Looking for black and white in the grey: Predicting the impact of non-native insects on North American host trees

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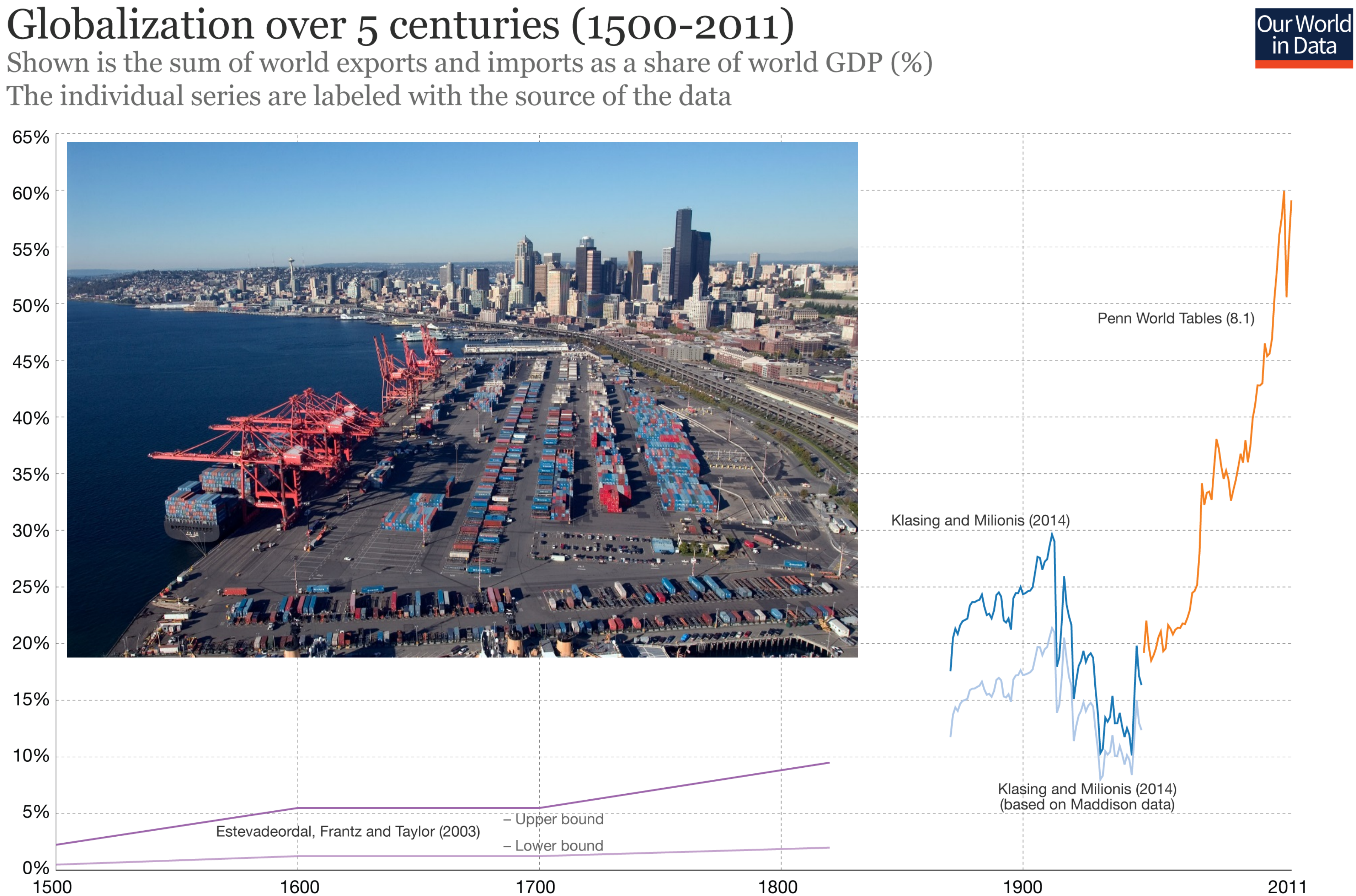
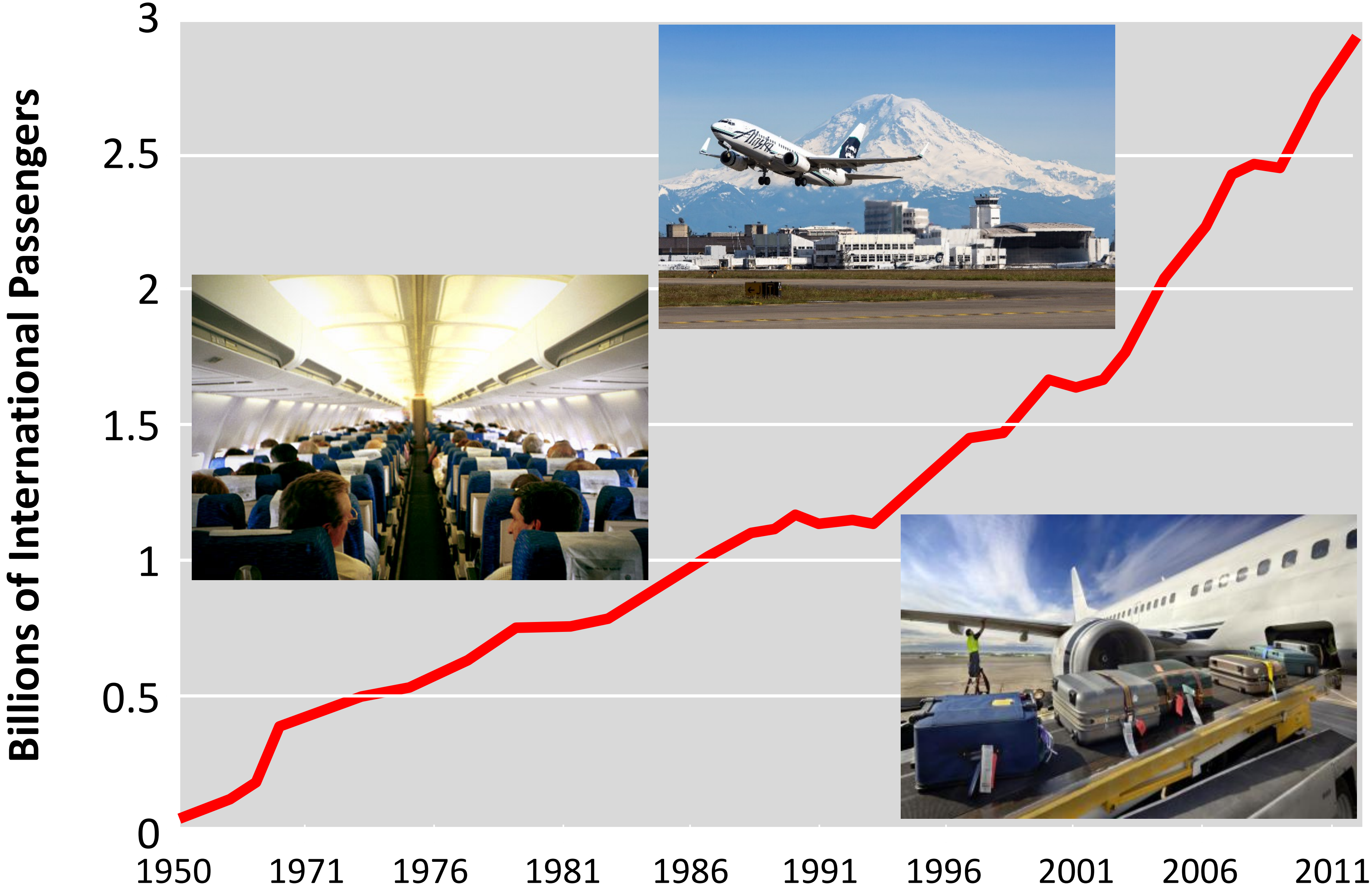
Global Trade over the last 500 Years



Data sources: Klasing and Milionis (2014), Estavadeordal, Frantz and Taylor (2003) and the Penn World Tables Version 8.1
The interactive data visualization is available at OurWorldinData.org. There you find the raw data and more visualizations on this topic.

