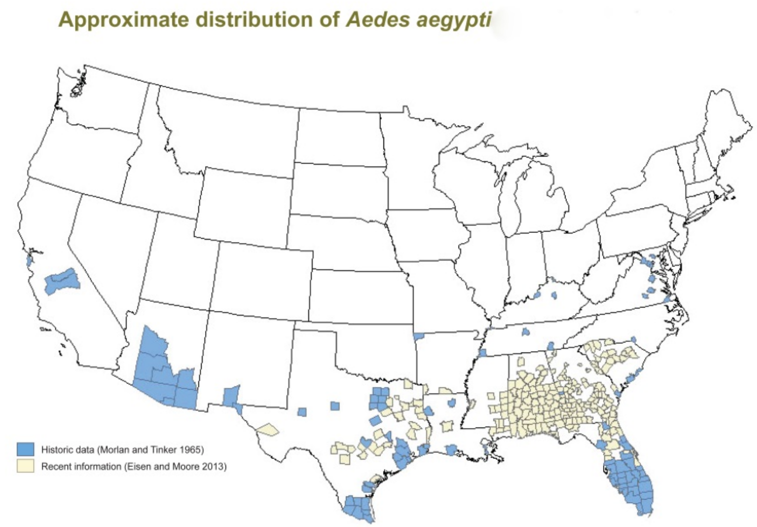
Climate change will greatly increase the range of Hemlock Woolly Adelgid in North America

Fig. 3. The current distribution of eastern hemlock (Tsuga canadensis; hatched areas) in the northeastern United States, superimposed on maps of current and projected minimum temperature thresholds for hemlock woolly adelgid survival (red, grey, and black areas). The current distribution of HWA in the US is limited to locations where minimum winter temperatures stay above –28.8 8C (white areas; Skinner et al. 2003). Based on recent climate projections (Fig. 2; Hayhoe et al. 2006), the area of hemlock protected by this extreme cold could be significantly reduced by 2070 (red areas). If HWA adapts to extreme cold (see text), hemlock may be limited to small pockets in the extreme northern portions of Maine, Vermont, New Hampshire, New York, and Wisconsin where temperatures drop below –35 8C (black areas).

Aedes mosquitoes vectors of Zika and West Nile will expand northward



*This map was developed using currently available information. *Aedes* albopictus mosquito populations (a known vector of chikungunya) may be detected in areas not shaded on this map, and may not be consistently found in all shaded areas. The shaded areas are NOT loactions of chikungunya transmission.



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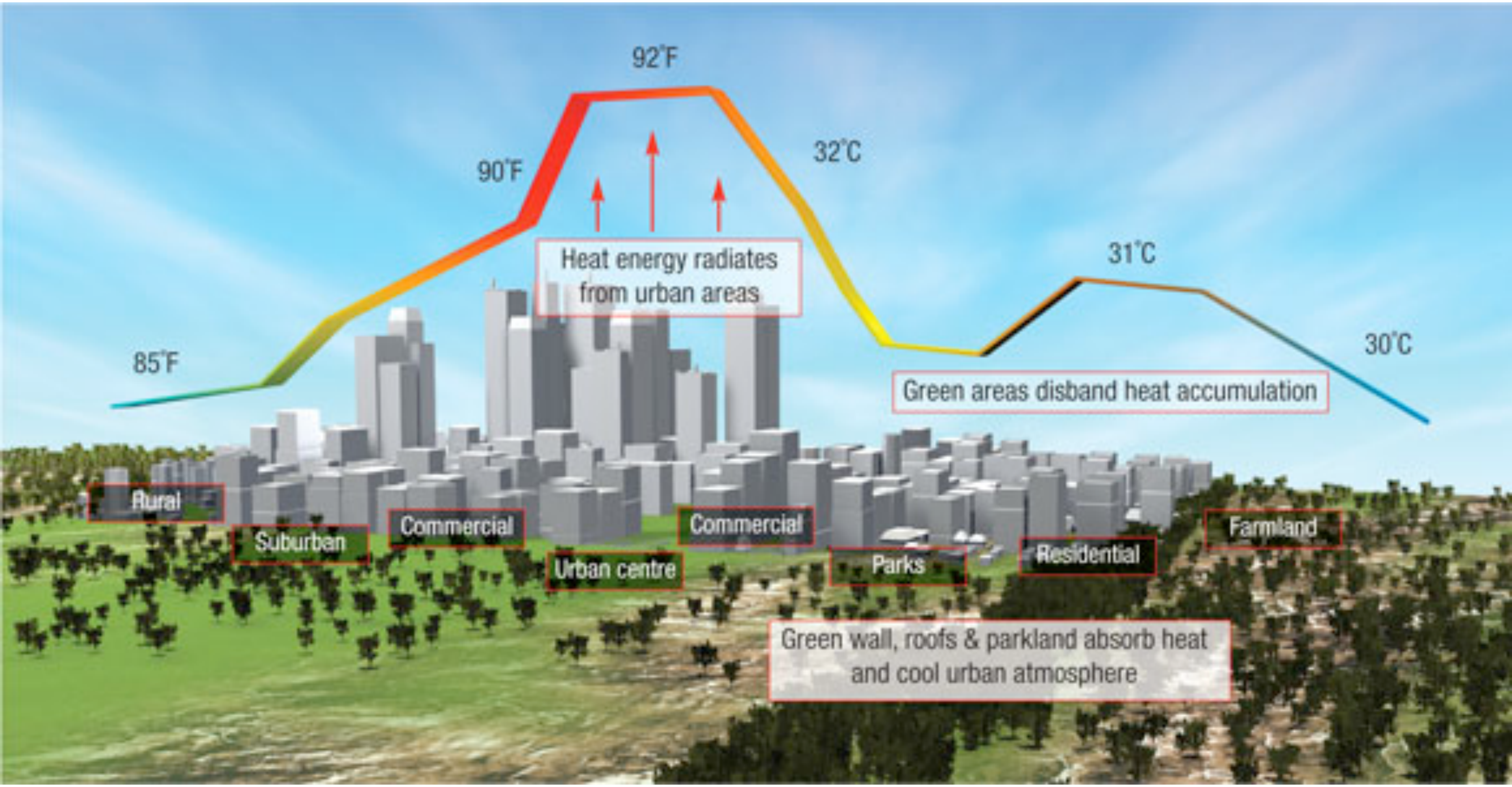
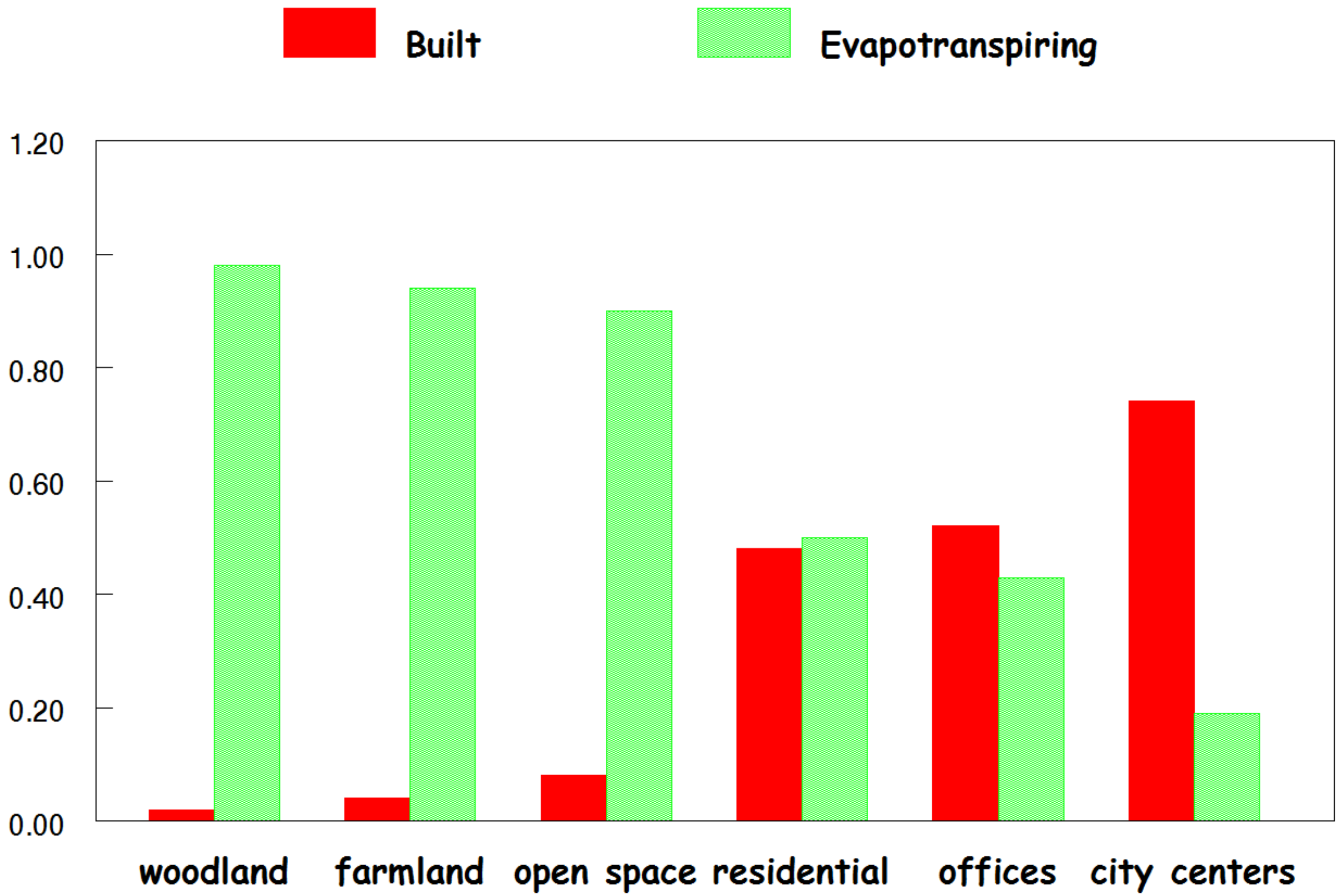

