Continental Dialogue, 2018

THE OHIO STATE UNIVERSITY

COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

A conceptual framework and practical solutions to forest invasions by PIPs

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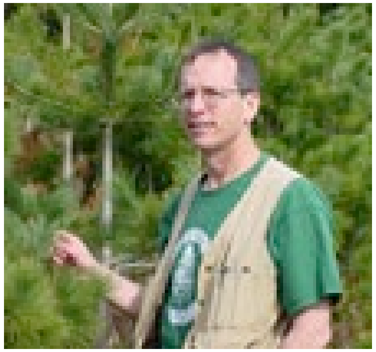

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frontiers in Ecology and Evolution

POLICY BRIEF
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Strategic Development of Tree Resistance Against Forest Pathogen and Insect Invasions in Defense-Free Space

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OPEN ACCESS

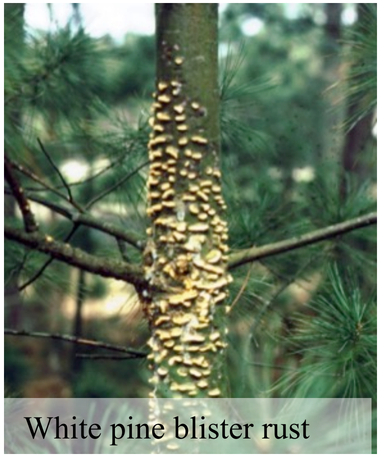
Tree-Killing PIPs

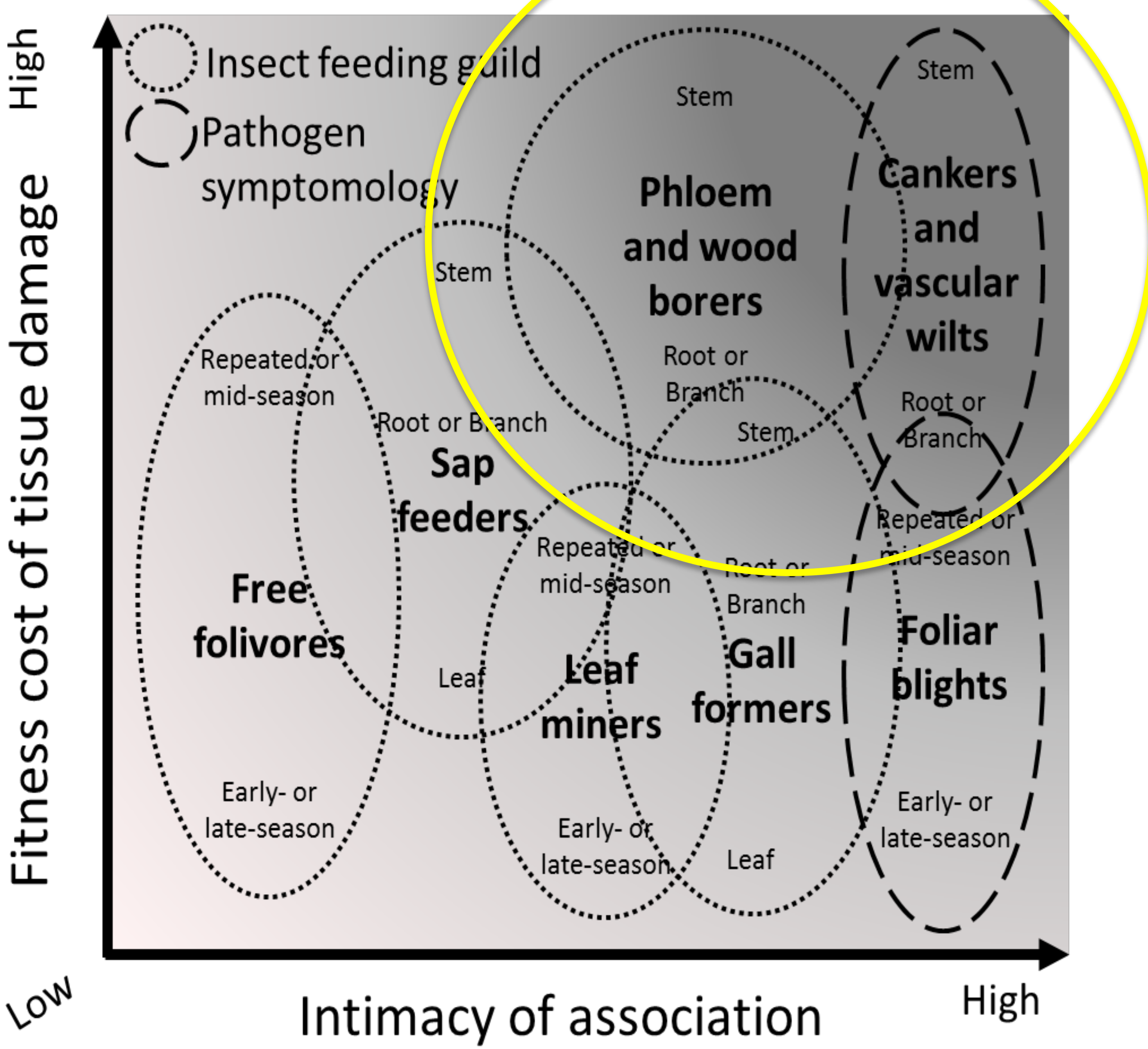
Tree-killing Phytophagous Insects and Phytopathogens (PIPs)

- intimately and cryptically associated with hosts
- **damage high fitness value host tissue**
- kill a large proportion of naïve host trees
- e.g. canker and wilt fungi, bark and wood borers


Laurel wilt


Emerald ash borer


White pine blister rust


Insect feeding guild
Pathogen symptomology
Fitness cost of tissue damage
High
Low
Intimacy of association
High
Stem
Phloem and wood borers
Root or Branch
Stem
Cankers and vascular wilts
Root or Branch
Repeated or mid-season
Stem
Root or Branch
Sap feeders
Leaf
Repeated or mid-season
Free folivores
Early- or late-season
Repeated or mid-season
Leaf miners
Early- or late-season
Stem
Root or Branch
Gall formers
Leaf
Repeated or mid-season
Foliar blights
Early- or late-season