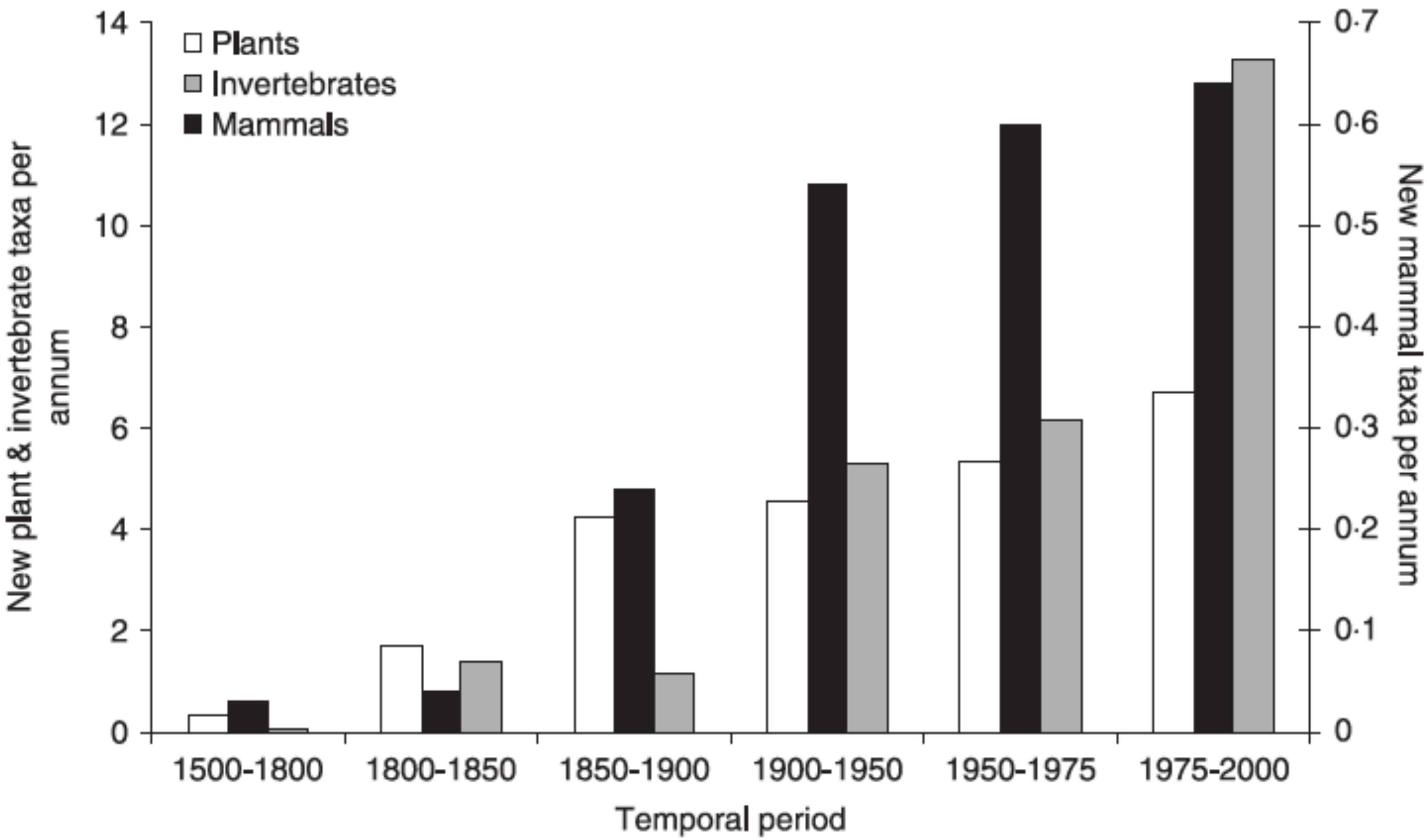
Passenger Air Traffic, 1950-2011



Source: International Civil Aviation Organization

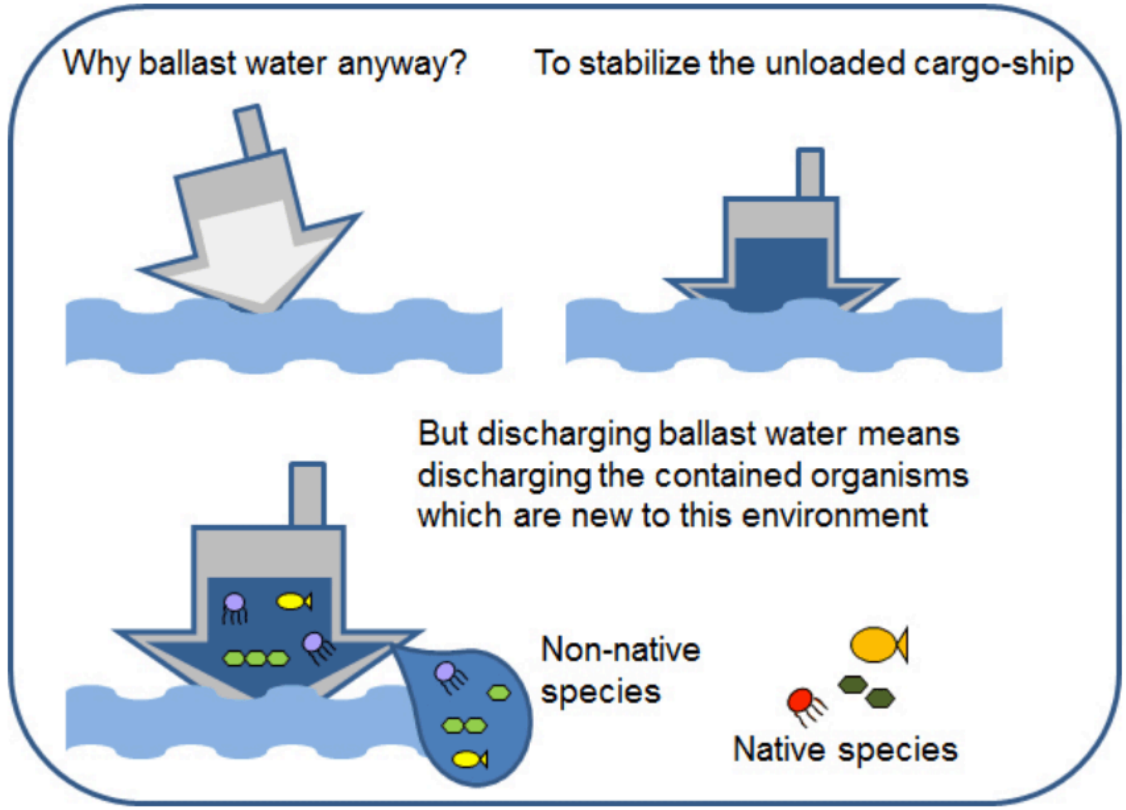
Movement of Biota by Humans

Linking trade to new non-native species: introduction into Europe by taxonomic group



Hulme (2009) *J. Applied Ecology* 46:10

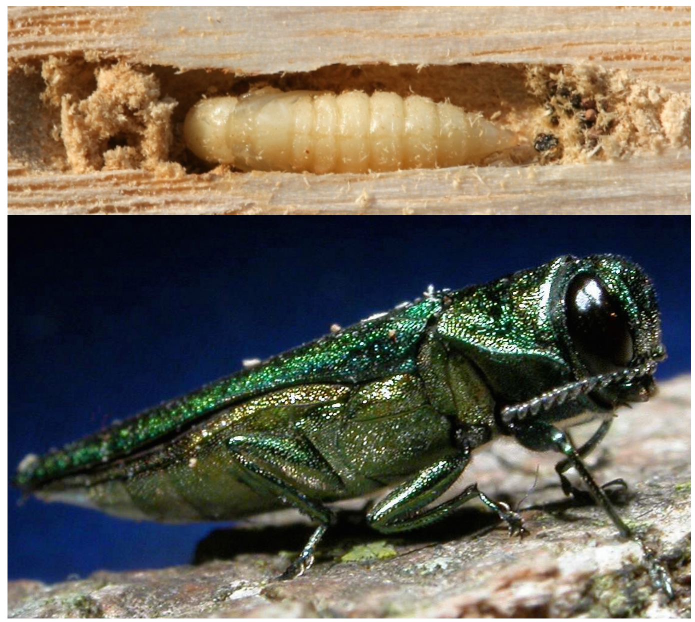
The increase in invasions by invertebrates



Zebra mussels

The increase in invasions by invertebrates

Solid wood packing material used in global trade



Emerald ash borer

Ash trees killed by emerald ash borer in Toledo, OH (Photo Credit: Dan Herms)

What we know:

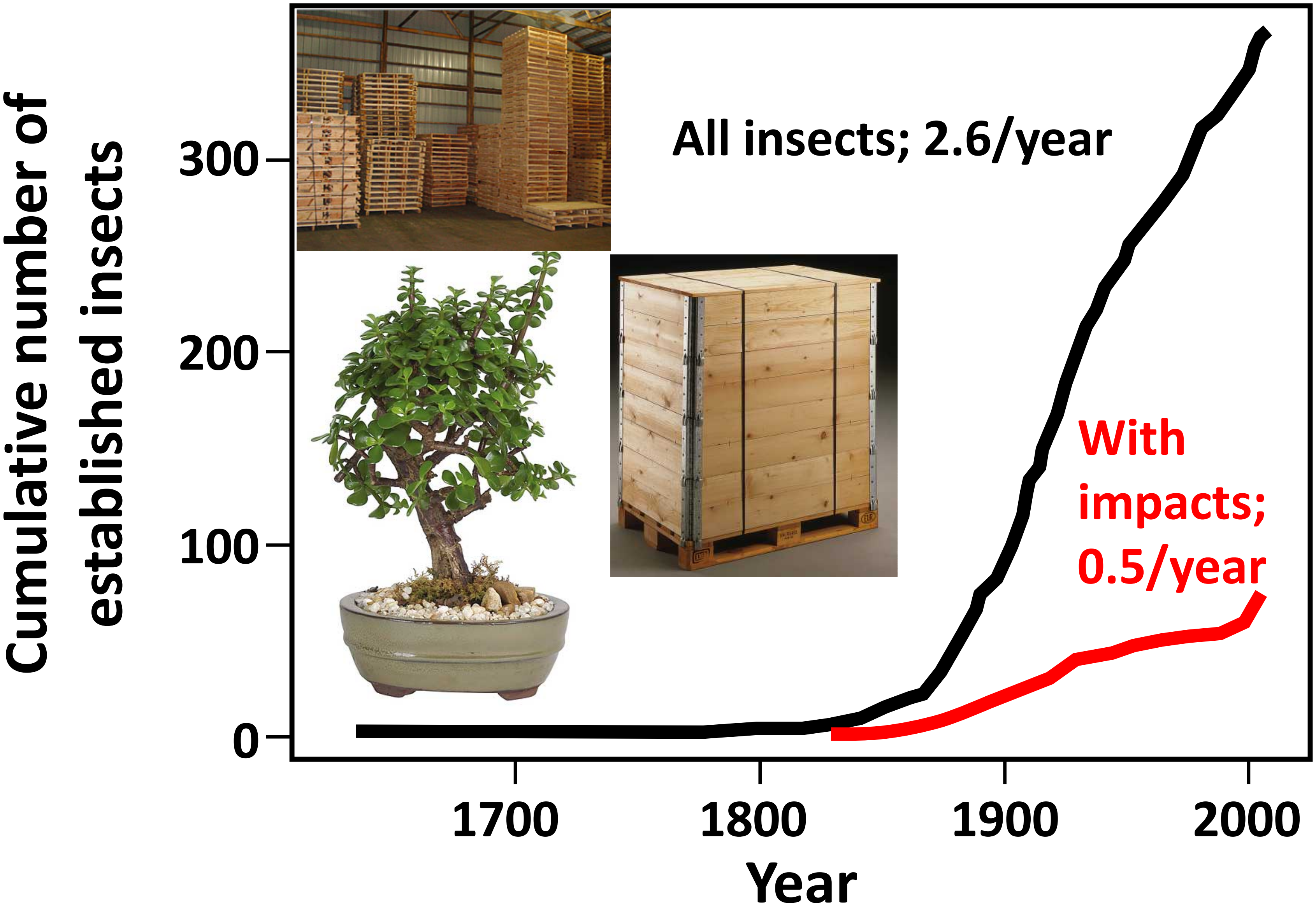
Lots of variation in establishment success!