92˚F
90˚F
32˚C
85˚F
Heat energy radiates from urban areas
31˚C
30˚C
Green areas disband heat accumulation
Rural
Suburban
Commercial
Urban centre
Commercial
Parks
Residential
Farmland
Green wall, roofs & parkland absorb heat and cool urban atmosphere

Proportional Cover in Urban Structural Types in Manchester



From Gill et al. 2008

Buildings reflect sunlight, warm plants, and act as heat sinks

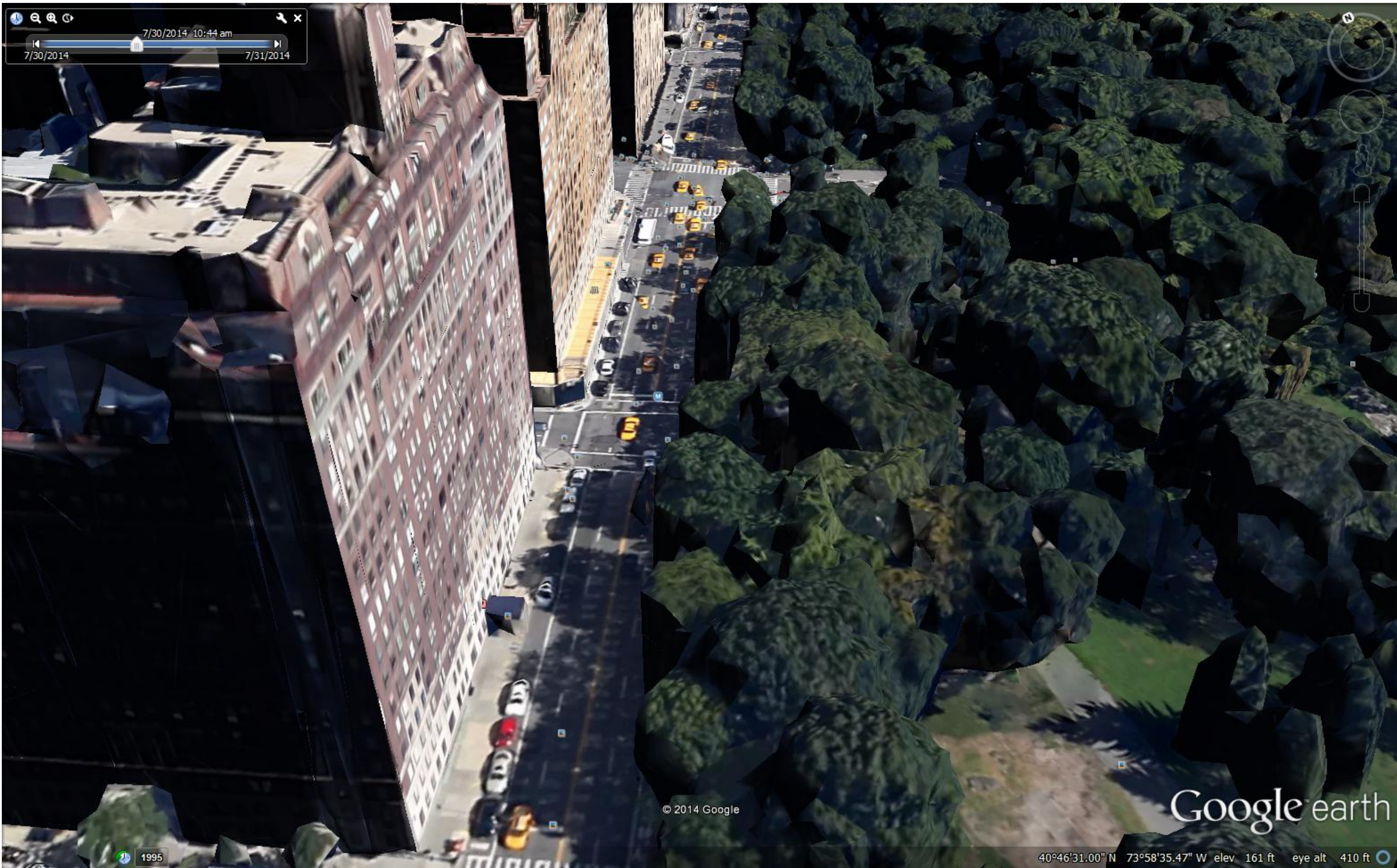
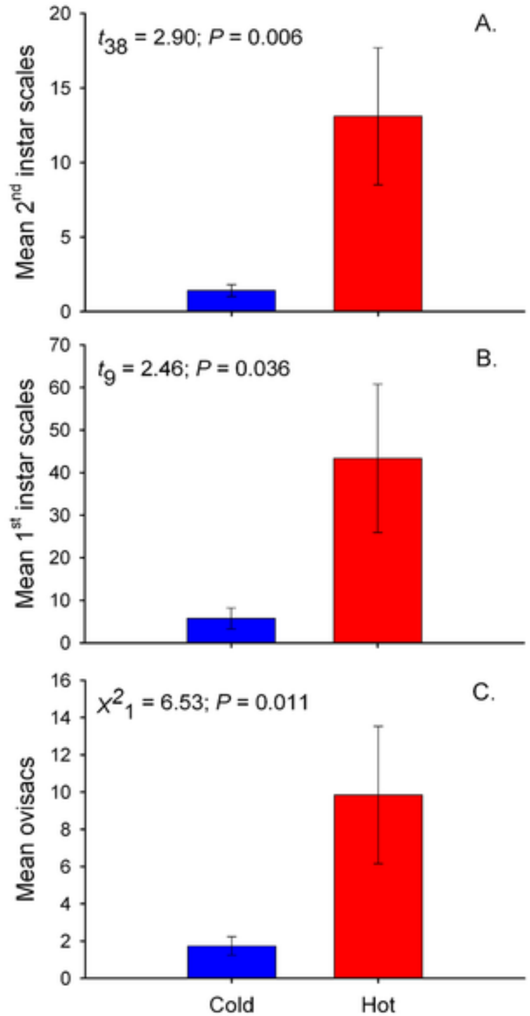