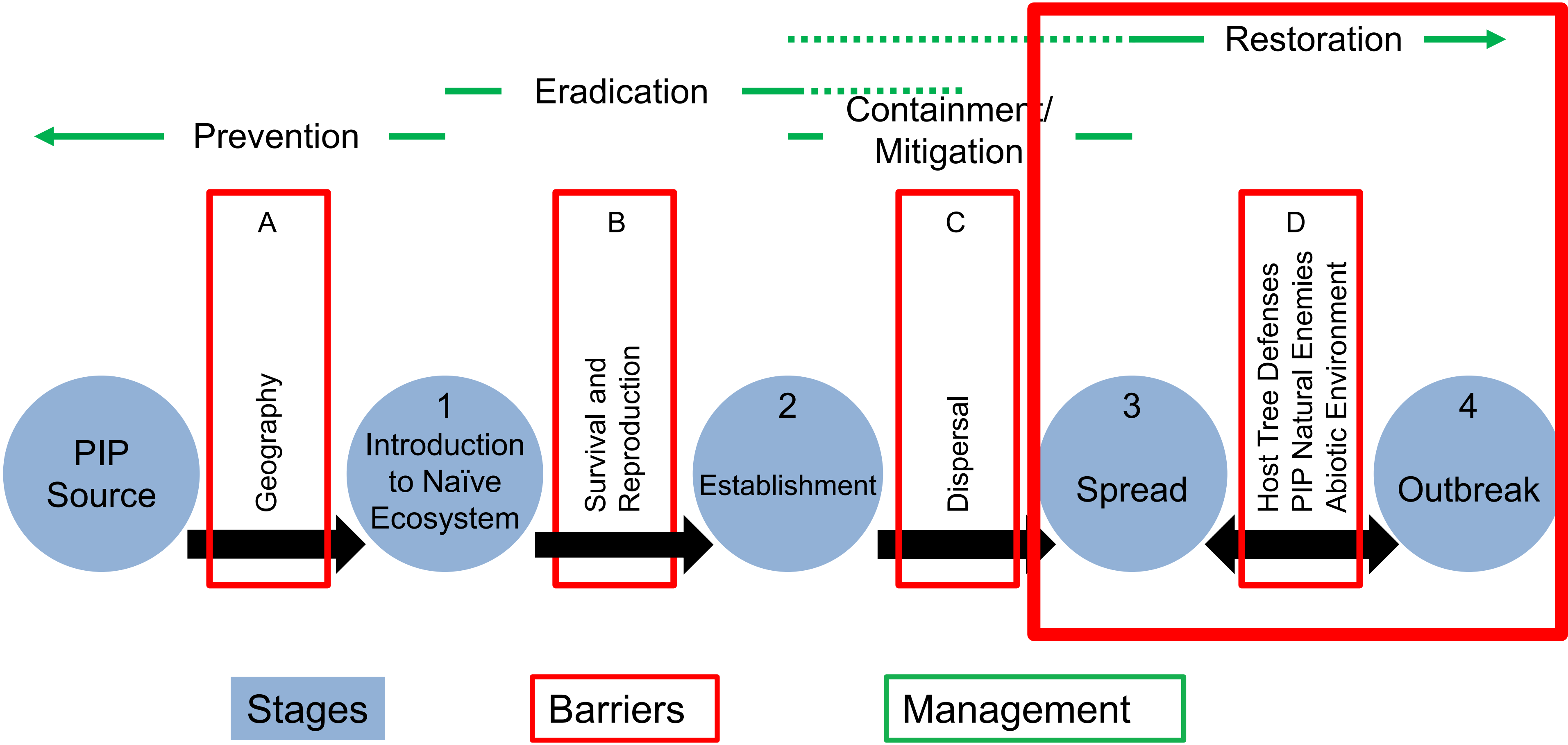
D. Showalter

Theses

- Identification and utilization of host resistance is **essential**
  - for **effective, long-term** management of
  - **select tree-killing pests**
  - for which **top-down control cannot work**
- **Early** and **sustained support** is required

Invasion Progression

Our focus is on *established* PIPs



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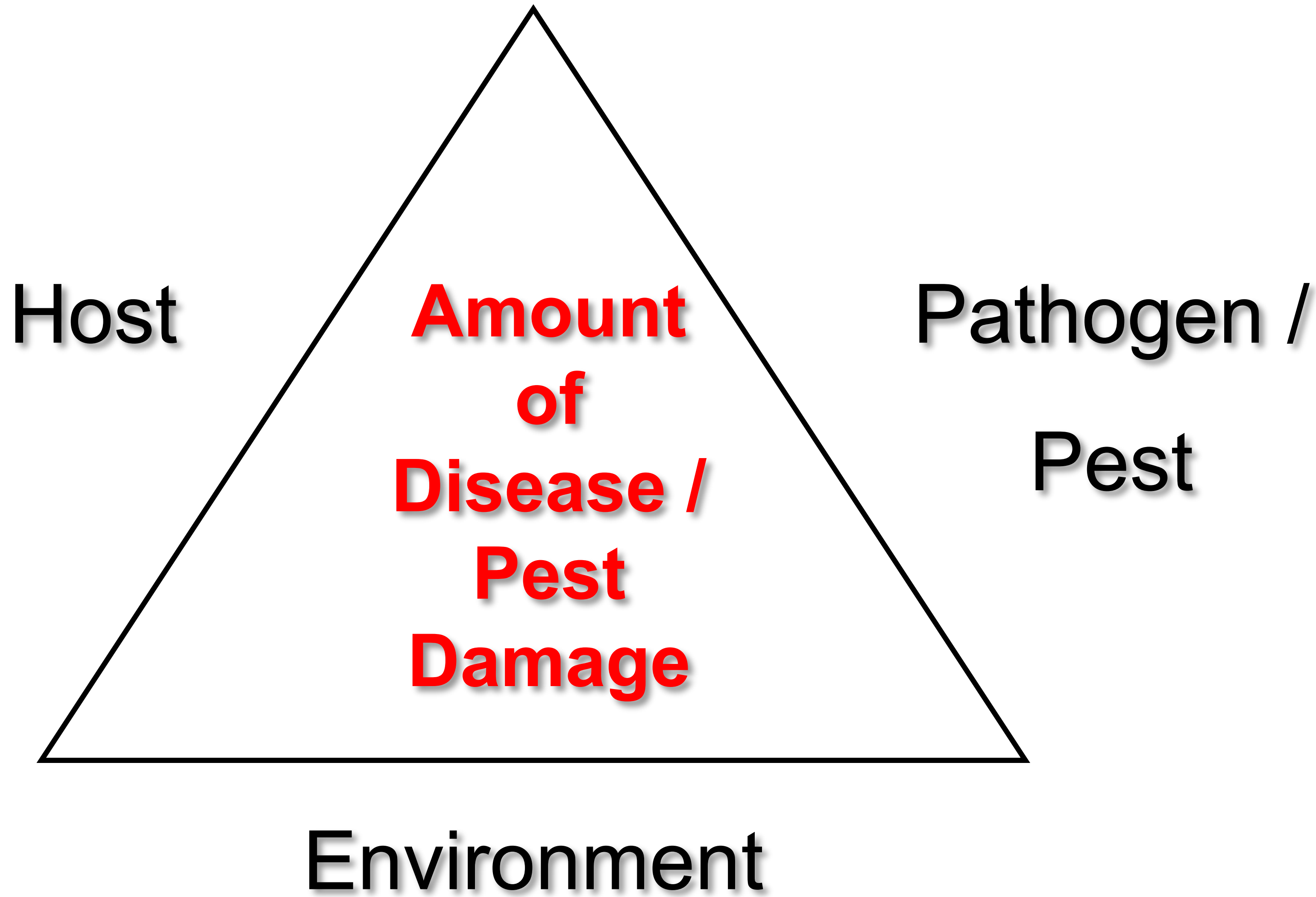
Adapted from Blackburn *et al* 2011. *Trends in Ecol and Evol*. 26:7

Disease/Pest Triangle



Almost always, in forest environments (landscape or regional scales):

- Eradication and containment do not work
- Biological or chemical control either do not exist, are not feasible, or are demonstrably ineffective
- Control of a conducive environment is not feasible

PNAS

Modeling when, where, and how to manage a forest epidemic, motivated by sudden oak death in California

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Edited by Simon A. Levin, Princeton University, Princeton, NJ, and approved March 25, 2016 (received for review February 10, 2016)

Sudden oak death, caused by *Phytophthora ramorum*, has killed millions of oak and tanoak in California since its first detection in 1995. Despite some localized small-scale management, there has been no large-scale attempt to slow the spread of the pathogen in California. Here we use a stochastic spatially explicit model parameterized using data on the spread of *P. ramorum* to investigate whether and how the epidemic can be controlled. We find that slowing the spread of *P. ramorum* is now not possible, and has been impossible for a number of years. However, despite extensive cryptic (i.e., presymptomatic) infection and frequent long-range transmission, effective exclusion of the pathogen from large parts of the state could, in principle, have been possible were it to have been started by 2002. This is the approximate date by which sufficient knowledge of *P. ramorum* epidemiology had accumulated for large-scale management to be realistic. The necessary expenditure would have been very large, but could have been greatly reduced by optimizing the radius within which infected sites are treated and careful selection of sites to treat. In particular, we find that a dynamic strategy treating sites on the epidemic wave front leads to optimal performance. We also find that "front loading" the budget, that is, treating very heavily at the start of the management program, would greatly improve control. Our work introduces a framework for quantifying the likelihood of success and risks of failure of management that can be applied to invading pests and pathogens threatening forests worldwide.

Phytophthora ramorum | constrained budget | landscape-scale stochastic epidemiological model | optimizing disease control | risk aversion

or not it is feasible to do so, remains a major challenge (15). However, understanding whether management can eradicate a pathogen or restrict its spread to uninvaded locations is critical in identifying cost-effective control strategies. We show here how mathematical modeling can be used to do this, using sudden oak death (SOD) in California (CA) as an example.