Although difficult to quantify, it is believed that only a minority of arriving species successfully establish in a new area (<20%)

There is even more variation in what will ultimately be invasive or noxious

The "tens" rule: 1 of 10 species will successfully establish; 1 of 10 of them will become a pest

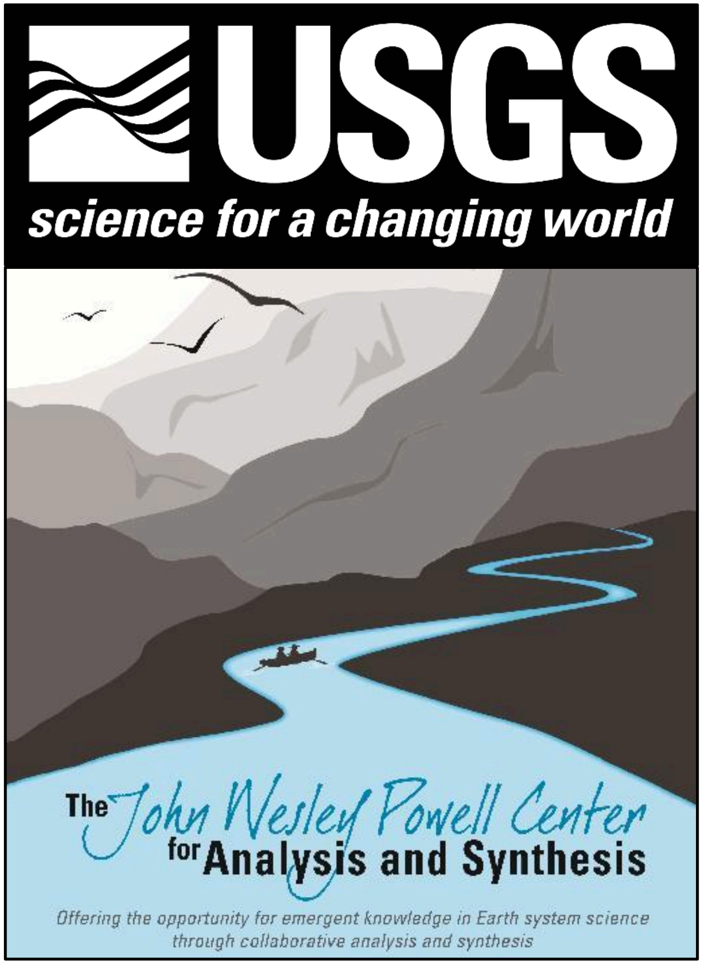
Non-native forest insect establishment in the United States



Aukema *et al*. (2010) *Bioscience* 60:886

Biological invasions: a known unknown
New species will continue to arrive, but we do not know which will be invasive/noxious or where they will be invasive/noxious

Can we turn this into a known known: can we better predict which species will be invasive/noxious and where?



Craig Allen – USGS/University of Nebraska
Matt Ayres – Dartmouth College
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Jessica Gurevitch – Stony Brook University
Nathan Havill – USDA Forest Service
Dan Herms – Ohio State University
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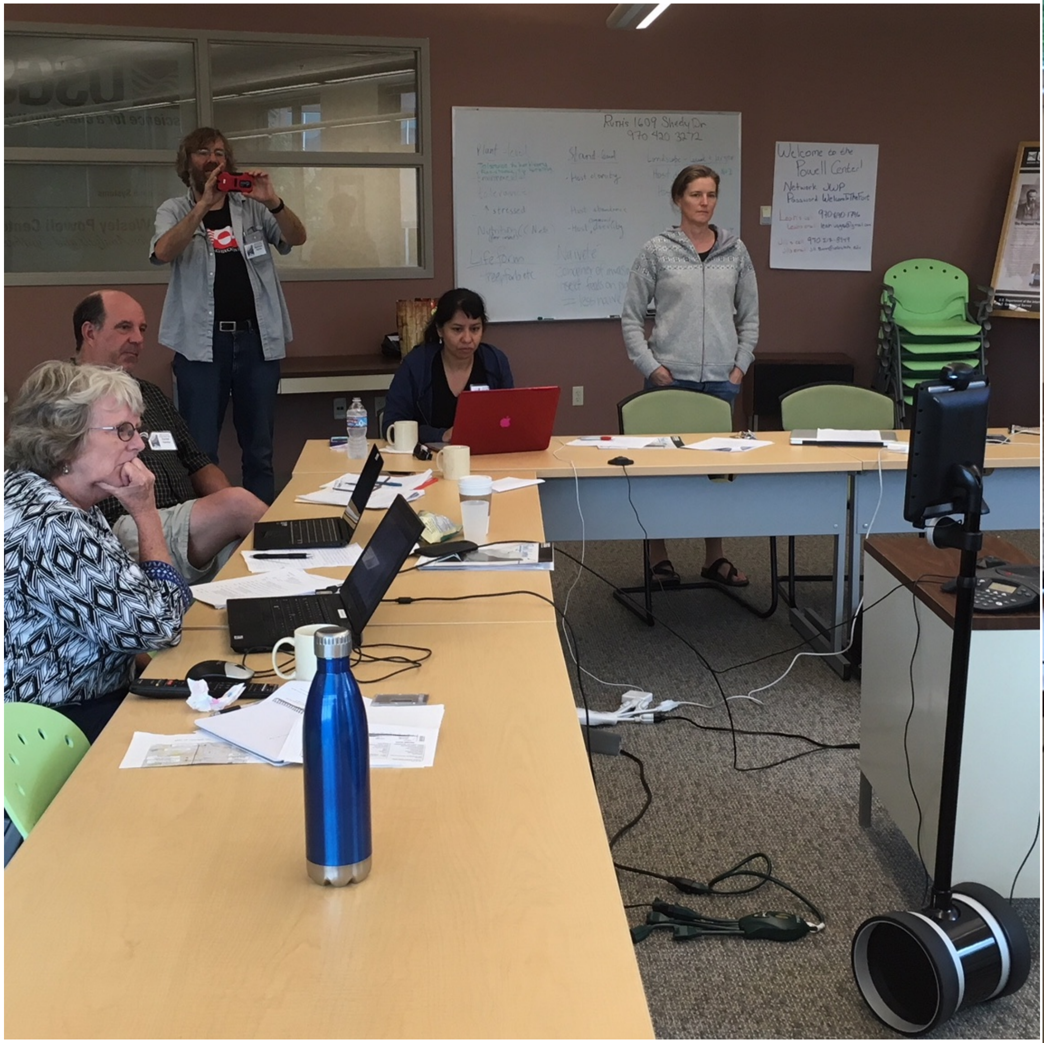
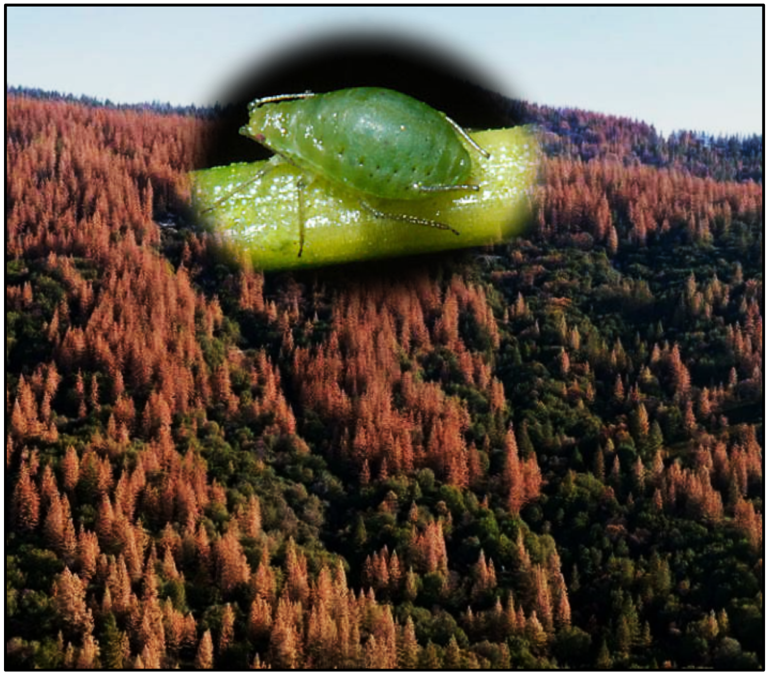
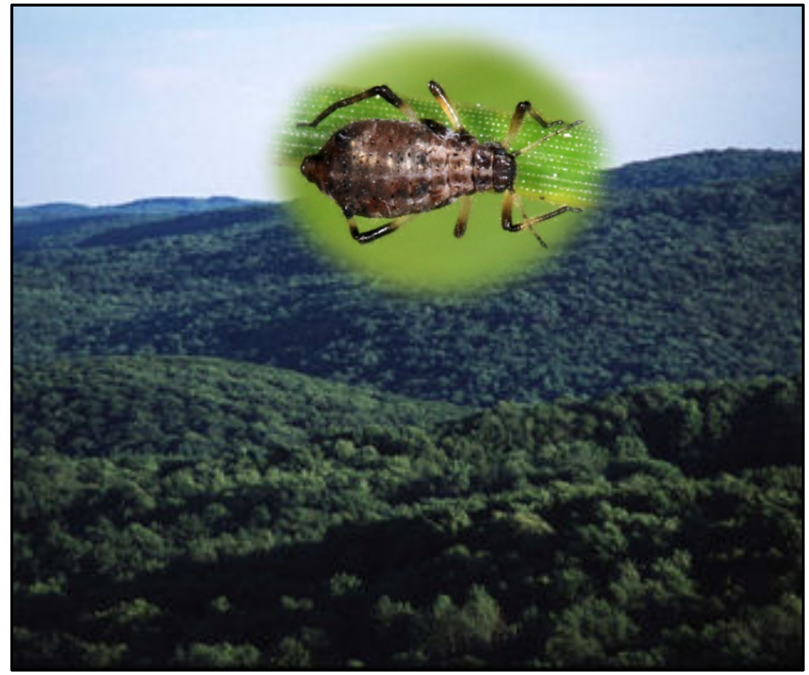
Travis Marsico – Arkansas State University
Angela Mech – University of Washington
Ken Raffa – University of Wisconsin
Michael Raupp – University of Maryland
Ashley Schulz – Arkansas State University
Kathryn Thomas – USGS
Patrick Tobin – University of Washington
Dan Uden – University of Nebraska