Figure 2. Parthenolecanium quercifex abundance across the Raleigh, NC urban heat island.

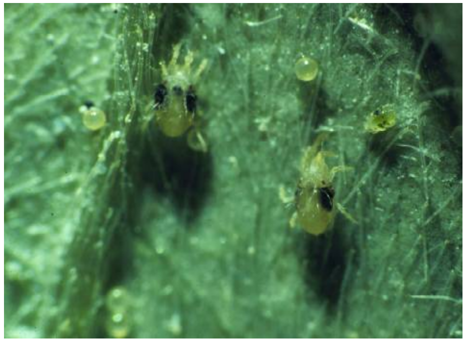


Meineke EK, Dunn RR, Sexton JO, Frank SD (2013) Urban Warming Drives Insect Pest Abundance on Street Trees. PLoS ONE 8(3): e59687. doi:10.1371/journal.pone.0059687
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0059687

Developmental times (days) for *Tetranychus urticae – two-spotted spider mite*

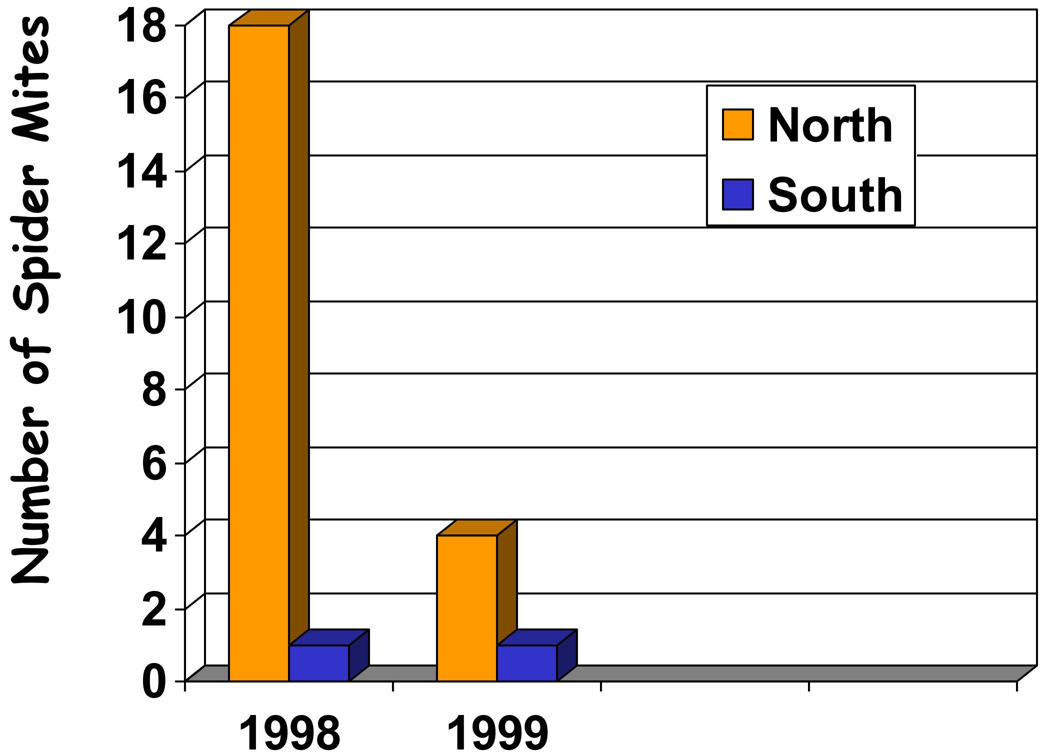
Developmental stage**

Temp. C	Egg	Larva	PN	DN	PQ	Total
15	14.3	6.7	5.3	6.6	3.5	36.3
20	6.7	2.8	2.3	3.1	1.7	16.6
30	2.8	1.3	1.2	1.4	0.6	7.3