SOD, caused by the oomycete *Phytophthora ramorum* (*PR*), has killed millions of oak (*Quercus* spp.) and tanoak (*Notholithocarpus densiflorus*) in CA since first detection in 1995 (16). The epidemic has been intensively monitored (17), and much is now known about *PR* epidemiology. However, questions remain about the feasibility of statewide control, introducing uncertainty and confusion into identifying regional management objectives. The epidemic also provides an opportunity for retrospective analyses of how effective control scenarios could have been, had they been introduced at different stages in the epidemic.

Here we extend a previously tested, spatially explicit, stochastic, statewide model, resolved to 250 × 250-m resolution (18), to compare the range of outcomes for different management scenarios, addressing the following questions:

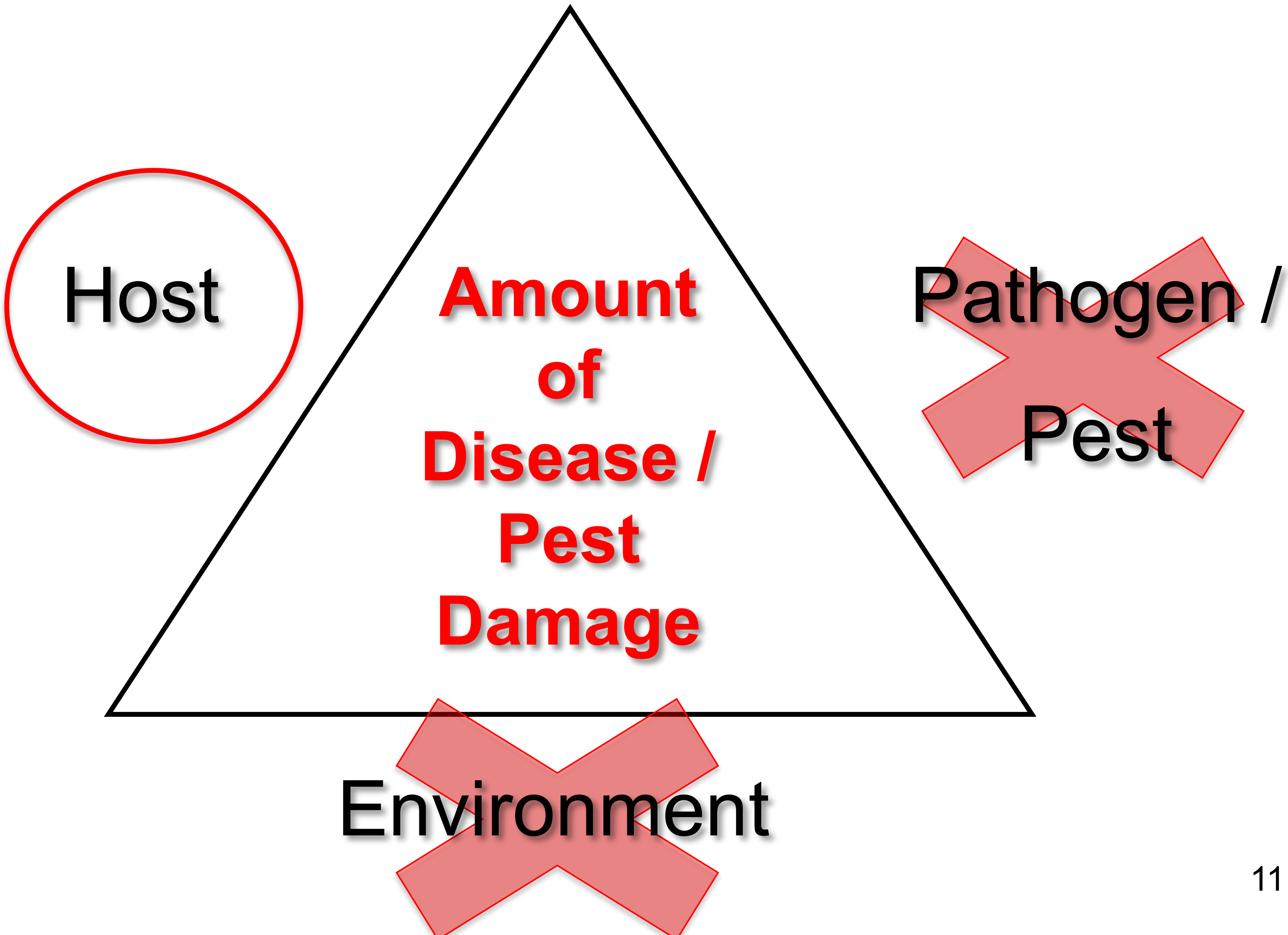
Could statewide prevention of continued pathogen spread be successful were it to start now, given the current size of the epidemic and the budget potentially available for treatment?

Could prevention of pathogen spread ever have been successful by management starting after the pathogen was sufficiently well characterized for control to have been realistic?

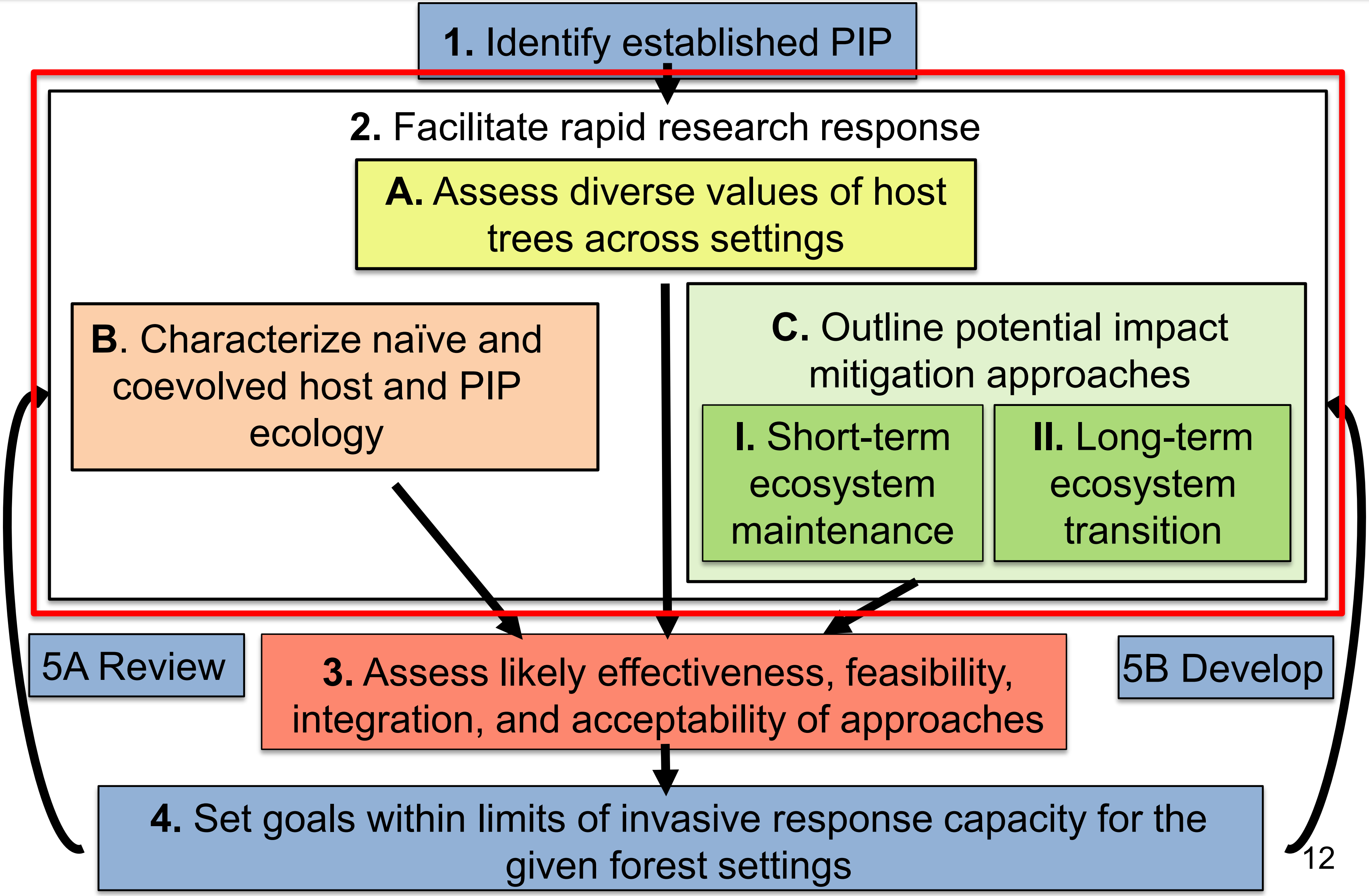
How could local and statewide deployment of management have been optimized?

