Cell PRESS

Emergence of the sudden oak death pathogen *Phytophthora ramorum*

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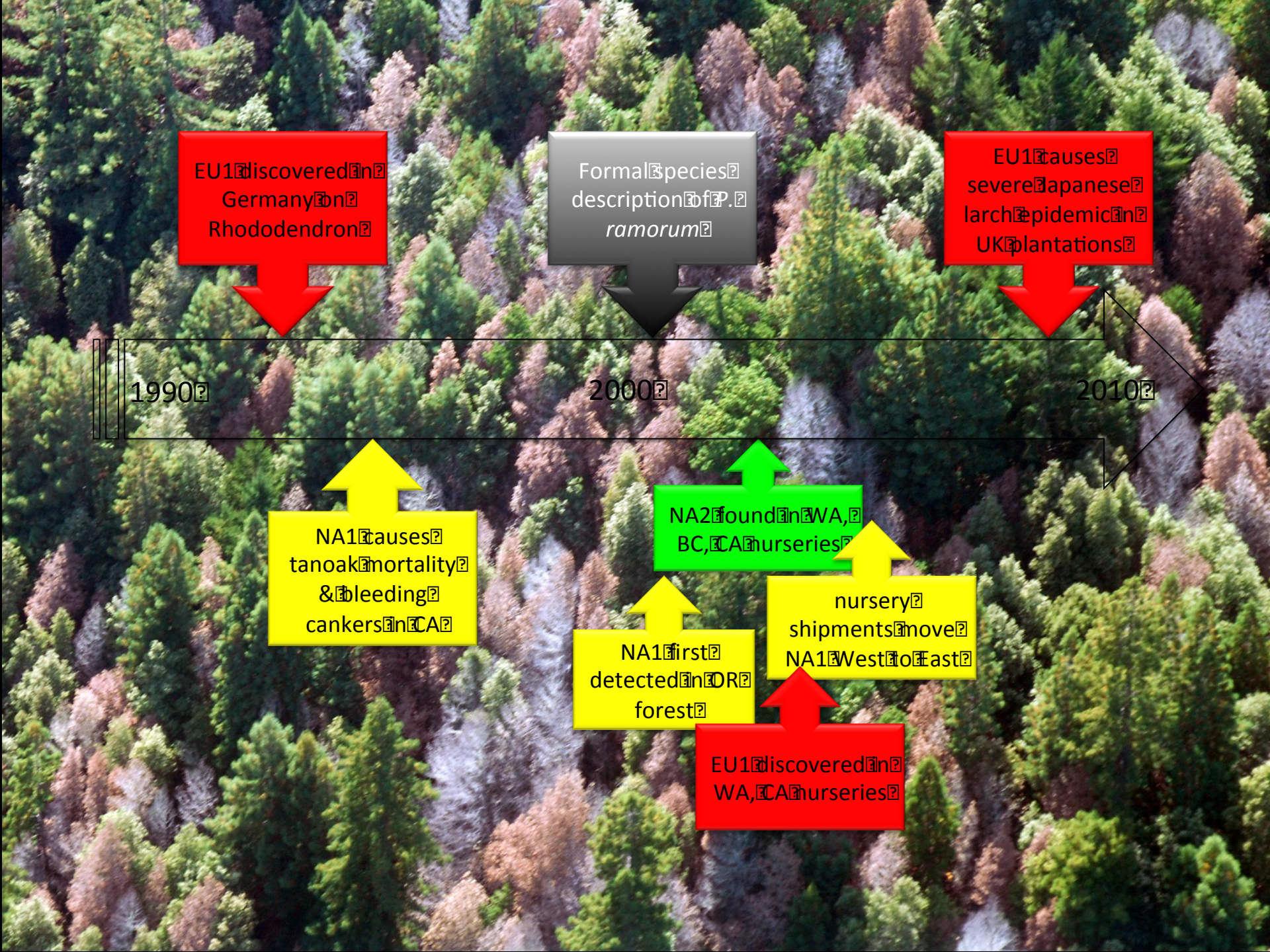

EU1 discovered in Germany on Rhododendron
Formal species description of P. ramorum
EU1 causes severe Japanese larch epidemic in UK plantations
1990
2000
2010
NA1 causes tanoak mortality & bleeding cankers in CA
NA2 found in WA, BC, CA nurseries
NA1 first detected in OR forest
nursery shipments move NA1 West to East
EU1 discovered in WA, CA nurseries