Source: http://mrec.ifas.ufl.edu/lso/spmite/b853a3.htm#Table1

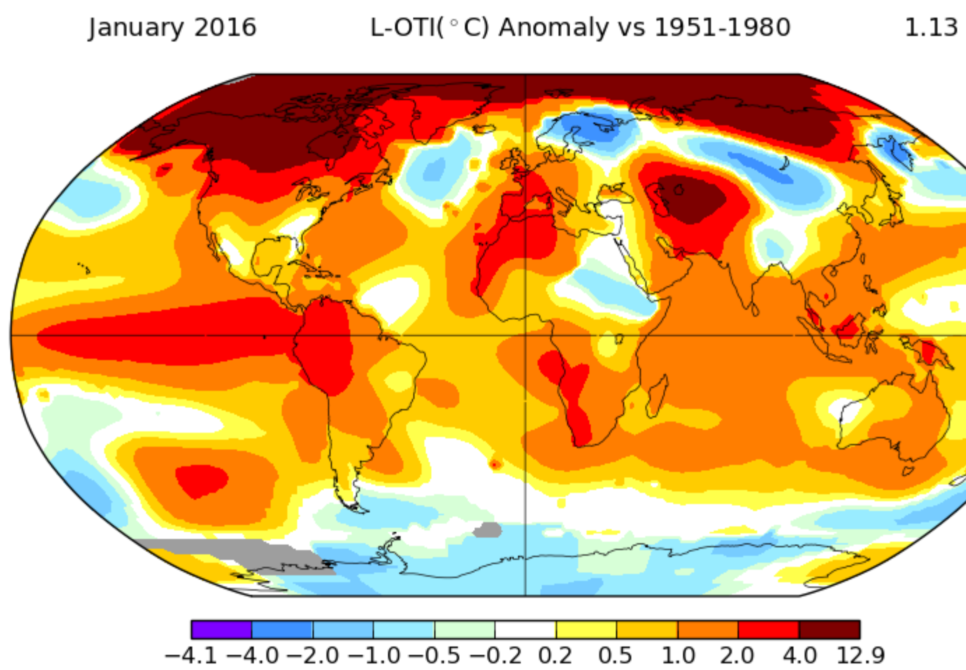
If you want to see mites, just direct your feet to the sunny side of the street - Berlin



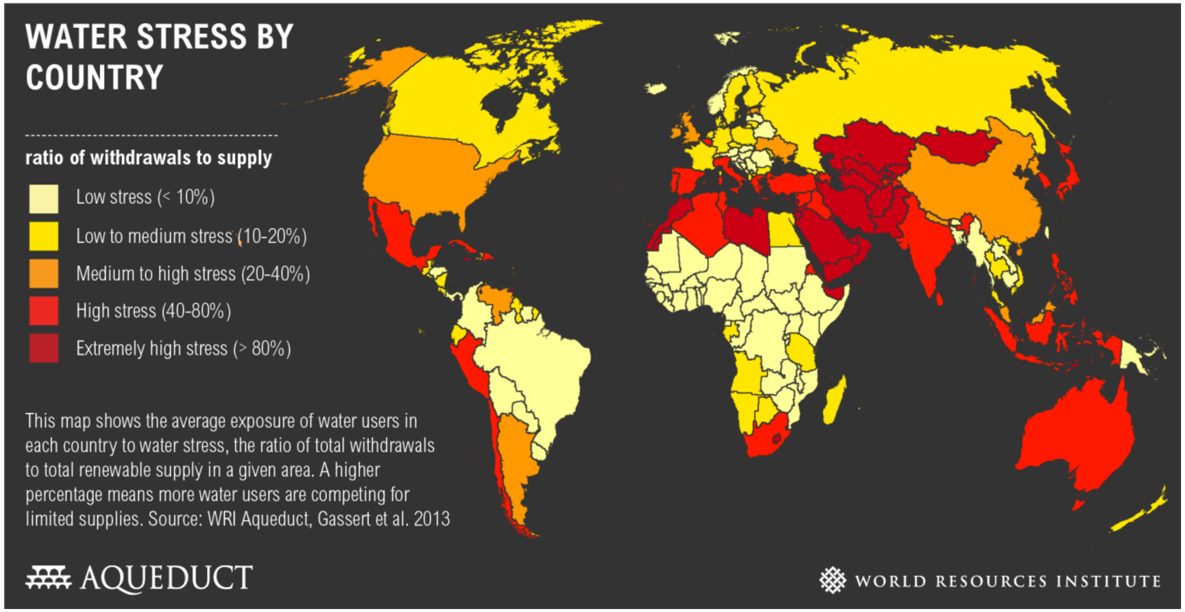
North side = lots of sun

South side = mostly shaded

Schneider et al. 2000



In many parts of the world, increased temperature will be accompanied by drought



Trees in urban sites experience more frequent and intense stress than trees in natural forests

- Water deficits
- Compacted soil deficient in nutrients and organic matter
- Human inputs - air pollution, de-icing chemicals, excess fertilizer
- Increased incidence of mechanical injury

Effects of Stress on Life History Traits

Trait	Insect Guild: Chewers	Suckers	Miners	Gallers	Borers
Growth	0	+			+
Fecundity	-	+	0		
Survival	0	0	0	-	+
Colonization	0	0	0	-	+

Koricheva J, Larsson S, Haukioja E. 1998; Herms 2002

What are some of the ecological and economic impacts of invasive species?

Emerald ash borer causes high mortality in natural ash stands

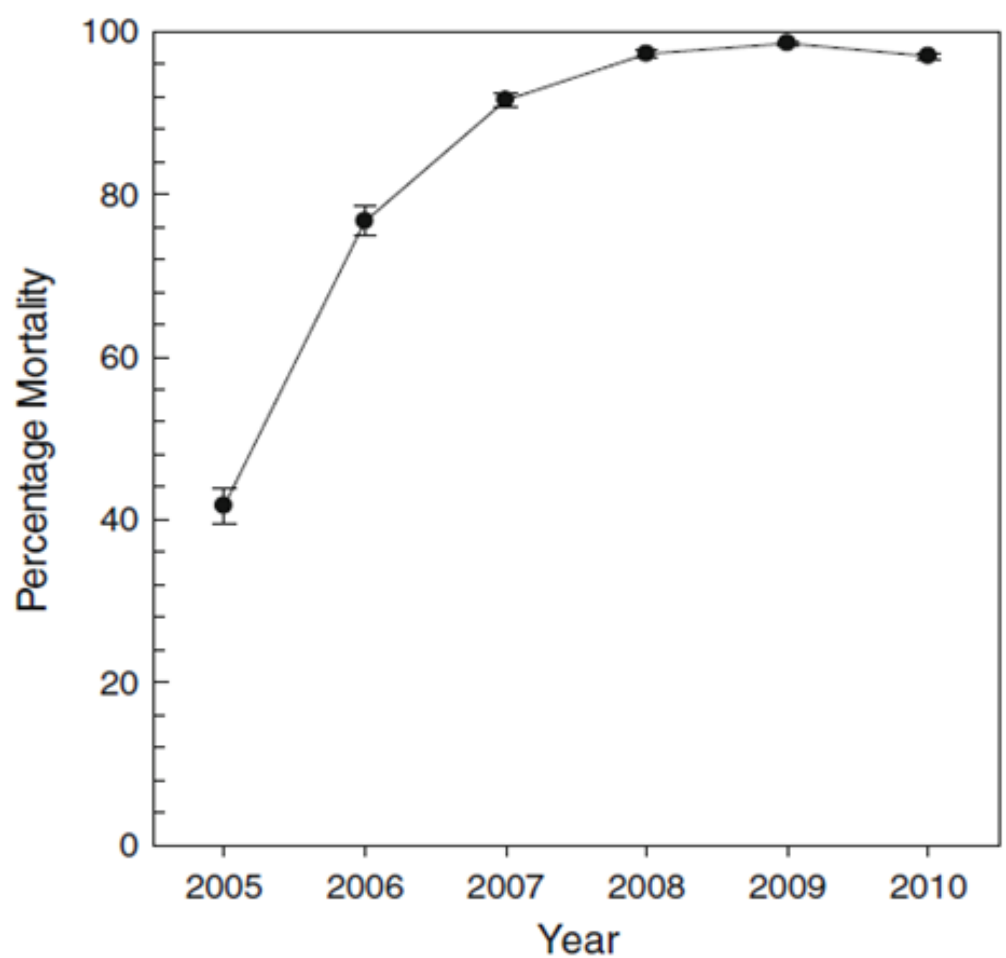


Fig. 4 Percentage ash mortality of trees ≥2.5 cm dbh in subplots and ≥12.5 cm dbh in main plots from 2005 to 2010 in 38 forested stands within the Huron River Watershed in southeastern Michigan