ECOLOGY

Disease/Pest Triangle

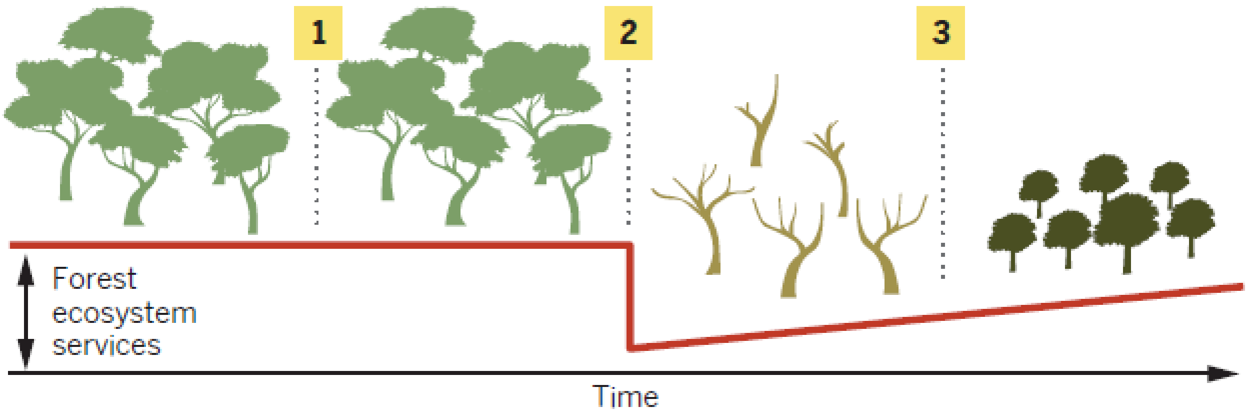


Response Framework

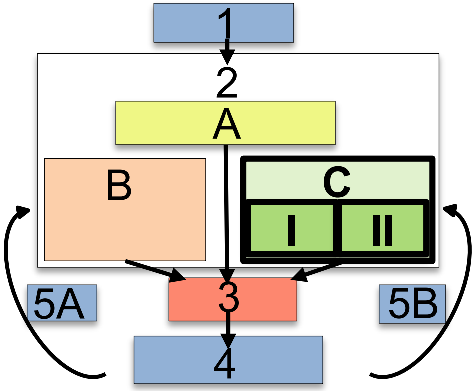


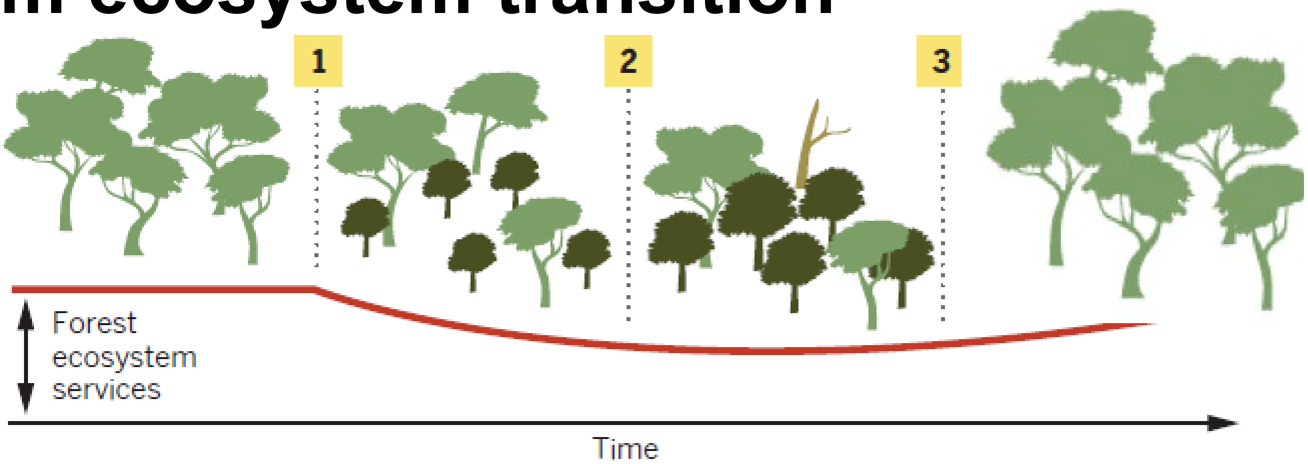
Available approaches

I. Short-term ecosystem maintenance



II. Long-term ecosystem transition





Millar and Stephenson 2015. *Science*. 349:6250

Long-term management

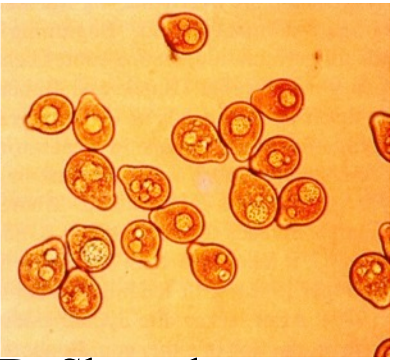
PIP populations and resulting host damage are driven by combinations of :

Absence of top-down constraints, e.g. biological control

=> invasions of "enemy-free space"

Absence of bottom-up constraints, host resistance

=> invasions of "defense-free space"



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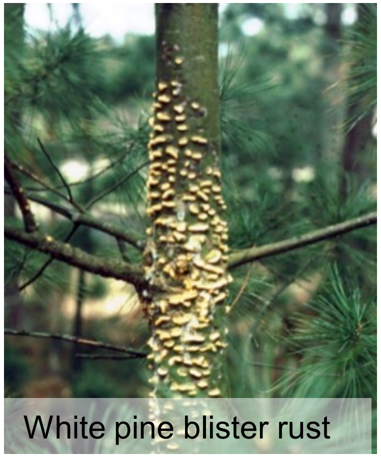
Host resistance is effective...

…with tree-killing PIPs, those that:

- are **cryptically** associated with their hosts
  (extremely difficult to detect – eradicate – contain)
- are **intimately** associated with their hosts
  (facilitates exchange of molecular signals in attack/defense)
- damage **high fitness value** host tissue
  (low damage tolerance, short acceptable lag for PIP control)
- **kill** a large proportion of **naïve host trees**
  (or coevolved trees with compromised defenses)