< 20% Cause Damage

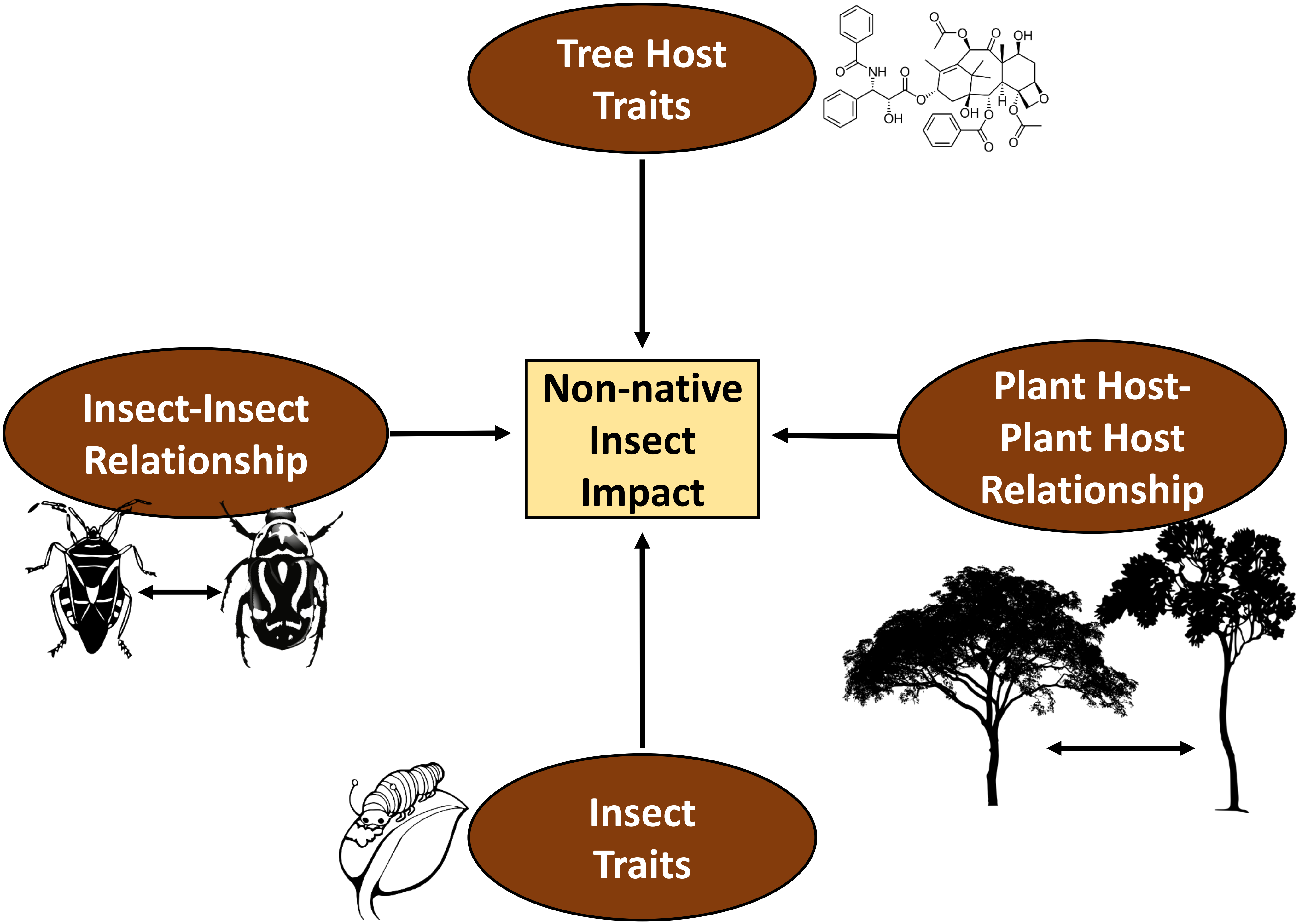


> 80% Cause No Damage



Multi-Billion Dollar Question

What are the factors that determine the impact of a non-native insect species?



Tree Host Traits
Insect-Insect Relationship
Non-native Insect Impact
Plant Host-Plant Host Relationship
Insect Traits

Impact on North American Hosts

No damage	Minor damage	Kills only stressed tree	Weakens tree; something else causes mortality	Kills healthy tree	Isolated/ Sporadic Mortality in population	Extensive/ Persistent Mortality in population	Wave of mortality across region	Functional Extinction
1	2	3	4	5	6	7	8	9

Low Impact (1–2)

Medium Impact (3–5)

High Impact (6–9)

Biol Invasions (2015) 17:3049–3061
DOI 10.1007/s10530-015-0935-y

CrossMark

ORIGINAL PAPER

Comparison of insect invasions in North America, Japan and their Islands

Takehiko Yamanaka · Nobuo Morimoto · Gordon M. Nishida · Keizi Kiritani · Seiichi Moriya · Andrew M. Liebhold

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Abstract Among the various animal taxa that are have established outside their native ranges, invasions by insect species are the most numerous worldwide. In order to better understand the characteristics of insect movement. Among the five regions, the oceanic islands, Hawaii and Ogasawara, appear to be the most prone to invasions. Specific insect orders such as the Blattodea, Siphonaptera, Thysanoptera and Hemiptera

Articles

Historical Accumulation of Nonindigenous Forest Pests in the Continental United States

JULIANN E. AUKEMA, DEBORAH G. McCULLOUGH, BETSY VON HOLLE, ANDREW M. LIEBHOLD, KERRY BRITTON, AND SUSAN J. FRANKEL

Nonindigenous forest insects and pathogens affect a range of ecosystems, industries, and property owners in the United States. Evaluating temporal patterns in the accumulation of these nonindigenous forest pests can inform regulatory and policy decisions. We compiled a comprehensive species list to assess the accumulation rates of nonindigenous forest insects and pathogens established in the United States. More than 450 nonindigenous insects and at least 16 pathogens have colonized forest and urban trees since European settlement. Approximately 2.5 established nonindigenous forest insects per year were detected in the United States between 1860 and 2006. At least 14% of these insects and all 16 pathogens have caused notable damage to trees. Although sap feeders and foliage feeders dominated the comprehensive list, phloem- and wood-boring insects and foliage feeders were often more damaging than expected. Detections of insects that feed on phloem or wood have increased markedly in recent years.

Keywords: invasive pests, forest insects, forest pathogens, feeding guild, detection rates

Nonindigenous insects and pathogens pose a significant threat to the productivity and diversity of forest ecosystems in the United States (Liebhold et al. 1995, Wilcove et al. 1998, Simberloff 2000, Allen and Humble 2002). Awareness of the ecological and economic impacts Act (1912). Subsequent regulatory efforts arose from the Organic Act (1944), the International Plant Protection Convention (1952), the Federal Plant Pest Act (1957), the National Environmental Policy Act (1970), and the Plant Protection Act (2000). Within the United States

Yamanaka *et al.* (2015): list of non-native insects in North America: ~3,500 species, of which ~1,900 species are herbivorous

Subset to non-native forest herbivorous insects using Aukema *et al.* (2010): ~450 species

Conducted initial study on conifer specialists (49 North American conifer host species)

Cupressaceae

Calocedrus
Chamaecyparis
Cupressus
Juniperus
Taxodium
Thuja

Pinaceae

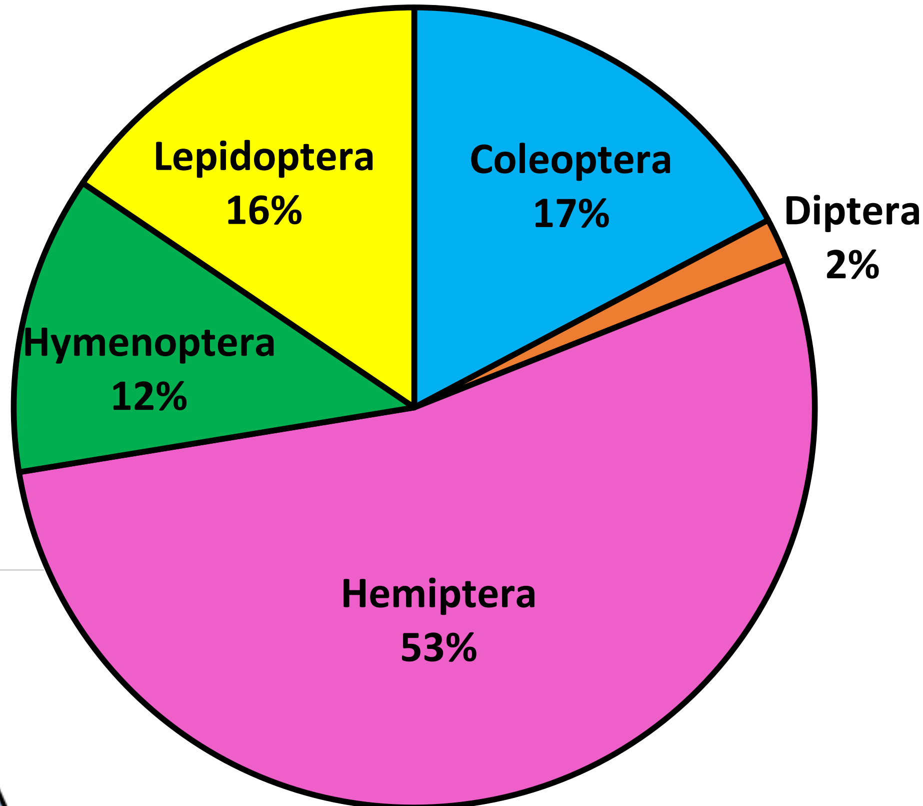
Abies
Larix
Picea
Pinus
Pseudotsuga
Sequoia
Tsuga