Sudden oak death

Tan oak, Marin County CA, 2000

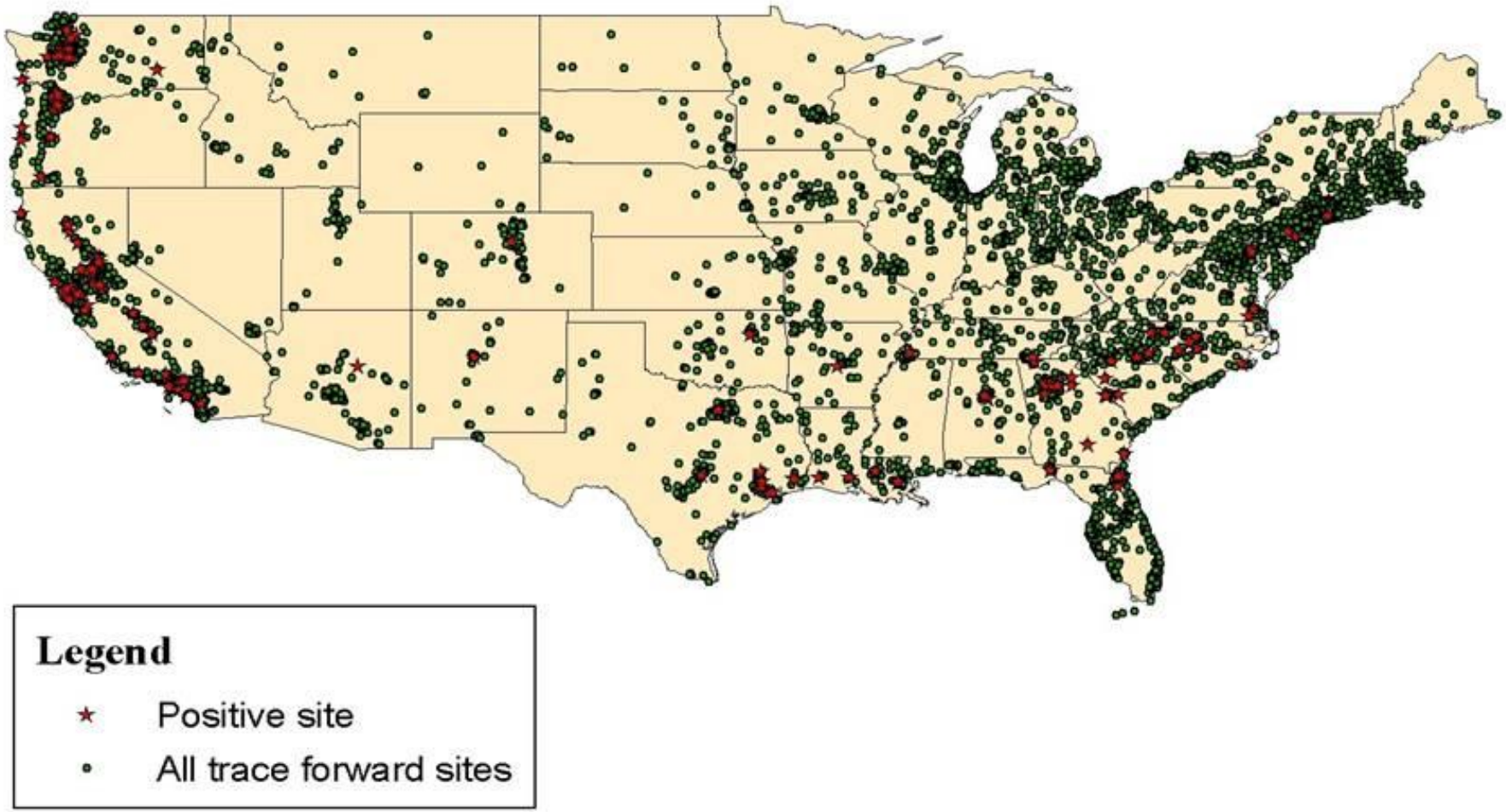