Laurel wilt


Emerald ash borer


White pine blister rust

Feasibility of Modern Trait Discovery and Development

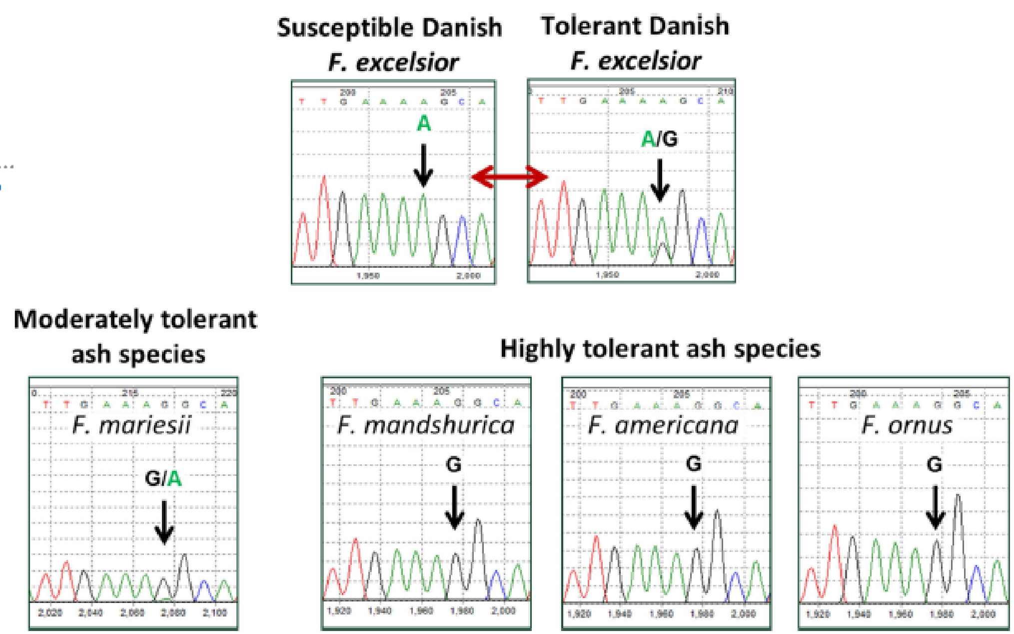
- **Mechanistic understanding of resistance traits though manipulative studies**
  - facilitates development and deployment
- **Cisgenesis**
  - rapid and controlled trait incorporation
  - potentially more widely acceptable than transgenesis
- **Transgenesis**
  - rapid and controlled trait incorporation
  - dramatically expands germplasm from which resistance traits can be drawn
  - **See chestnut blight resistance example provided by Bill Powell's group at SUNY ESF**

Feasibility of Modern Trait Discovery and Development

- **Marker-assisted selection/ molecular breeding**
  - reduce time and labor cost of continually phenotyping selections
  - genetic, genomic, transcriptomic, chemical markers
  - enables non-destructive screening of naïve populations, informing management

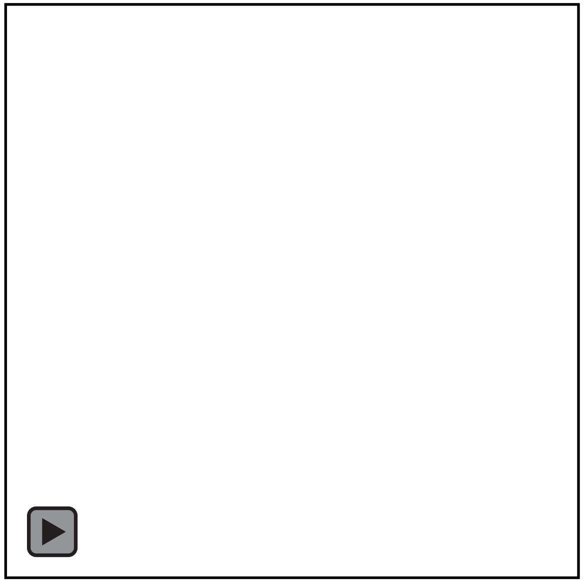
Molecular markers for tolerance of European ash (*Fraxinus excelsior*) to dieback disease identified using Associative Transcriptomics

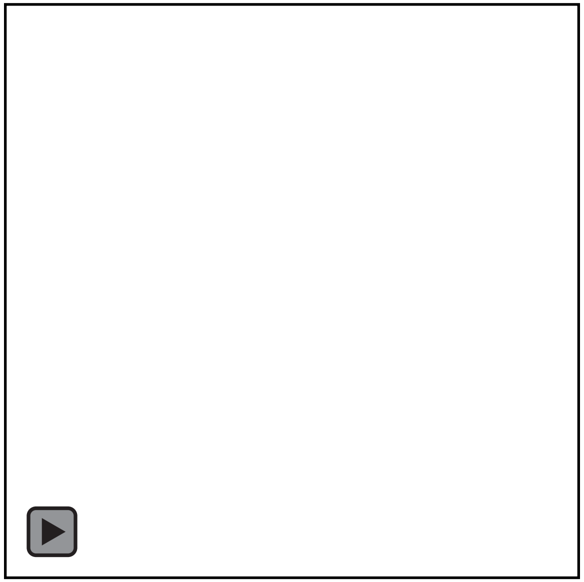
Harper *et al* 2016. *Sci. Rep.* 6:19335

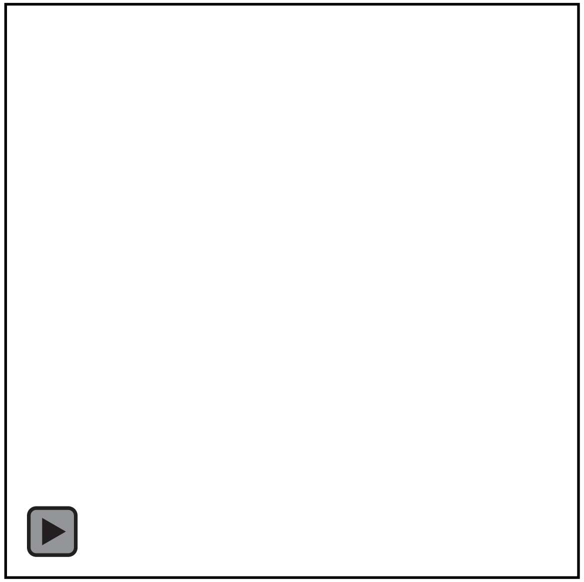


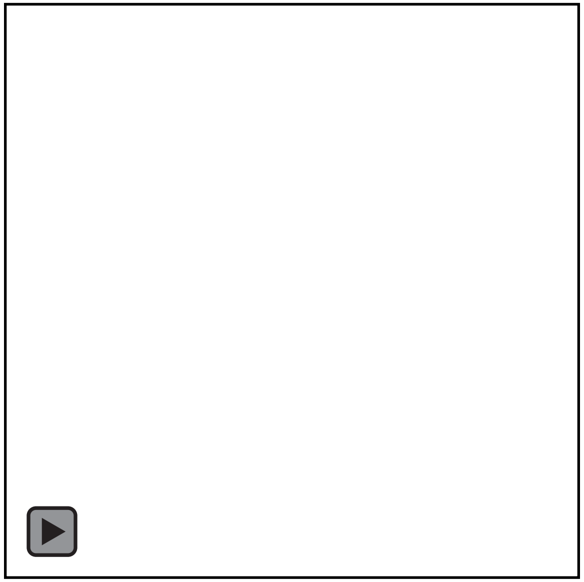
Fourier-Transform InfraRed (FTIR) spectroscopy