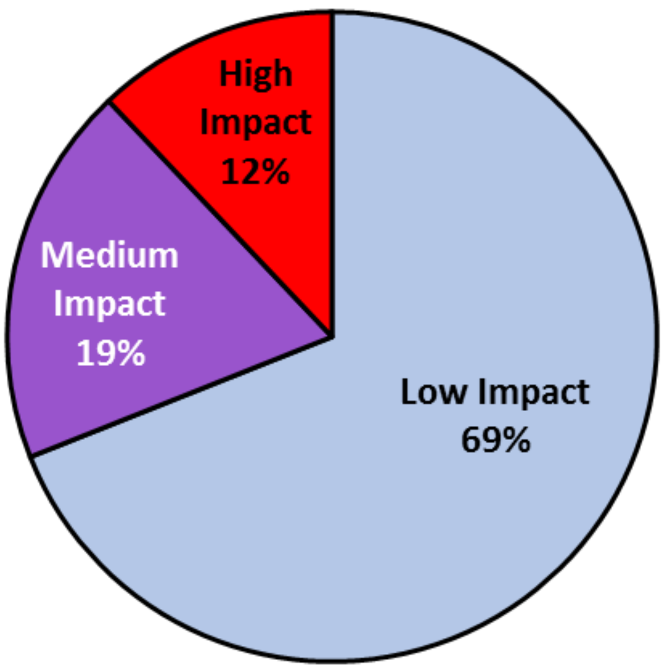
Taxaceae

Taxus

*Two NA genera with no association with non-native insects (*Sequoiadendron* & *Torreya*)

58 Conifer Specialist Species (5 taxonomic orders)



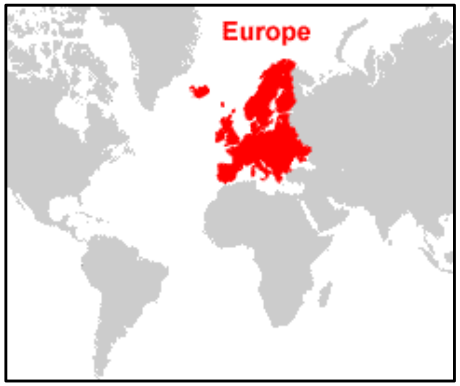


20 Families

Adelgidae
Aphididae
Cicadellidae
Coccidae
Diaspididae
Matsucoccidae
Miridae
Cecidomyiidae
Cerambycidae
Curculionidae
Cochylidae
Coleophoridae
Gelechiidae
Geometridae
Tortricidae
Yponomeutidae
Diprionidae
Pamphiliidae
Siricidae
Tenthredinidae

1. Insect Traits (*n* = 58 insect species)

Feeding Guild

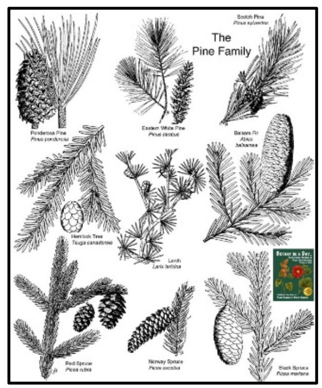


Native Range

Dispersal Mechanism

Fecundity

Reproductive Strategy



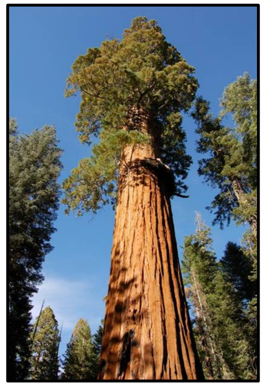
Host Genera in Native Range

Considered Pest in Native Range

No insect traits were found to influence impact

2. Host Plant Traits (*n* = 49 host species)

Shade Tolerance



Lifespan

Foliage Texture

Bark Thickness

Drought Tolerance

Carbon:Nitrogen

Growth Rate

Information-Theoretic Approach

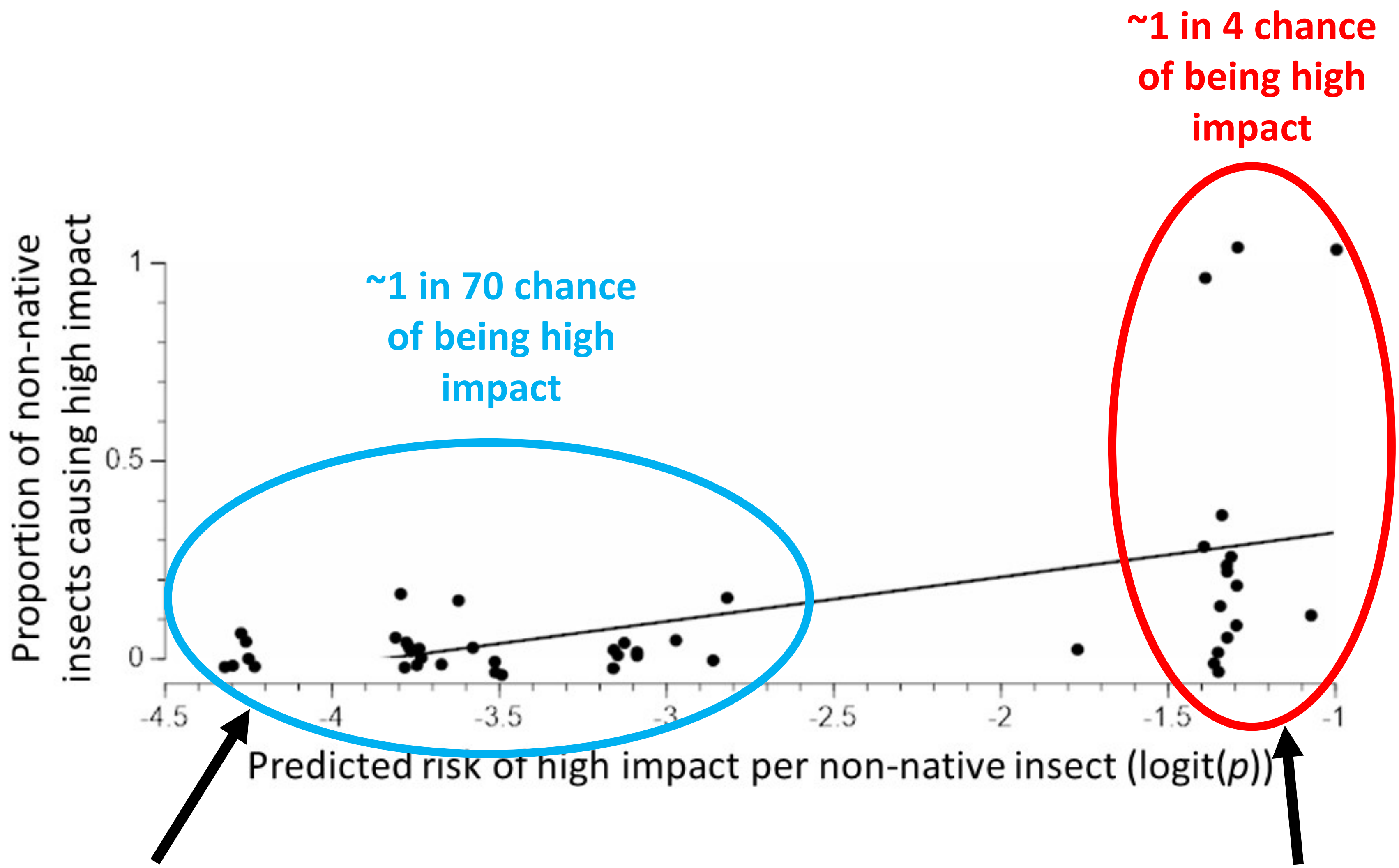
- Compares & ranks multiple, alternative, plausible models (i.e. hypotheses) based on degree of support from the data

Model	K	AICc	ΔAICc	w
Shade Tolerance + Drought Tolerance	6	109.5468	**0.0000**	0.7911
Growth Rate	3	114.7650	5.2182	0.0582
Wood Density + Growth Rate	4	114.9286	5.3817	0.0537
Wood Density	2	115.5670	6.0202	0.0390
Null Model	1	116.8493	7.3024	0.0205
Foliage Texture + Growth Rate	5	116.8634	7.3165	0.0204
Foliage Texture	3	118.6046	9.0578	0.0085
Drought Tolerance	4	119.1416	9.5947	0.0065
Global Model	14	121.8415	12.2946	0.0017
Fire Tolerance + Drought Tolerance	7	124.8342	15.2874	0.0004

Shade Tolerance & Drought Tolerance influence impact.

79% of AICc weight assigned to model → high level of support from data

P[High Impact] ~ Shade tolerance + Drought Tolerance



- **0% = High Shade Tolerance**
- **53% = Low Drought Tolerance**

- **100% = High Shade Tolerance**
- **88% = Low Drought Tolerance**

***Pinus, Larix, & Juniperus* species**

***Abies, Picea, & Tsuga* species**

Why High Shade Tolerance + Low Drought Tolerance?