Coast Live Oak, Marin County CA, 2000

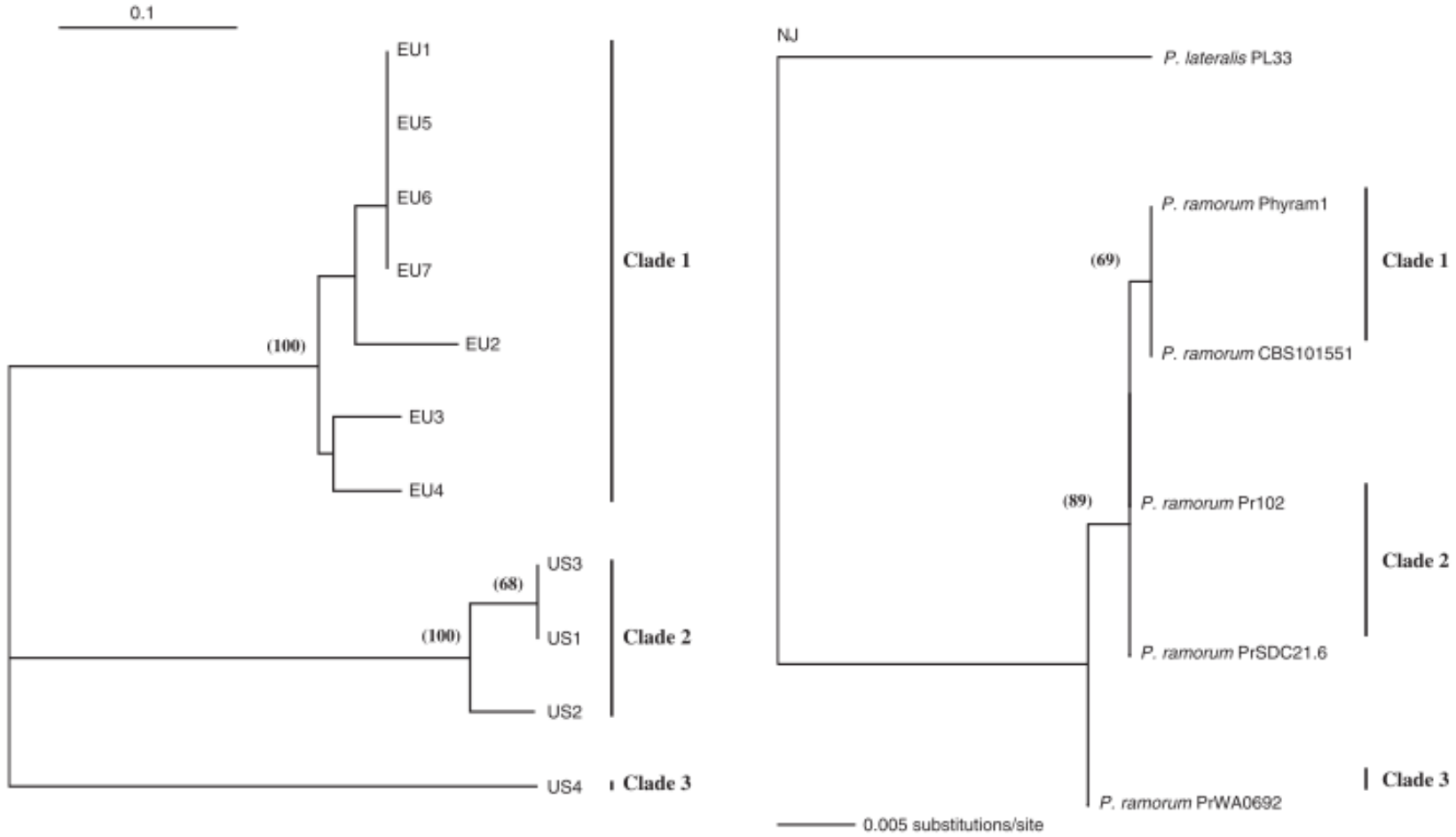
Photos courtesy Marin County Fire Dept.