Chemical fingerprints

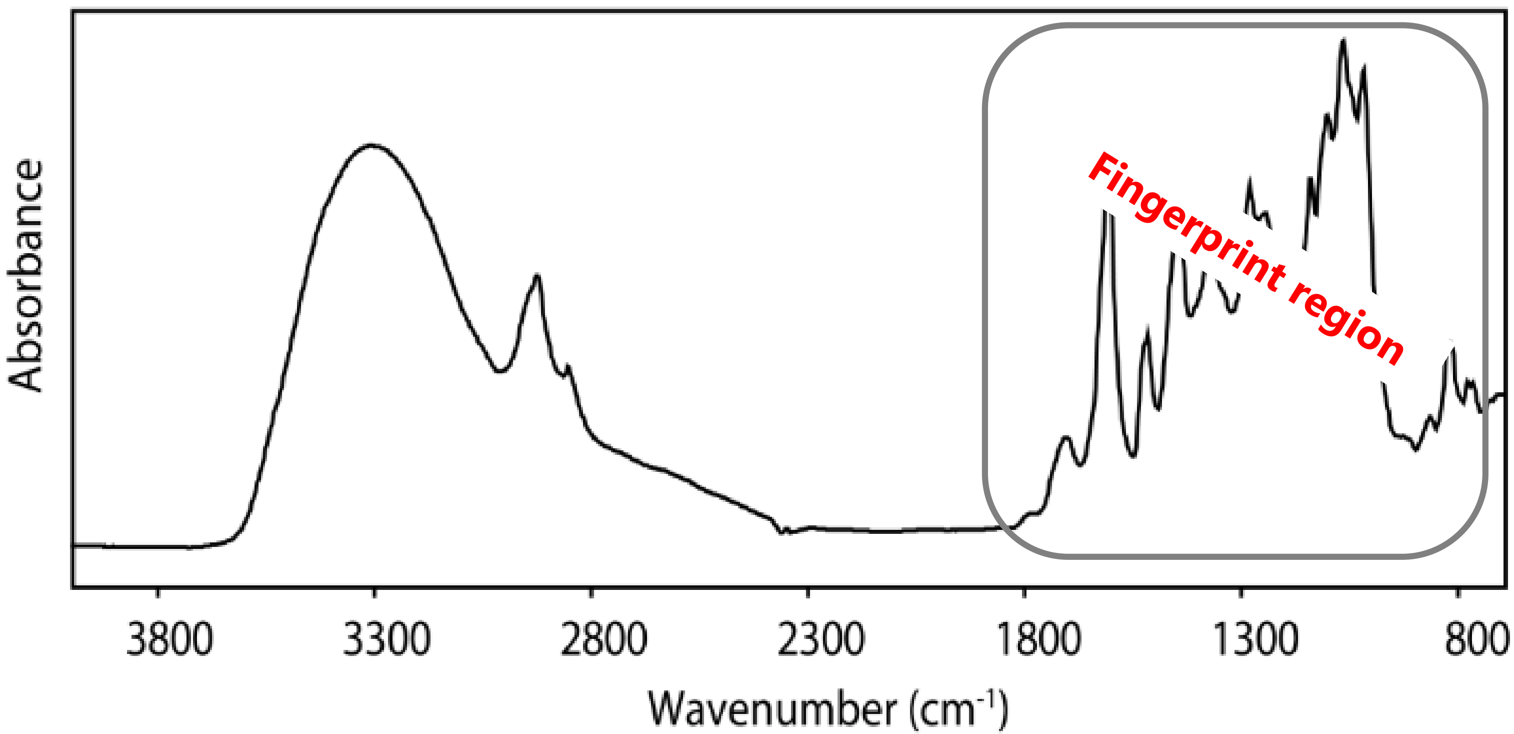








Coast live oak resistance in sudden oak death

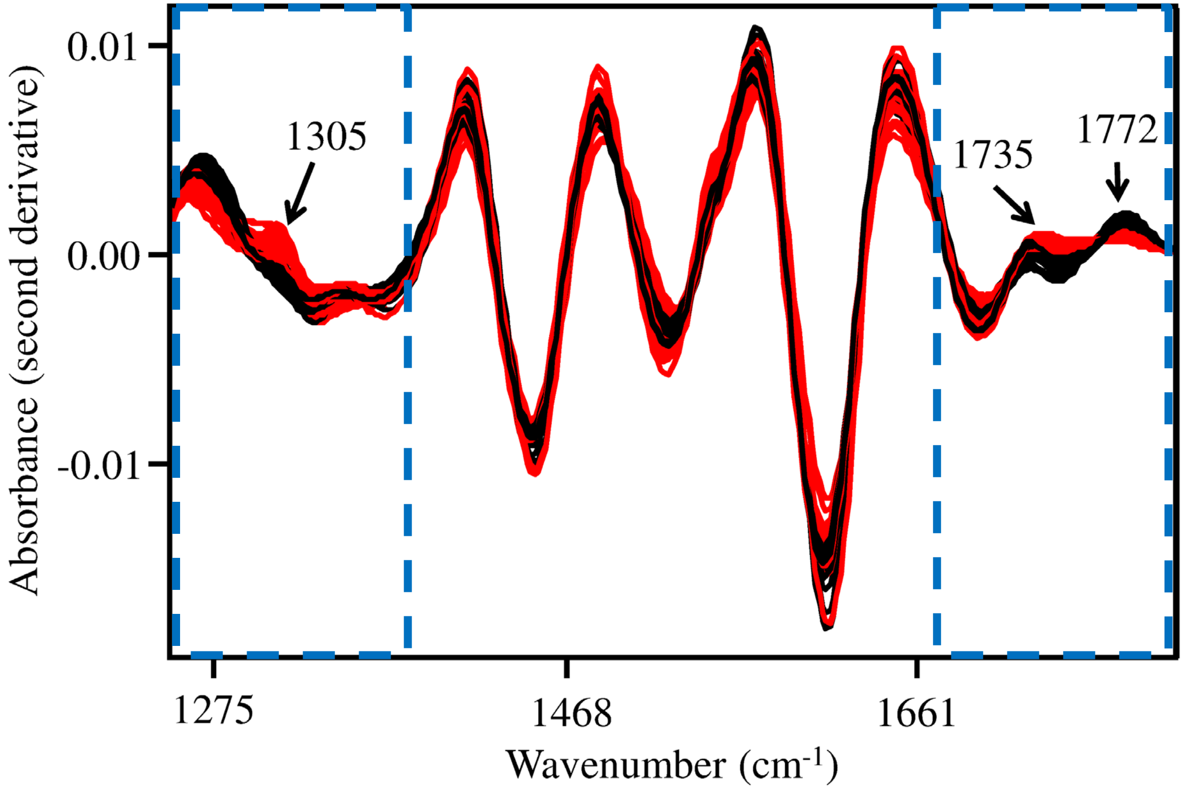


Chemical fingerprint data can be analyzed using various chemometric methods, such as PCA, SIMCA or PLSR

Courtesy: Caterina Villari

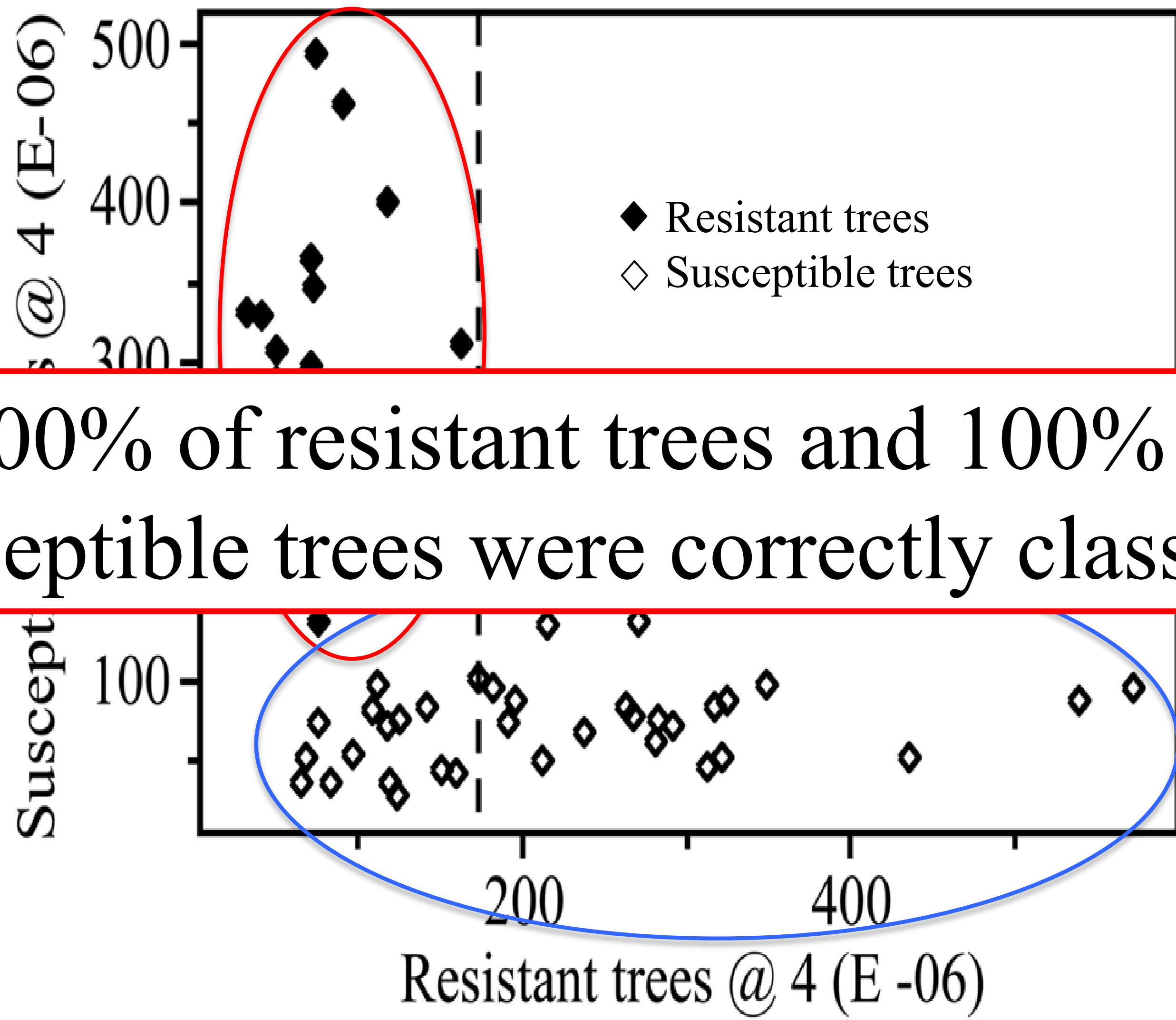
Coast live oak resistance in sudden oak death