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THE DILEMMA OF PLANTS: TO GROW OR DEFEND

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ABSTRACT

Physiological and ecological constraints play key roles in the evolution of plant growth patterns, especially in relation to defenses against herbivores. Phenotypic and life history theories are unified within the growth-differentiation balance (GDB) framework, forming an integrated system of

22 November 1985, Volume 230, Number 4728 SCIENCE

Resource Availability and Plant Antiherbivore Defense

Phyllis D. Coley, John P. Bryant, F. Stuart Chapin, III

Herbivores exert a major impact on plants, both in ecological and evolutionary time scales. Insects have caused greater economic loss to American agriculture than the combined effects of damage from drought and freezing and herbivory on different species can range from 0 to 100 percent during herbivore population outbreaks (4). This orders-of-magnitude range in herbivore damage among species within a single community is primarily a reflection of palatability

nature and quantity of plant defenses are determined by the resources available in the local habitat. We suggest that natural selection favors plants with slow growth rates and high levels of defense in environments with low resource availability and that plants with faster growth rates and lower defense levels are favored under conditions of high resource availability. We will first outline the proposal and present the evidence from natural systems and then discuss how these ideas compare with current theories on plant apparency and the evolution of plant defenses.

Resource Limitation and Plant Growth Characteristics

Resource Availability Hypothesis

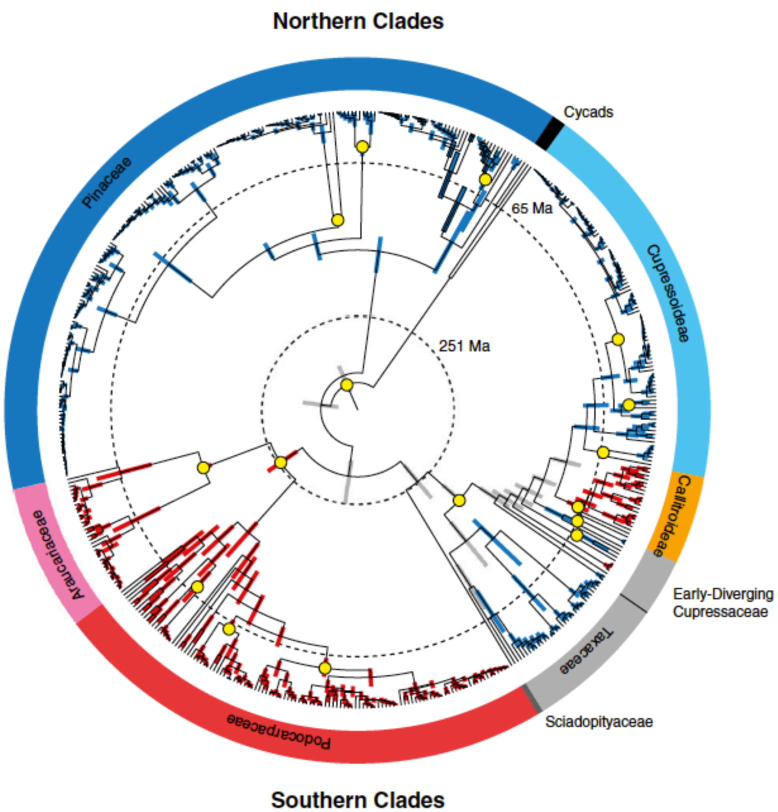
Shade Tolerant/Drought Intolerant Species

- Have a small carbon budget
- Lower concentration of constitutive defenses, perhaps they tend to be less attacked by native insects
- This could open a window of susceptibility to non-native specialists insects

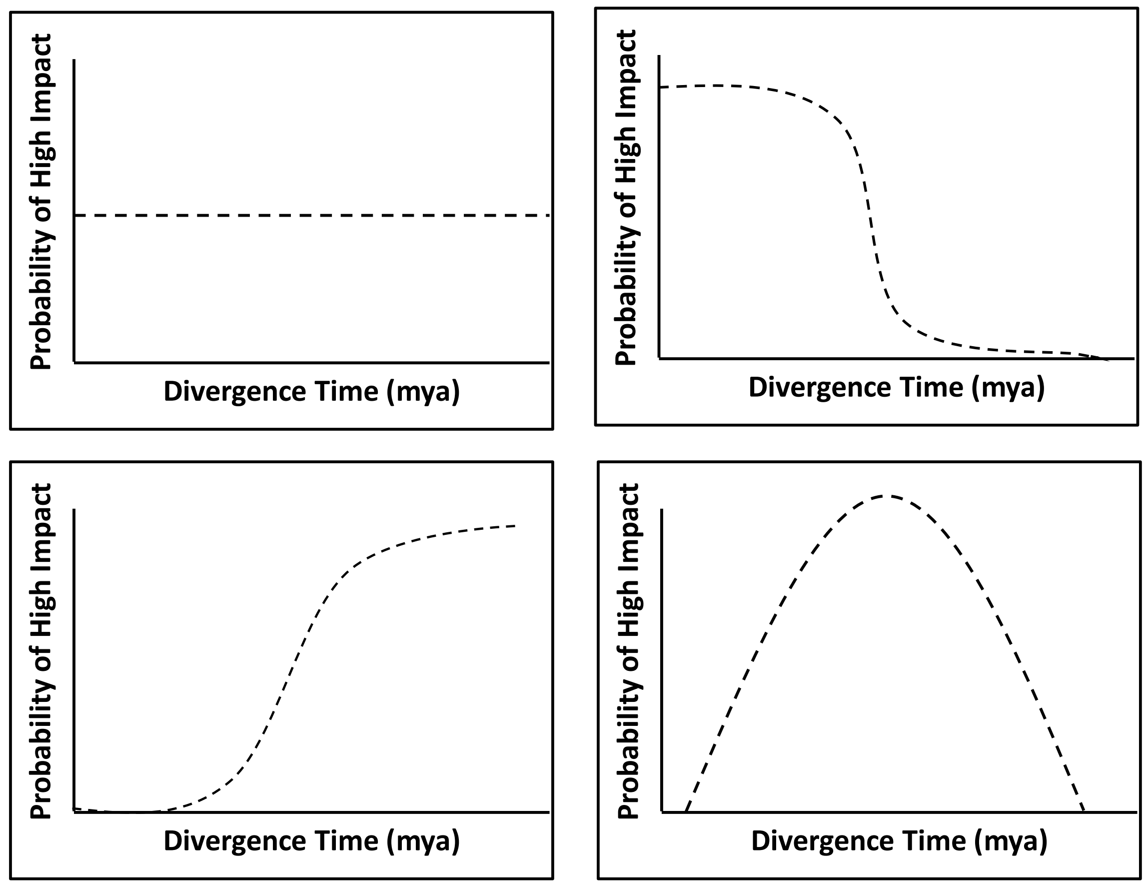
3. Native Host-North American Host Phylogenetic Distance (222 Host Pairs)

Red Pine ⟷ **Scots Pine**

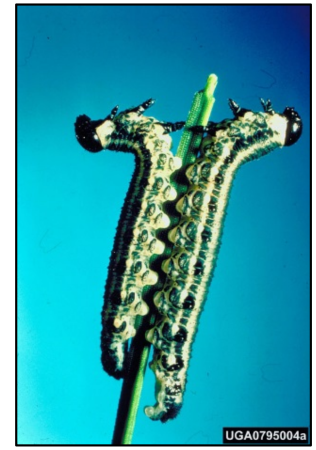
Divergence time to most recent common ancestor = 13.42 mya