Ramorum leaf blight

Eradication

Trace-forwards and positive detections across the U.S. July 2004



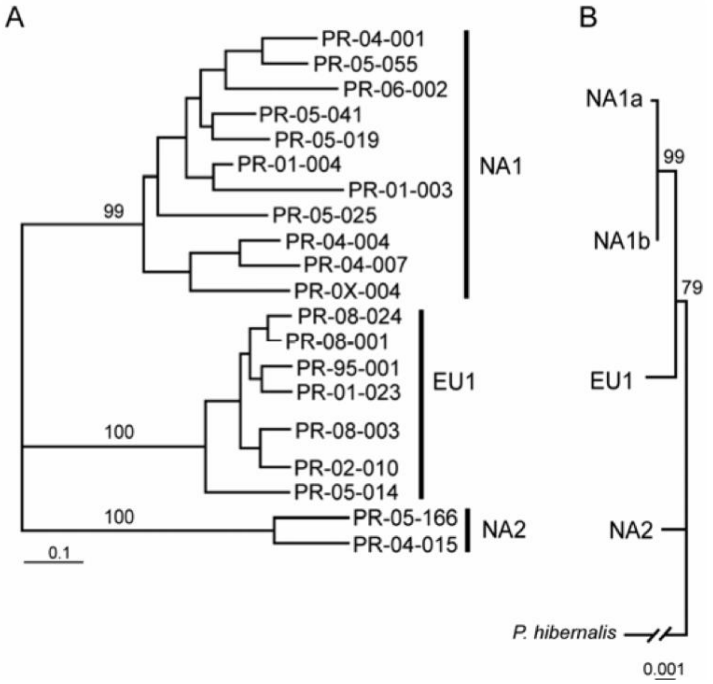


Ivors et al. 2006

TABLE 2. Current nomenclature and characteristics of the known *Phytophthora ramorum* clonal lineages (adapted from Ivors et al. [26])

Clonal lineage	Current distribution	Environment	Mating type	Colony growth[a]
NA1	North America	Forests, nurseries	A2	Slower
NA2	North America	Nurseries	A2	Faster
EU1	Europe, North America	Gardens, woodlands, nurseries[c]	A1[b]	Faster

[a] Based upon measurements of radial growth of representative isolates of each lineage grown on cornmeal or V8 juice agar (3,6,26,38).
[b] Lineage EU1 is predominantly of A1 mating type with rare findings of A2 isolates in Belgium (37).
[c] In the United States, the EU1 lineage is only found in nurseries, but is not very common relative to the NA1 lineage.



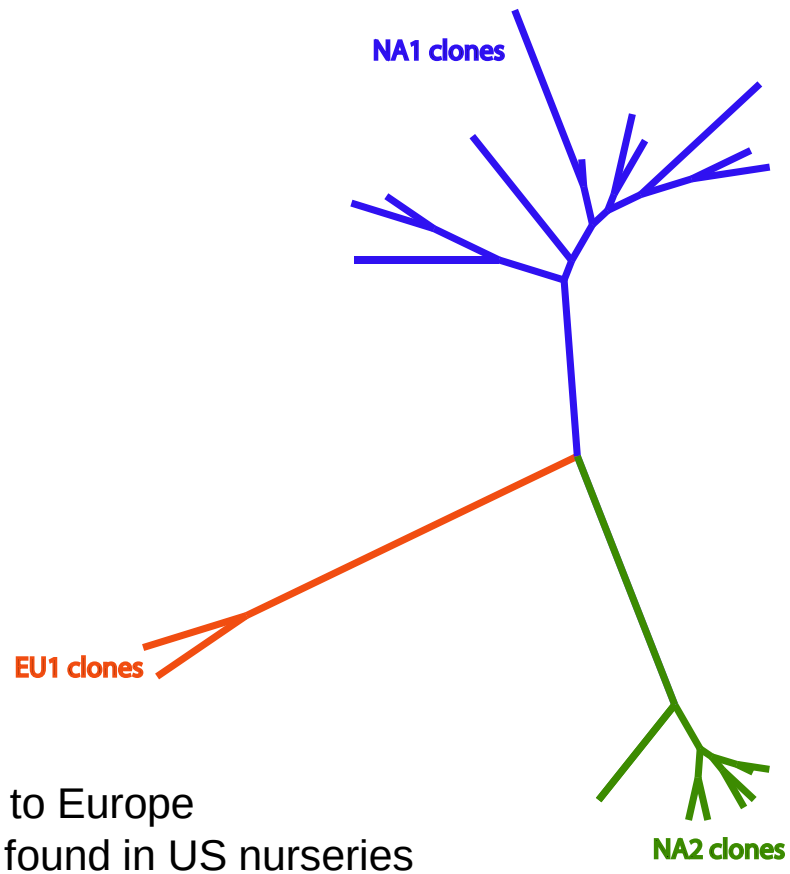
Standardizing the Nomenclature for Clonal Lineages of the Sudden Oak Death Pathogen, *Phytophthora ramorum*