Anna Conrad



Conrad et al. 2014. Frontiers in Plant Science 5

Coast live oak resistance in sudden oak death



100% of resistant trees and 100% of susceptible trees were correctly classified

SIMCA Coomans plot

Conrad et al. 2014. Frontiers in Plant Science 5

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Ash resistance to *H. fraxineus* (ash dieback)

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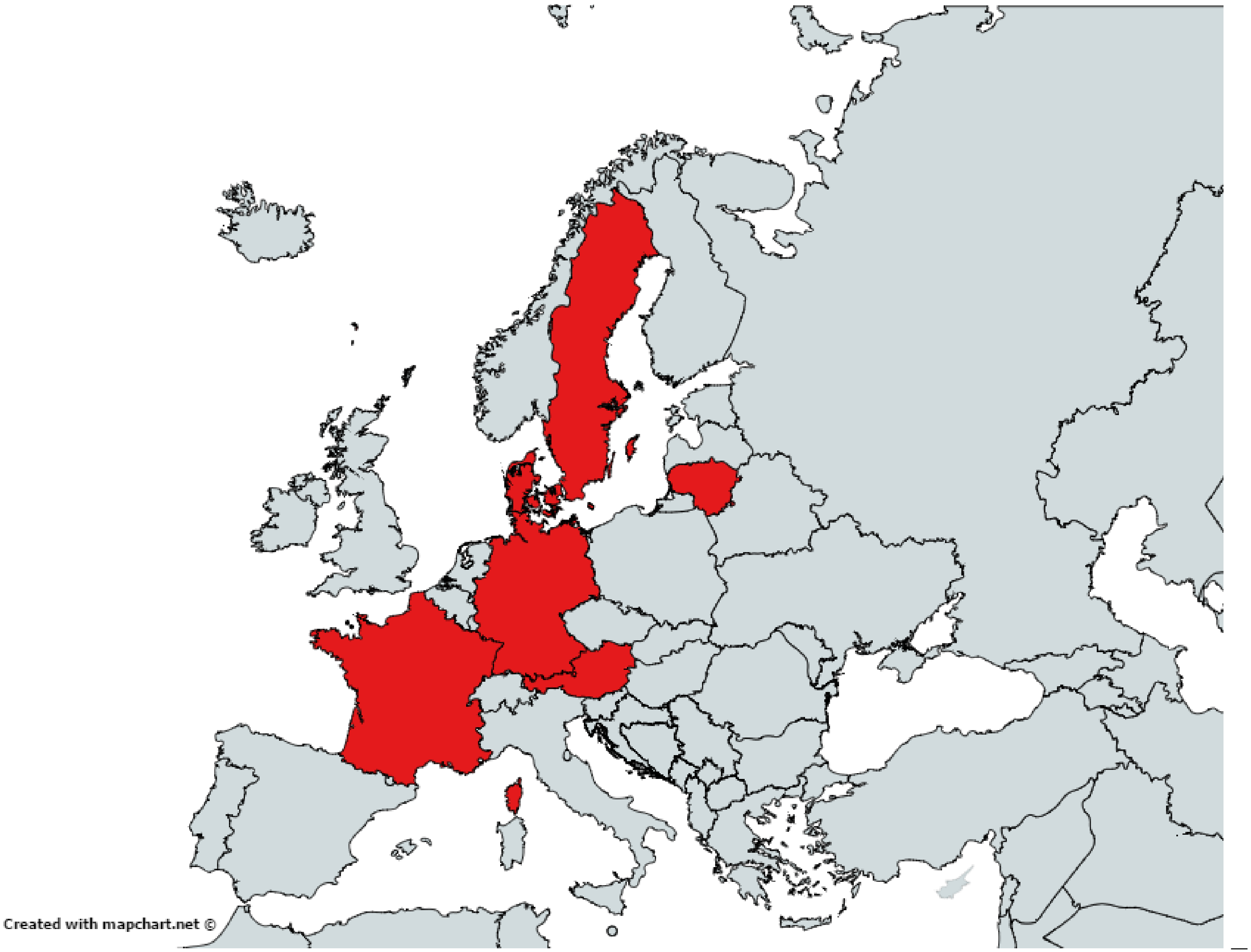
Ash resistance to *H. fraxineus* (ash dieback)



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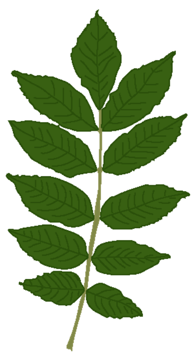
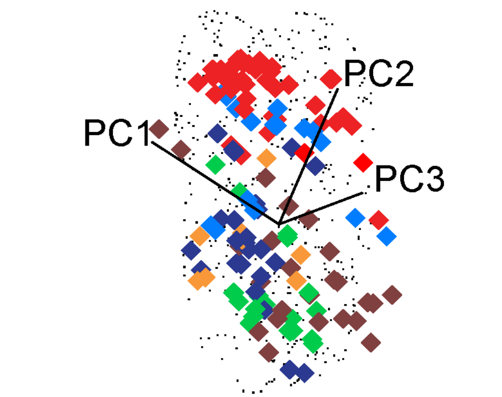
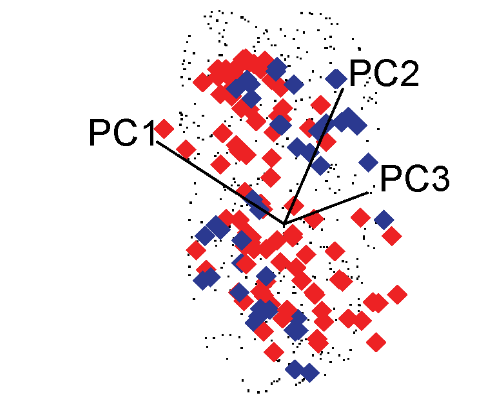
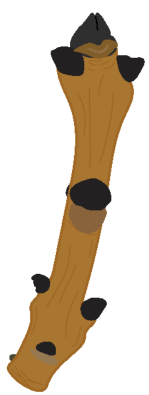
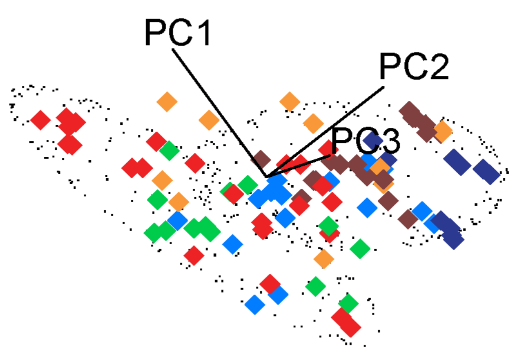
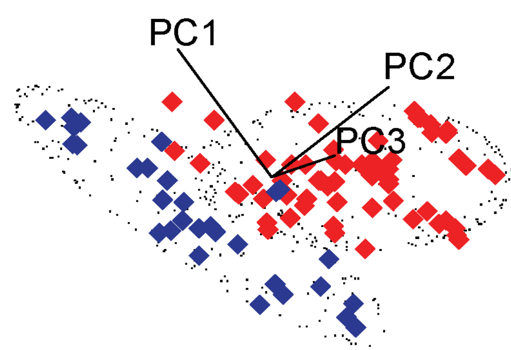
Ash resistance to *H. fraxineus* (ash dieback)