Following ash mortality there is virtually no recruitment of ash

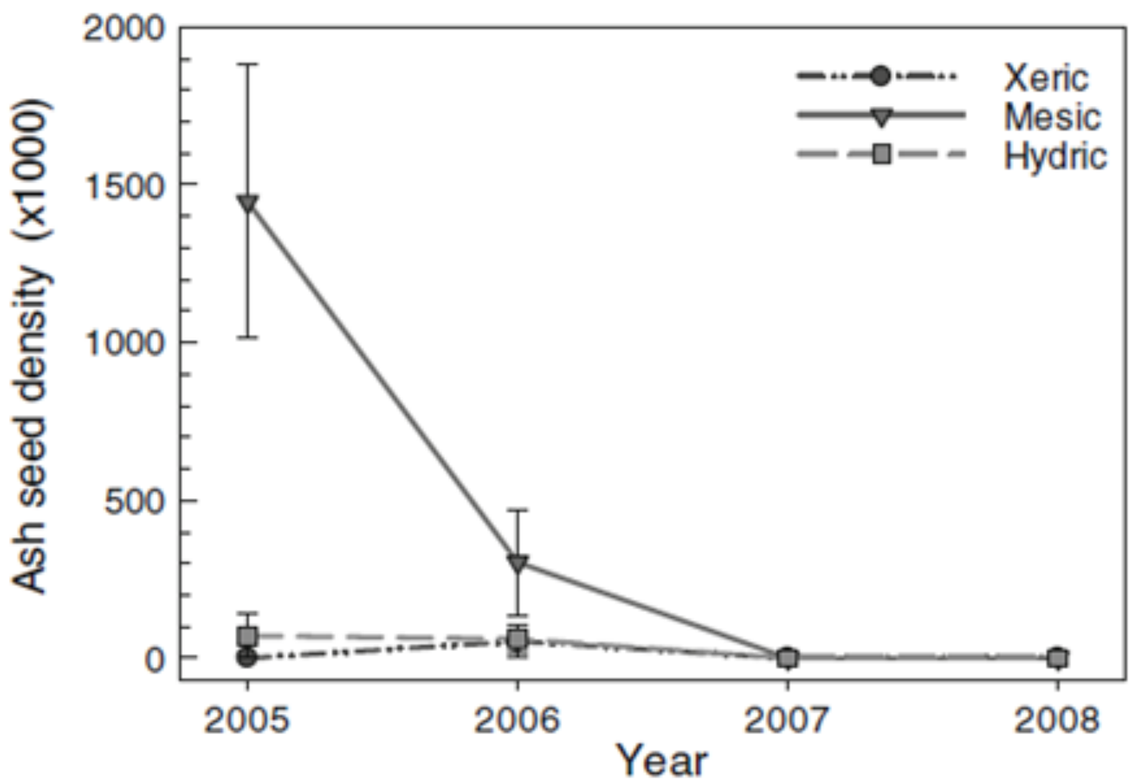
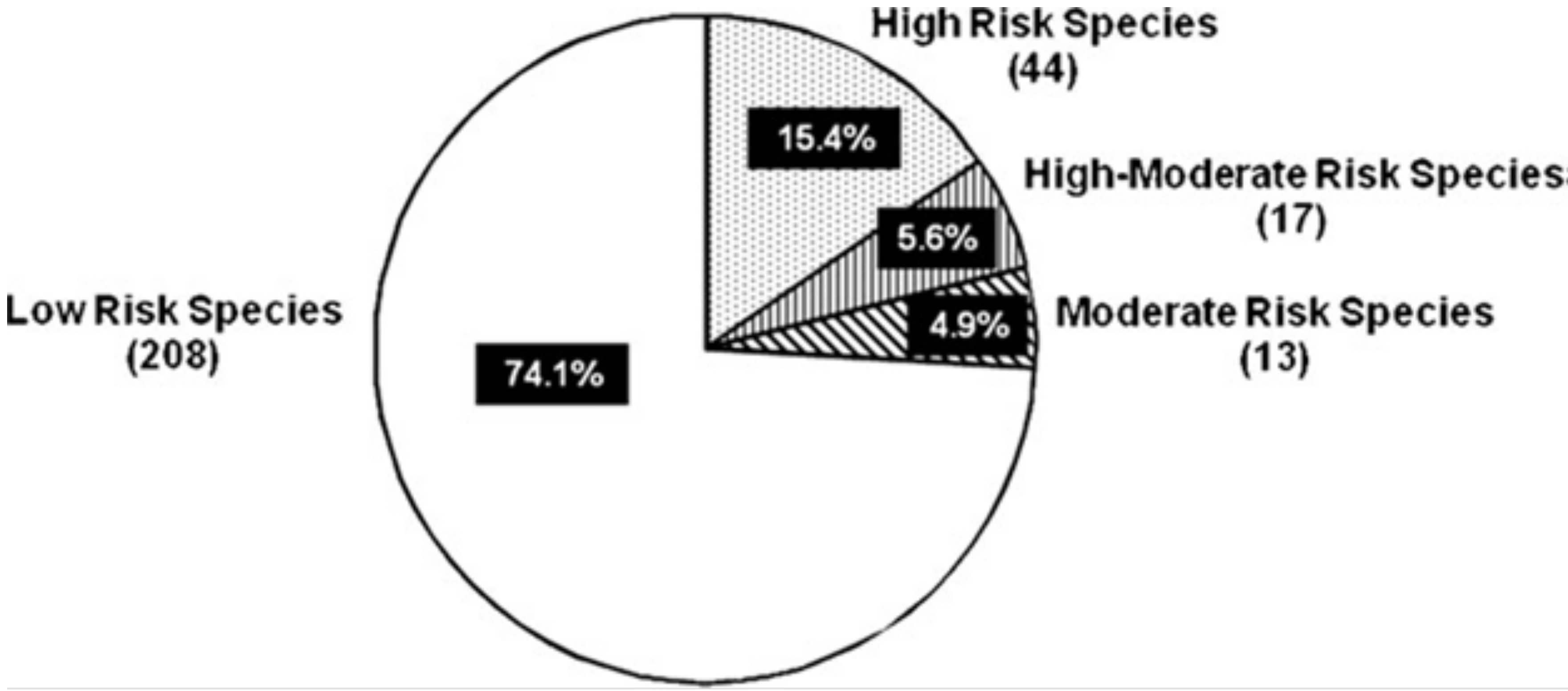


Fig. 5 Density of viable ash seeds in 18 forested stands across three hydrological classes within the Upper Huron River Watershed in southeastern Michigan

Fig. 1 Percentage of arthropod species in high (associated only with ash), high-moderate (ash and one other plant species), moderate (ash and two other plant species), and low (ash and three other plant species) risk endangerment categories.