Niklaus J. Grünwald, Erica M. Goss, Kelly Ivors, Matteo Garbelotto, Frank N. Martin, Simone Prospero, Everett Hansen, Peter J. M. Bonants, Richard C. Hamelin, Gary Chastagner, Sabine Werres, David M. Rizzo, Gloria Abad, Paul Beales, Guillaume J. Bilodeau, Cheryl L. Blomquist, Clive Brasier, Stephan C. Brière, Anne Chandelier, Jennifer M. Davidson, Sandra Denman, Marianne Elliott, Susan J. Frankel, Ellen M. Goheen, Hans de Gruyter, Kurt Heungens, Delano James, Alan Kanaskie, Michael G. McWilliams, Willem Man in 't Veld, Eduardo Moralejo, Nancy K. Osterbauer, Mary E. Palm, Jennifer L. Parke, Ana Maria Perez Sierra, Simon F. Shamoun, Nina Shishkoff, Paul W. Tooley, Anna Maria Vettraino, Joan Webber, and Timothy L. Widmer

Phytopathology (2009) 99:792-795

European and North American *P. ramorum* isolates form three distinct genetic groups

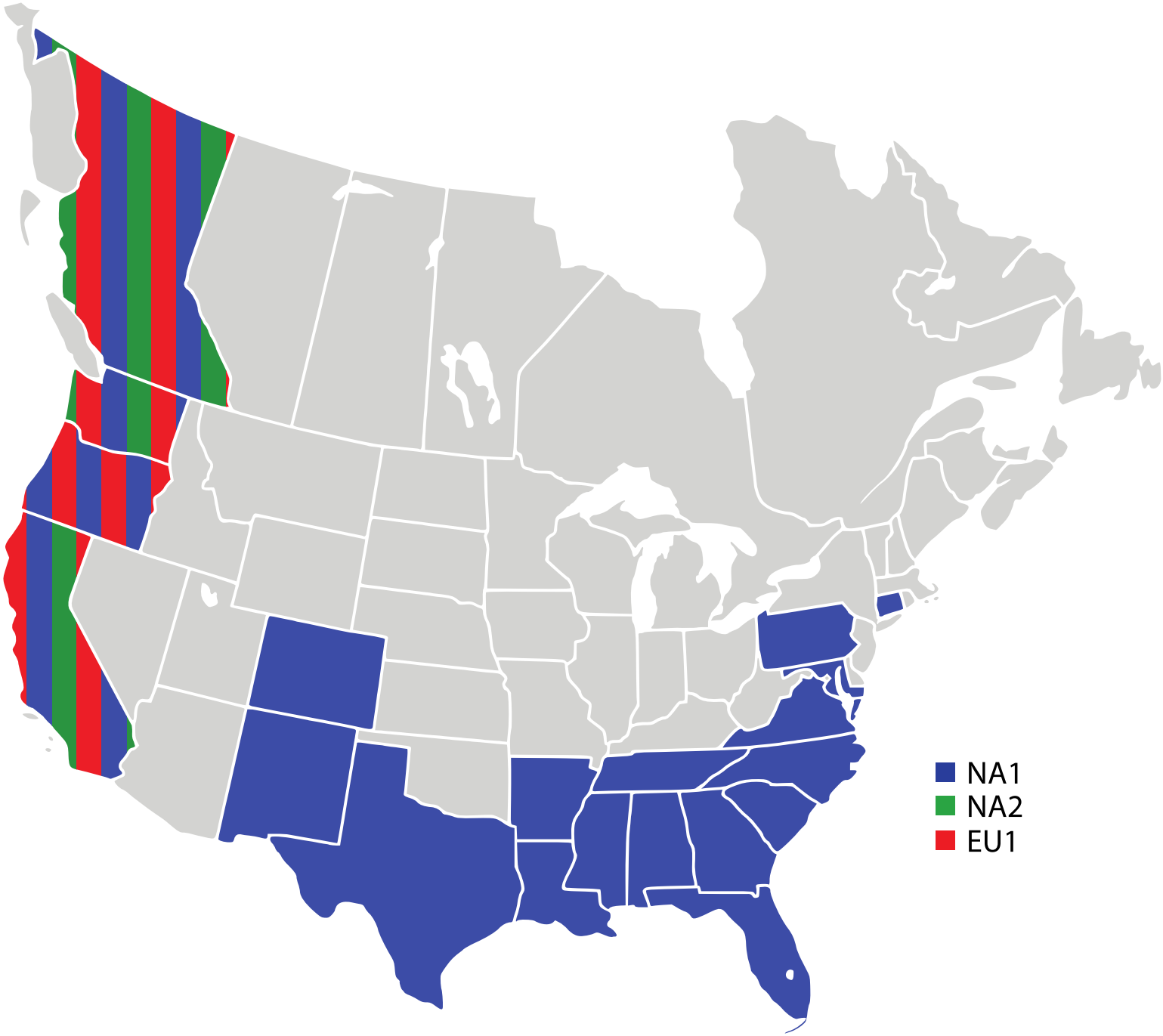
(AFLP, microsatellites, nuclear and mitochondrial DNA)