Training models

	Geographic location	Resistance phenotype
	◆ AT ◆ DE ◆ DK ◆ FR ◆ LT ◆ SE	◆ Resistant ◆ Susceptible
		
		

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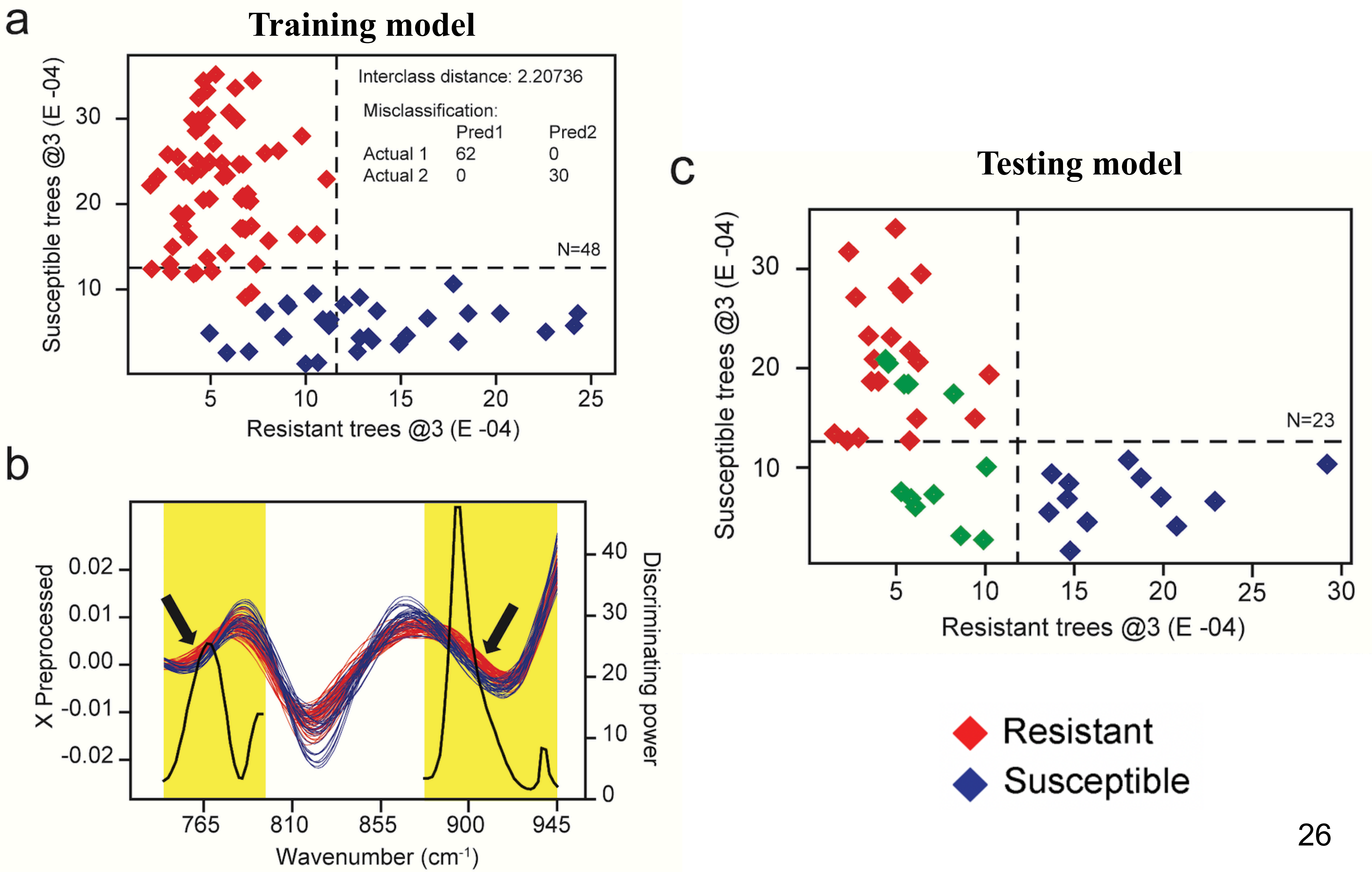
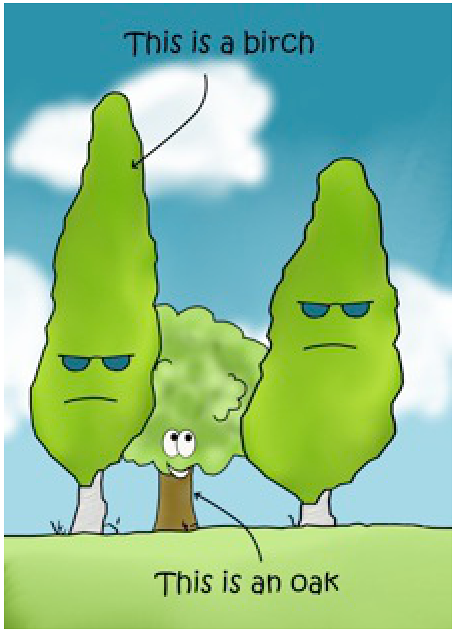


Modern Host Resistance Programs

- **Trait Deployment**
  - Incorporating genotypic and phenotypic heterogeneity for durability/ resilience

(Emerging) Effectiveness of Modern Resistance Deployment

- **Understanding of resistance durability**
  - Combining diverse quantitative and qualitative mechanisms across time and/or space
  - Guided by assessments of PIP evolutionary potential
- **Associational/ landscape resistance concepts**
  - May allow for deployment of genetically diverse resilient populations vs. only resistant individuals
  - Includes other forms of heterogeneity
    - Stand structure/age, species composition
      - → increased biodiversity



Conclusion

Deployment of tree resistance to counter black swan events is **feasible** and **essential** for:

- **effective**
- **long-term management**

And, it is arguably the only real solution to forest ecosystem restoration following invasions by tree killing PIPs

Corollary: Work on resistance should be initiated and sustained as soon as a tree-killing PIP is discovered

Traditional approach

Four elements:

Start working on resistance!

- Prevention
- Early Detection & Rapid Response
- Management & Mitigation
- Restoration & Rehabilitation

Recommendations

Avoid any delays in providing sustained program support

- Example: USDA APHIS has invested **$315 million since 2002** to combat emerald ash borer (Dr. Paul Chaloux, personal communication, 2017)
- < 1% has been spent on research on ash resistance
- **Imagine where we'd be today if even just one third of the total, i.e. $100 million, had been spent on resistance instead of measures that have been clearly shown to be ineffectual**

Recommendations

Better still, we should always be ready for invasion events:

- Create, organize, and characterize locally adapted germplasm collections for important tree species
- Improve quantification and communication of unique long-term value of tree species
- Develop rational deployment strategies (nascent understanding: interactions between multiple invasives, climate, and land use changes will always remain a challenge)

Recommendations

We propose to establish:

- Physical infrastructure permanently funded by national governments and/or international agreements to conduct screening and progeny trials
  - Including field sites and appropriate biosafety level facilities
  - Adequate base funding
  - Staffed by forest tree geneticists, breeders, and ecologists working in close collaboration with tree pathologists and entomologists on staff as well as in academia.

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