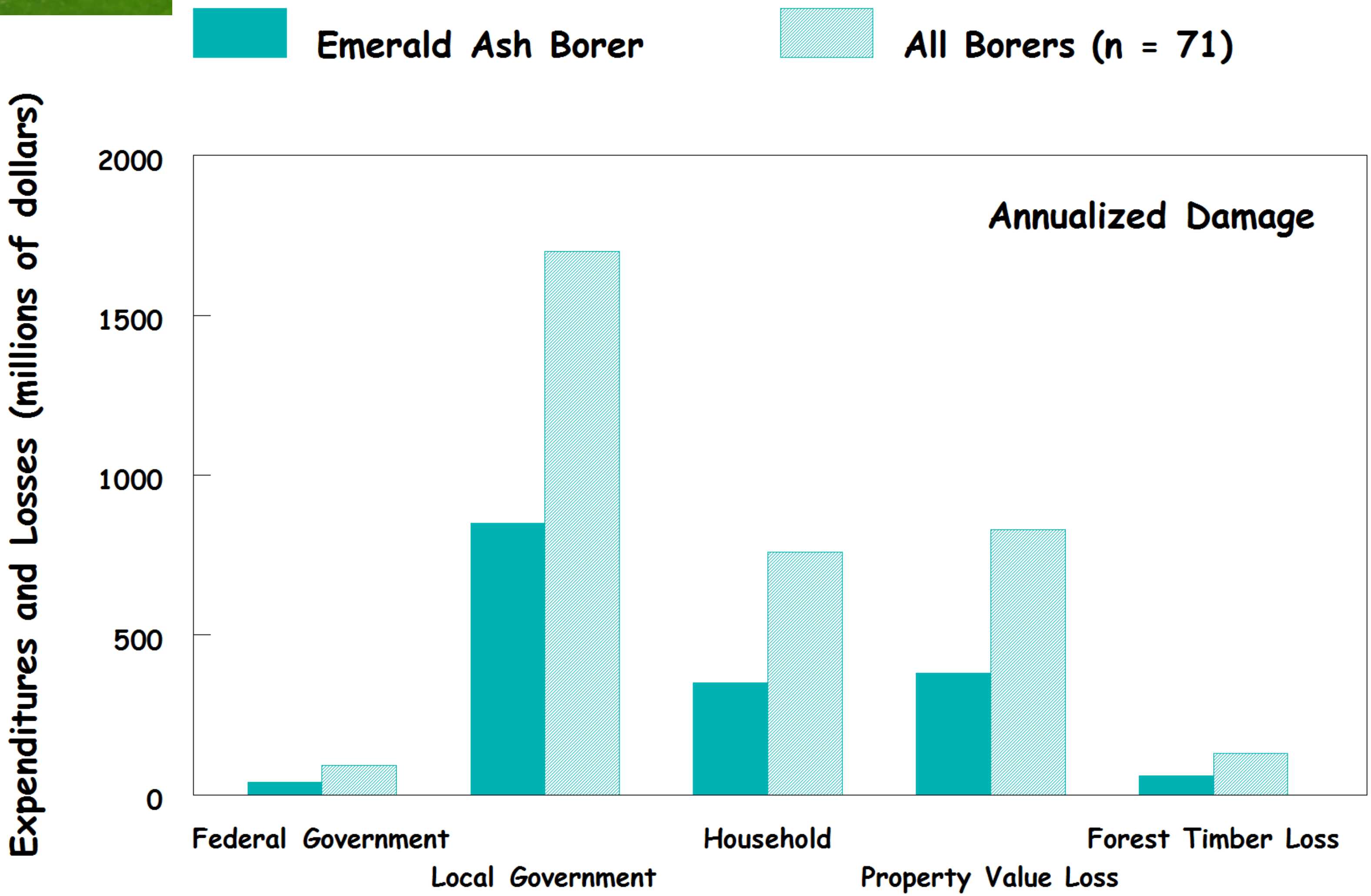


Economic impacts

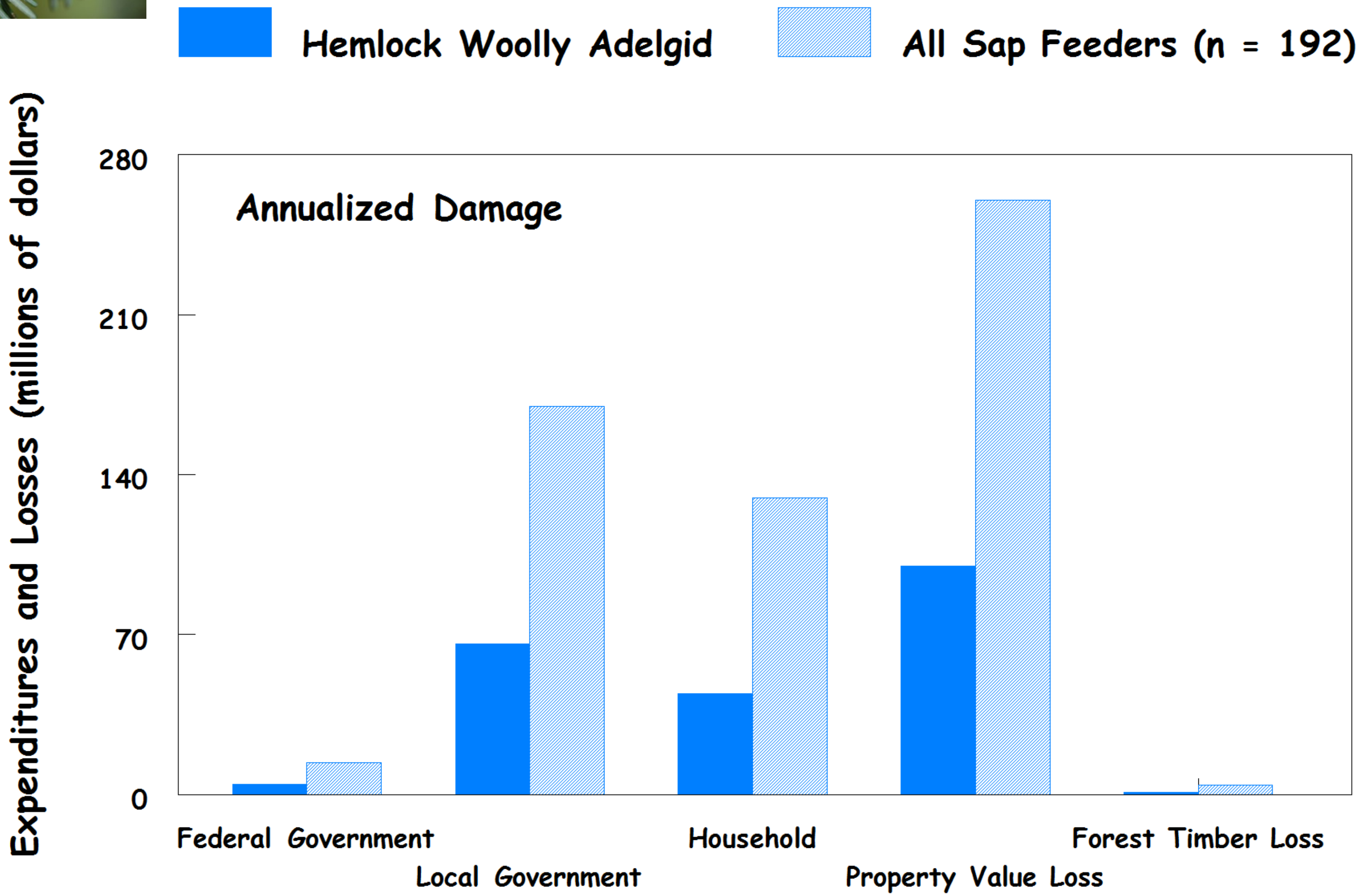
US expenditures on invasive species cost > $120 billion annually