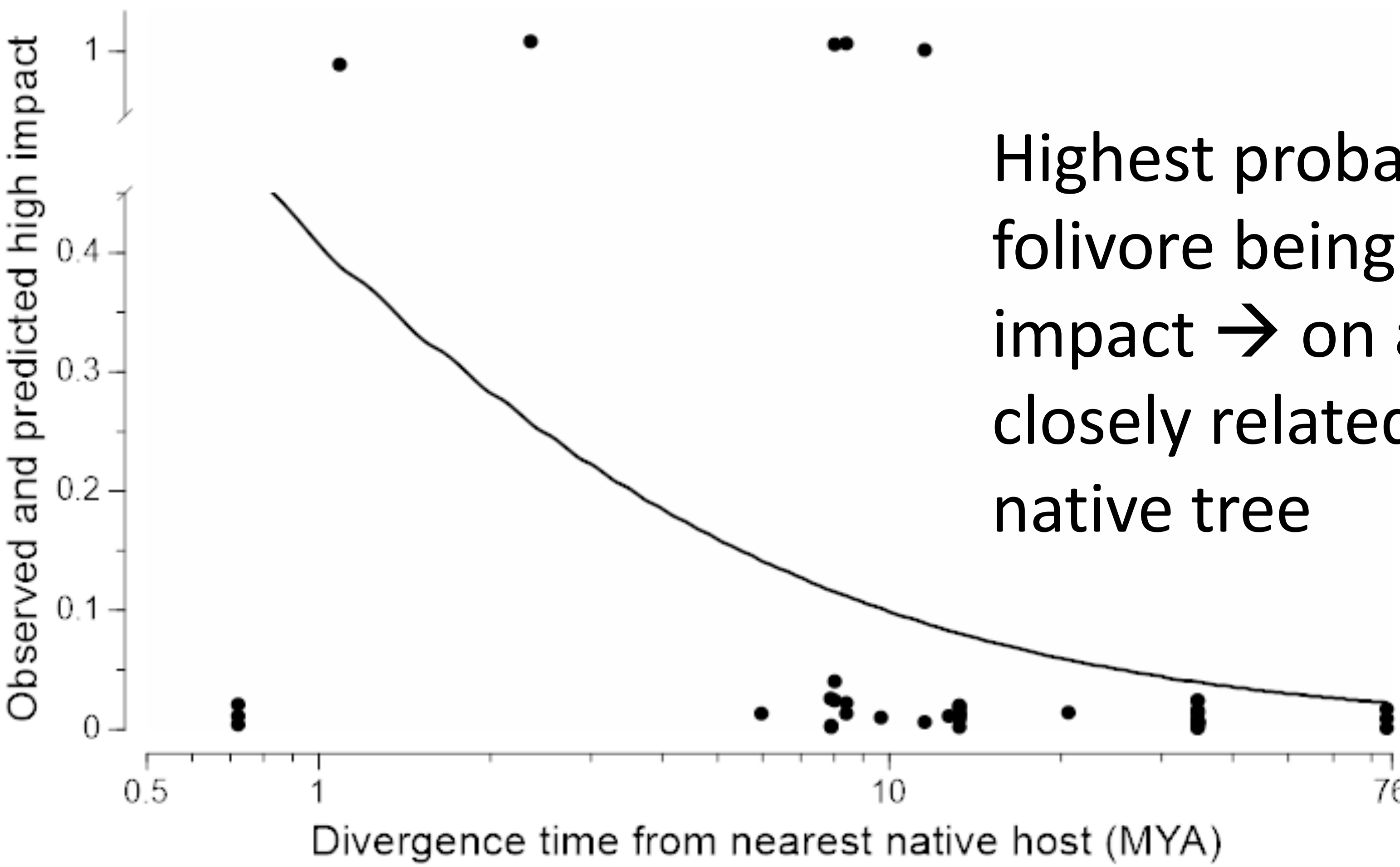


Leslie *et al*. (2012) *PNAS* 109:16271



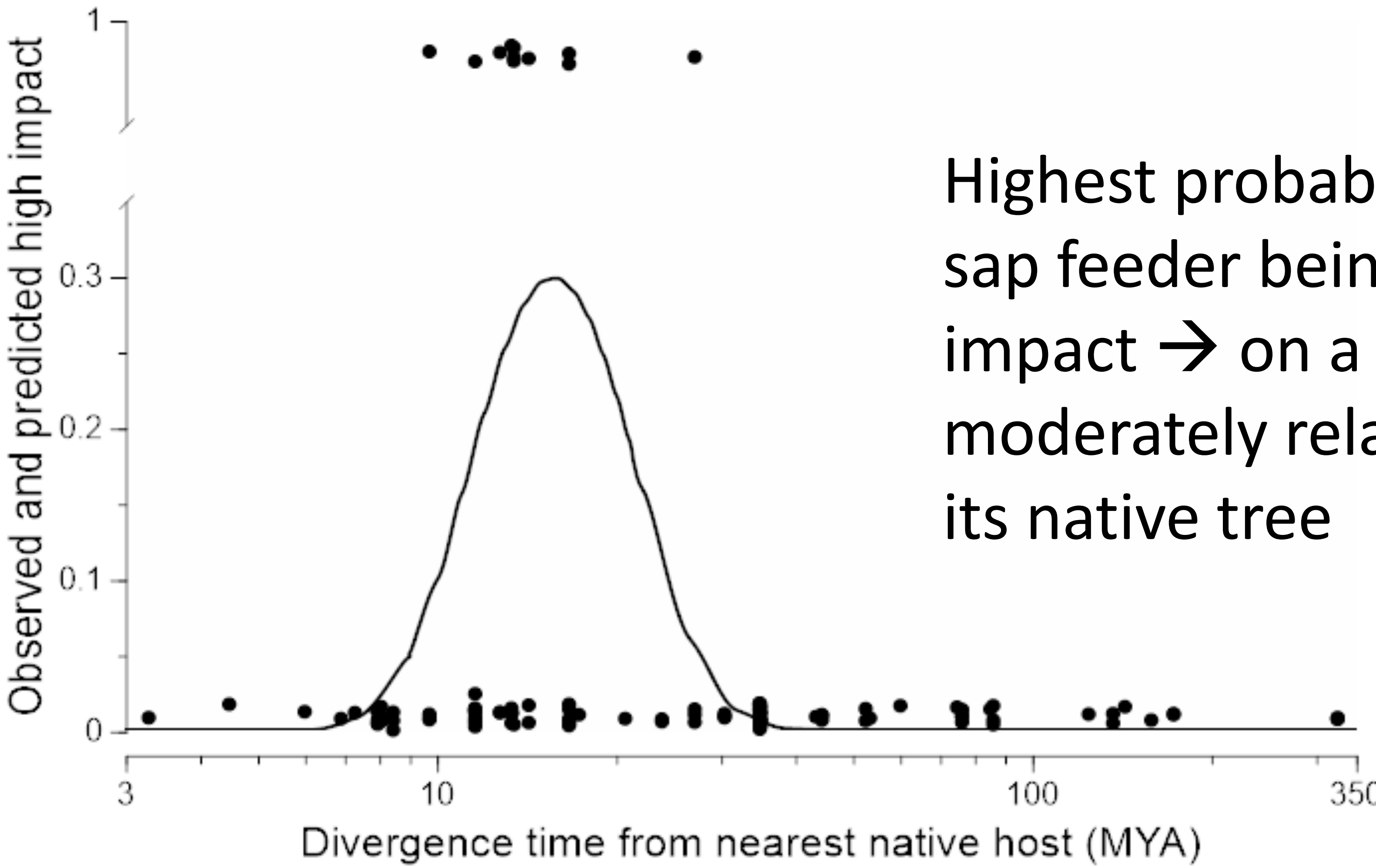
Native Host – North America Host Divergence and Folivores





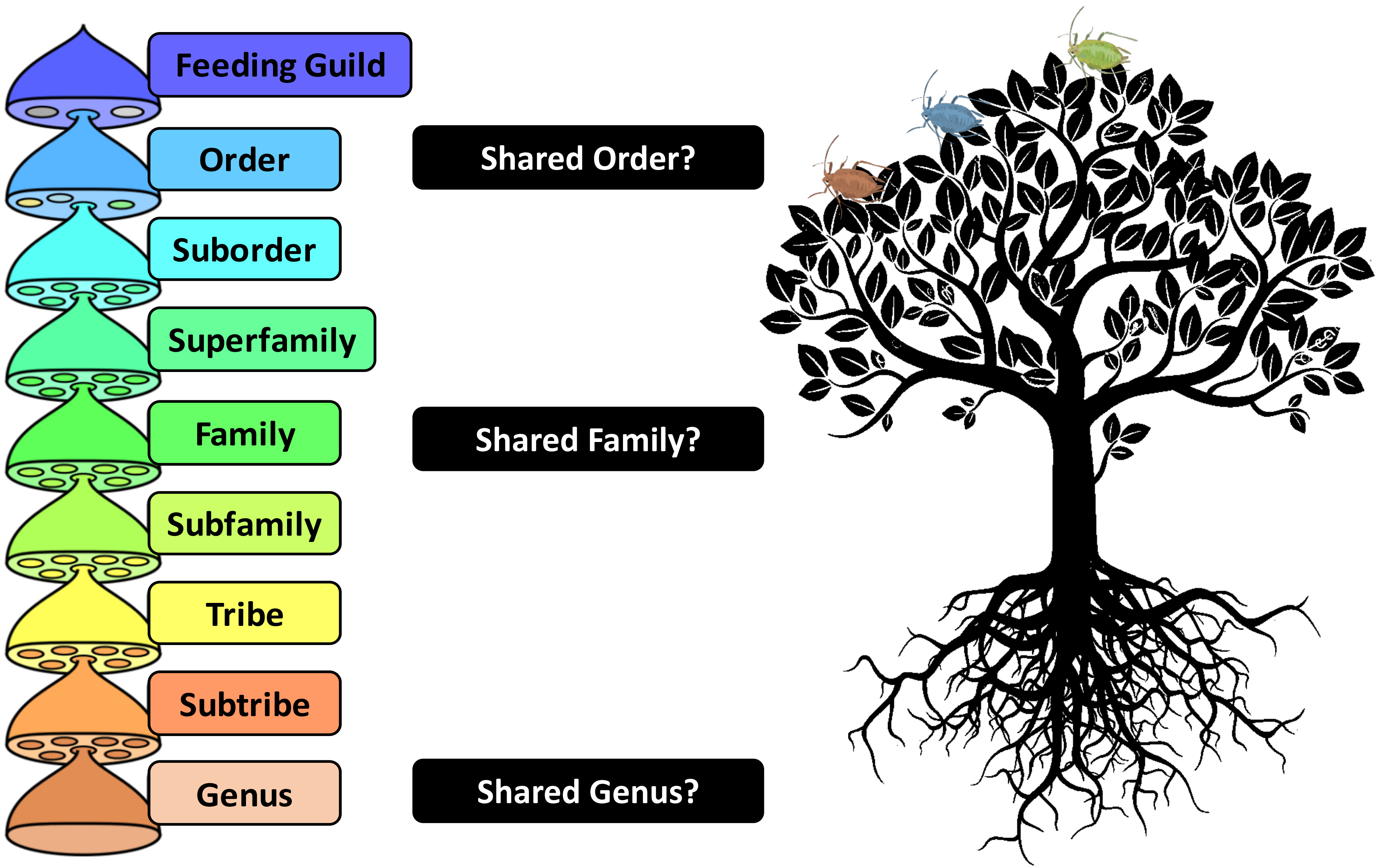
Highest probability of a folivore being high impact → on a tree closely related to its native tree