UK, Australia, India, Brazil, South Africa > $330 billion annually

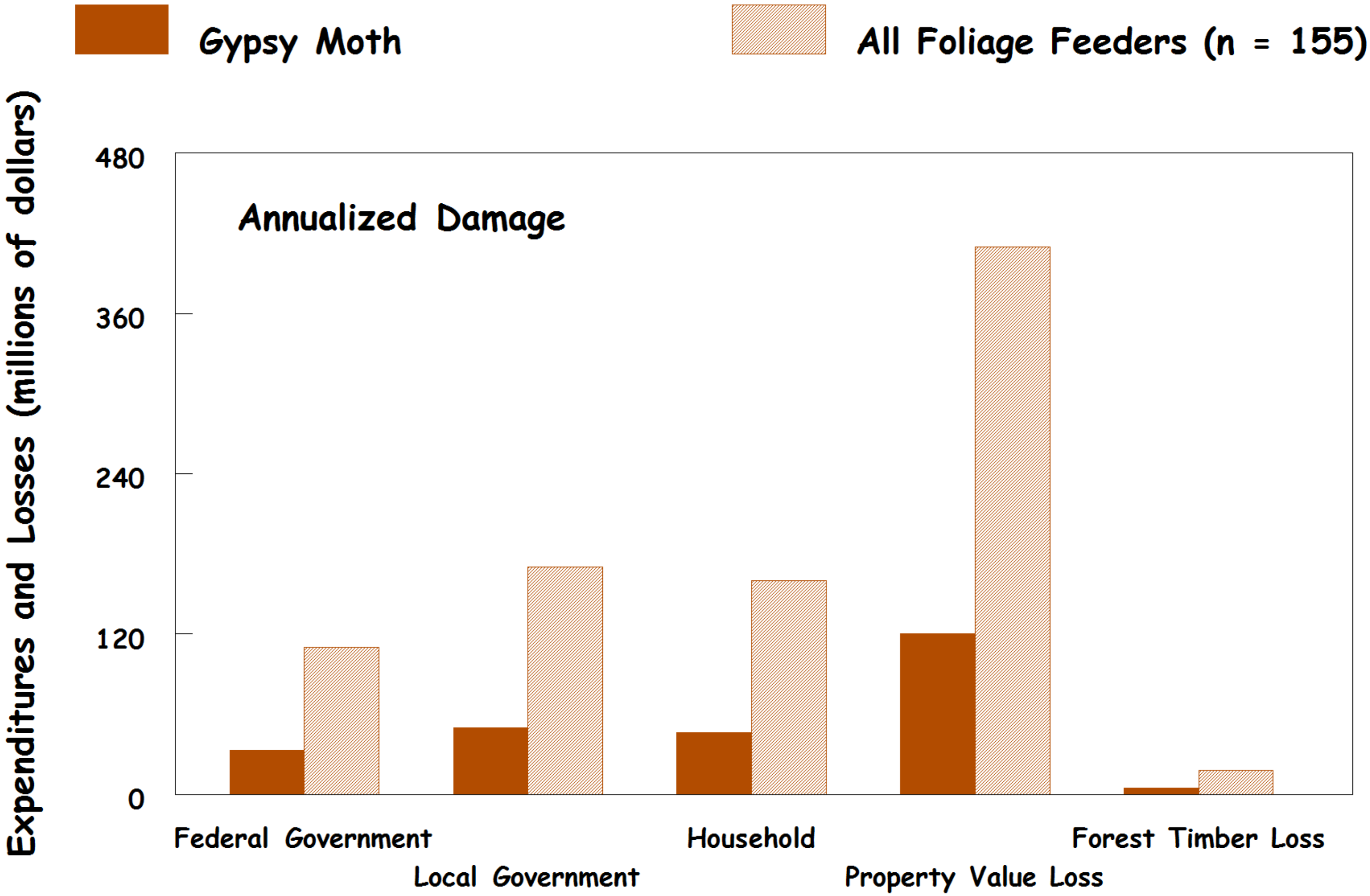
Expenditures include detection and prevention of invasions, eradication and management attempts, crop loss, public health costs, lost property values, disrupted cultural activities



Aukema et al. 2011

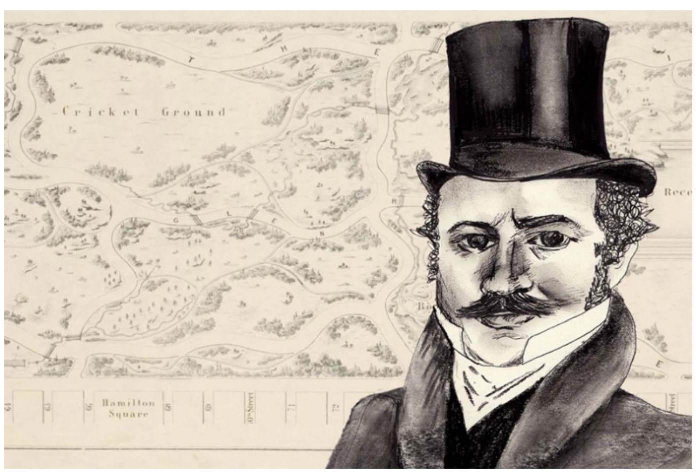


Aukema et al. 2011



Aukema et al. 2011

Quirky societies of the 18th and 19th centuries were devoted to introducing "useful" species into area where they were not found. This resulted in invasions of animals like starlings and blackbirds to North America. Eugene Schieffelin, a member of one of these societies, released 100 starlings in Central Park, NY in 1890. His mission was to establish all birds mentioned by Shakespeare to the New World. Thanks Eugene.



Insects as weapons of bioterrorism?

In World War II, the mass production and release of Colorado potato beetles to destroy enemy food supplies was considered.

Disease-carrying fleas were sprayed from low-flying airplanes and bombs packed with flies and a slurry of cholera bacteria were dropped. An estimated 440,000 people died.

During the Cold War, a facility to produce 100 million yellow-fever-infected mosquitoes a month was planned, an "Entomological Warfare Target Analysis" of vulnerable enemy sites was created and the dispersal and biting capacity of (uninfected) mosquitoes was tested by secretly dropping the insects over cities.

Jeffrey Lockwood "Six-Legged Soldiers: Using Insects as Weapons of War (Oxford)"

Insect pests of eucalyptus in California – A case of domestic bioterrorism?

Photo credits – UC System

FORUM

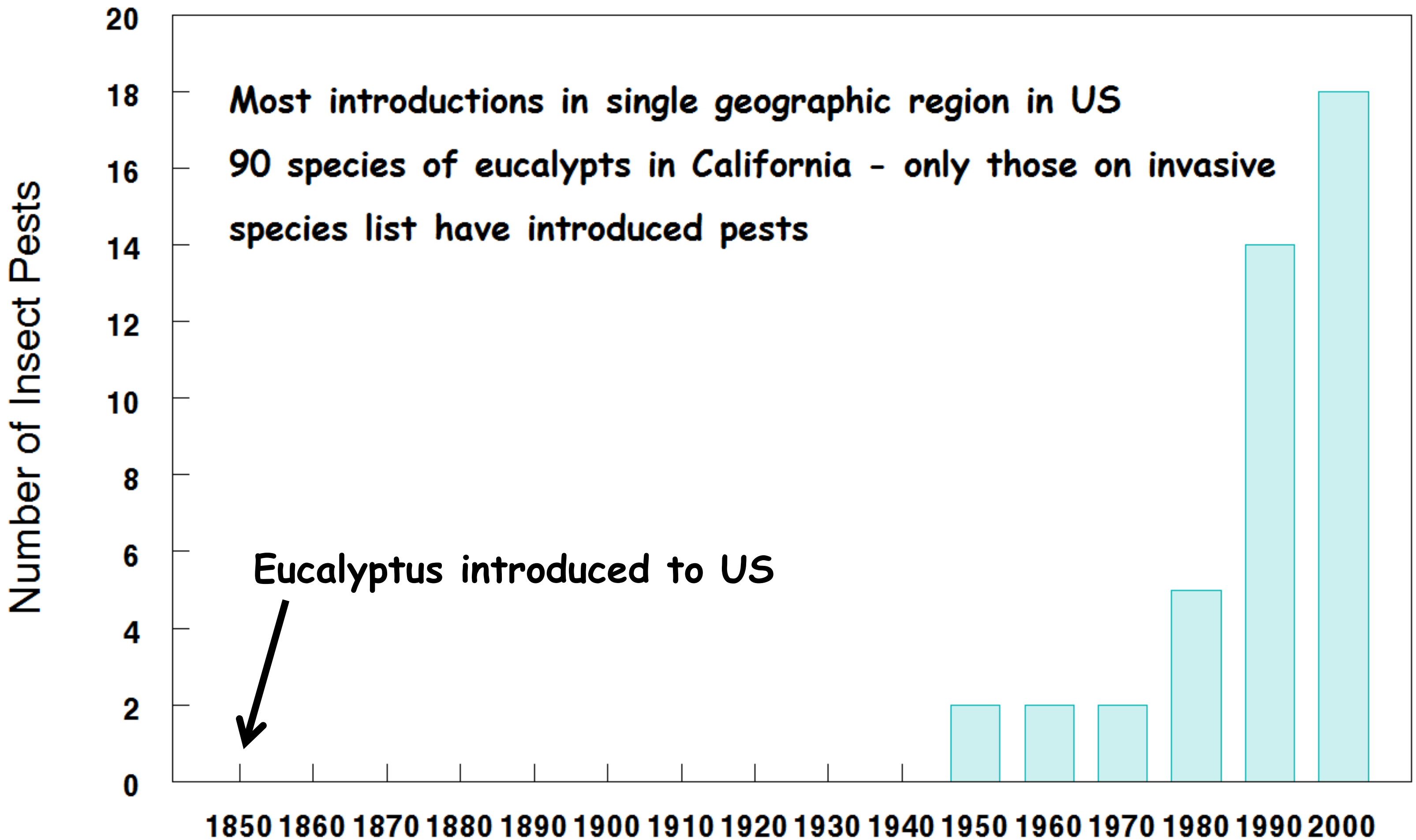
Accumulation of Pest Insects on Eucalyptus in California: Random Process or Smoking Gun

TIMOTHY D. PAINE,[1,2] JOCELYN G. MILLAR,[1] AND KENT M. DAANE[3]

J. Econ. Entomol. 103(6): 1943–1949 (2010); DOI: 10.1603/EC10214

ABSTRACT *Eucalyptus* spp., native to Australia, have been introduced into many parts of the world as important timber and ornamental trees. Although the trees have important silvicultural qualities, they also have generated intense dissatisfaction, particularly among groups of individuals in California. The trees have benefited from the lack of insect pests and diseases in their adventive ranges but that has changed over the past four decades. In California, two species of insect herbivores were introduced between the time trees were first introduced to the state in the middle of the 19th century and 1983. Between 1983 and 2008, an additional 16 Australian insect pests of eucalyptus have become established in the state. The modes or routes of introduction have never been established. However, examinations of different temporal and spatial patterns suggest that the introductions were nonrandom processes. It is possible that they occurred because of increased trade or movement of people, but the hypothesis that there were intentional introductions also must be considered. The rapid accumulation of introduced herbivores on an ornamental plant system in a single state is a cautionary example of what could happen if a major food or fiber crop were intentionally targeted.

KEY WORDS *Eucalyptus*, invasive species, intentional introductions, insect herbivores, adventive range


Most introductions in single geographic region in US
90 species of eucalypts in California - only those on invasive species list have introduced pests
Eucalyptus introduced to US
Number of Insect Pests
0
2
4
6
8
10
12
14
16
18
20
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

How can we enhance resiliency in urban forests?

1. Increase biodiversity – genetic, species, plant communities – involve landscape architects, desingers, and urban planners
2. Use native and non-native plants to enhance ecosystem services - alternative resources for pollinators and natural enemies - more flowering plants
3. Reduce threats of importing exotic species – legislation - tools, education, and training needed to enhance early detection, rapid mitigatation
4. Mitigate climate change though use of fossil fuels, plant more trees, shrubs and ground covers
5. Replace impervious surfaces with ones that allow infiltration – more green spaces in urban areas
6. Apply soil amendments, nutrients and pesticides on a prescription basis

Michael J. Raupp

With Chalara dieback of ash, you surely don't want to see me. So keep me out and enjoy the rest of the conference.

Bartlett Tree

University of Maryland,
Department of Physical Plant

United States National Arboretum

Central Park Conservancy

13 North American Cities

212 Homeowners in MD

NRI USDA (2005-35303-16269)
USDA-NIFA-SCRI (2011-51181-30937)
International Society of Arboriculture - Tree Fund (2005)
McIntire Stennis Project (No. MD-ENTM-0416)
Maryland Agricultural Experiment Station -#MD-ENTO-8732 for supporting this research.

Arboricultural Association® cares for trees

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