Native Host – North America Host Divergence and Sap Feeders



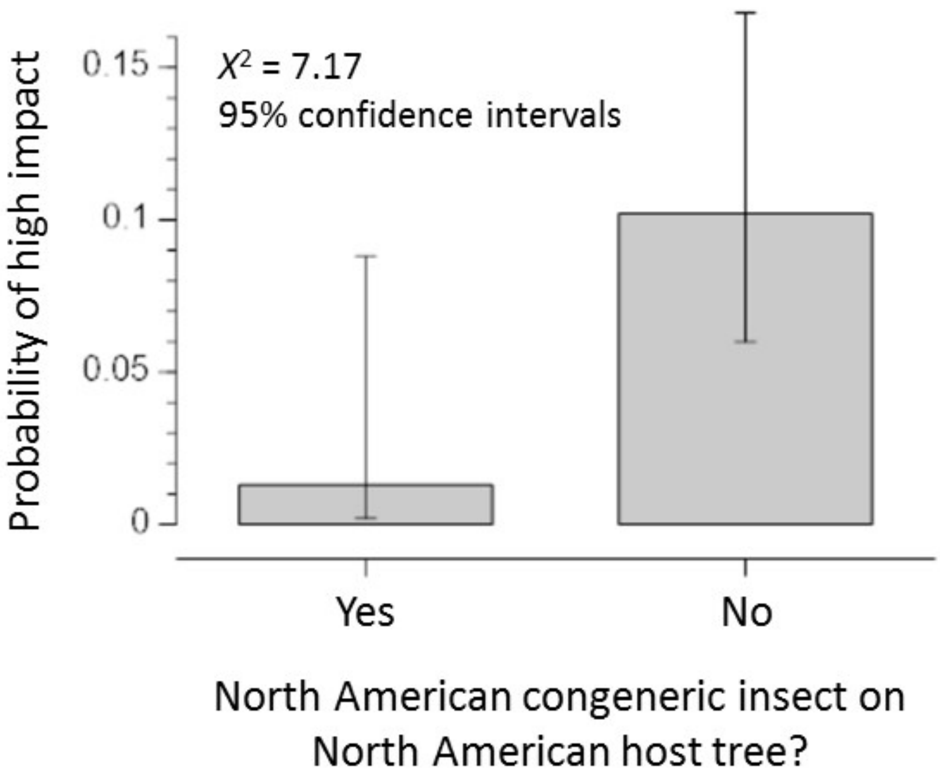
Highest probability of a sap feeder being high impact → on a tree moderately related to its native tree

4. Insect Relatedness
(*n* = 203 insect-insect-tree pairs)

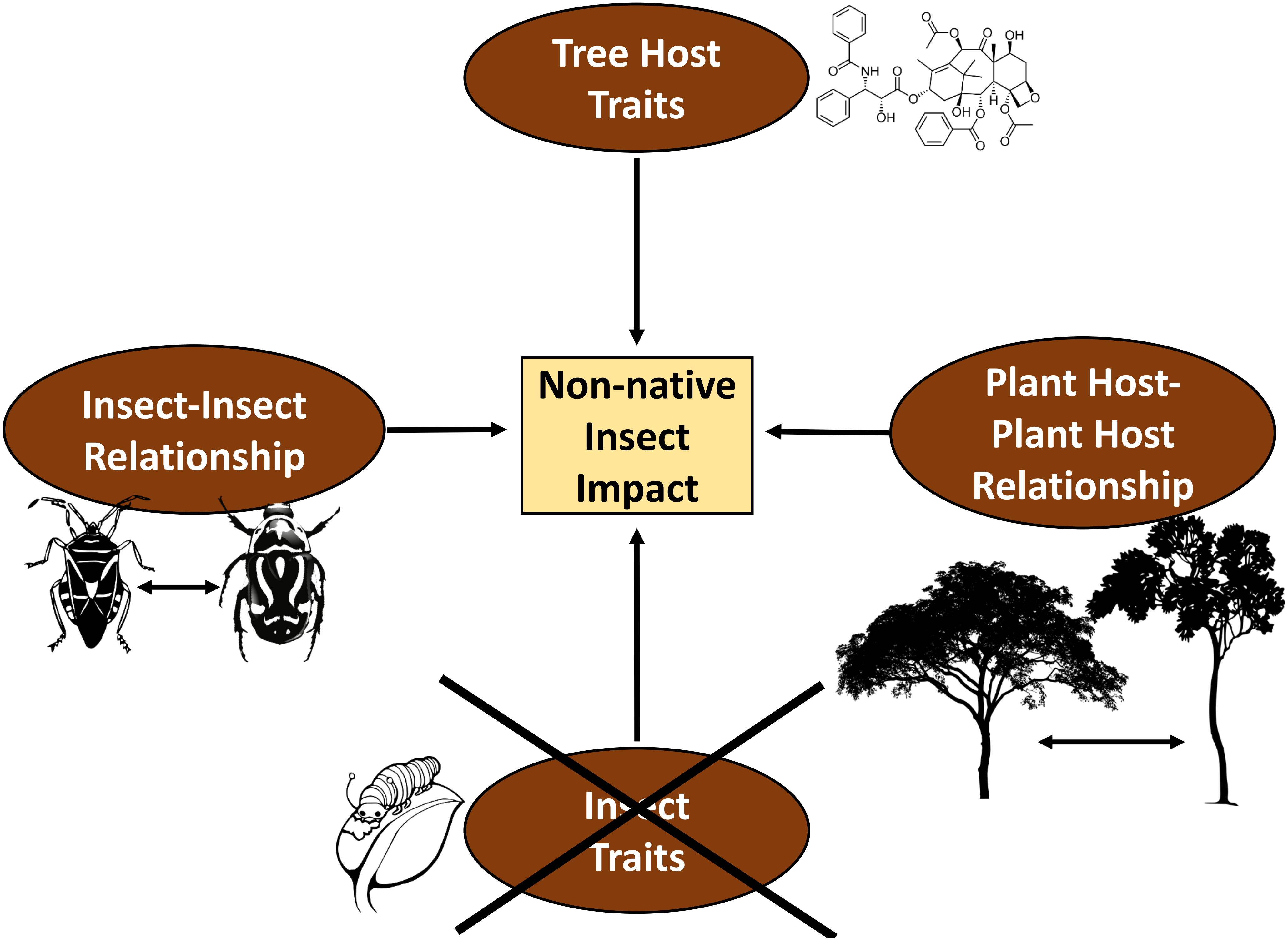


Insect Relatedness Model Comparison (3 models)

Model	K	AICc	ΔAICc	w
Shared genus	2	98.7783	0.0000	0.8909
Null model	1	103.9076	5.1293	0.0686
Shared family	2	104.9576	6.1793	0.0406



- **Tree could be adapted to similar feeding by congener, so not as sensitive**
- **Tree's defenses against congener could be effective against non-native**
- **Congener's natural predators could attack non-native insect**



Tree Host Traits
Non-native Insect Impact
Insect-Insect Relationship
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Insect Traits

Overall Composite Model

Predicted risk for insect (i) on tree (t) for model (m)

Observed high impact proportion for model (m)

Overall risk of insect (i) on tree (t)

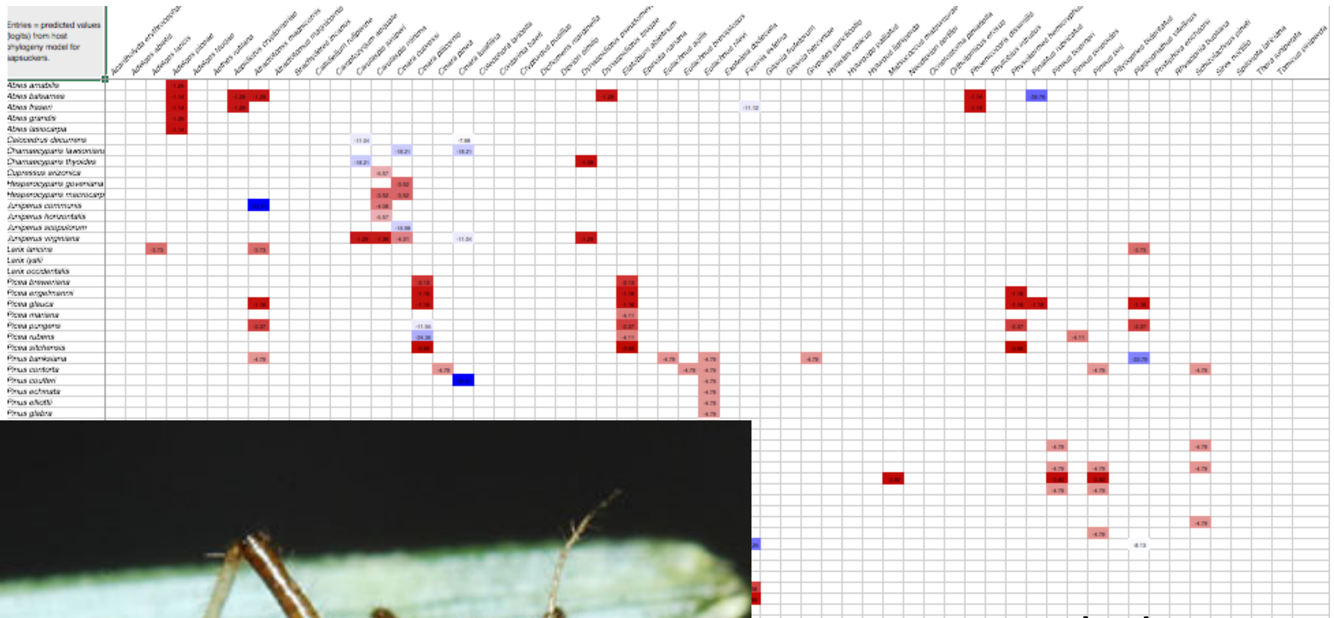
Observed high impact proportion for dataset (0.073)

$$R_{t,i} = \frac{\sum_{m=1}^{3} \operatorname{logit}(\widehat{P_{m,t,i}}) - \operatorname{logit}(P_{m..})}{N_m} + \operatorname{logit}(P_{...})$$

Number of models used (1-3)

Average of the 3 model residuals

Using our combined model (host plant traits, insect traits, host-host phylogeny, and insect phylogeny) in prediction



Large pine aphid
Native to Eurasia.
Pest on Scots pine, sometimes Corsican pine. Recently detected in North America

Entries = predicted values (logits) from host phylogeny model for sapsuckers.	*Cinara pinea*
Pinus banksiana	
Pinus contorta	~ 0.8%
Pinus coulteri	
Pinus echinata	
Pinus elliottii	
Pinus glabra	
Pinus monticola	
Pinus palustris	
Pinus ponderosa	~ 0.8%
Pinus pungens	
Pinus radiata	
Pinus resinosa	~ 44%
Pinus rigida	~ 0.8%
Pinus serotina	
Pinus strobus	~ 3.7%
Pinus taeda	~ 0.8%
Pinus virginiana	~ 0.8%

Future Directions

Using composite model to predict risk for non-native species not currently established (or very recently introduced) in NA

Currently modeling hardwood specialists

Expanding project to generalist herbivorous insects

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