NA1
- limited to North America
- responsible for forest epidemics
- most common lineage in US nurseries
- A2 mating type

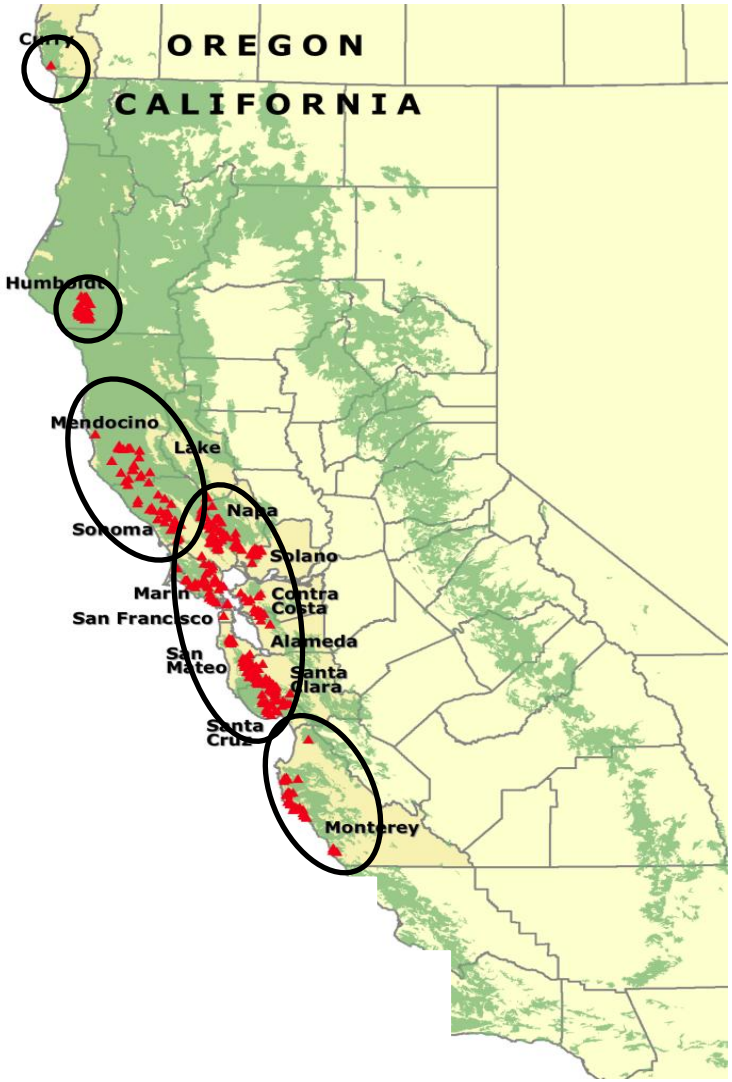
EU1
- initially limited to Europe
- now regularly found in US nurseries
- A1 mating type (A2 rare in Belgium)

NA2
- US nurseries
- A2 mating type

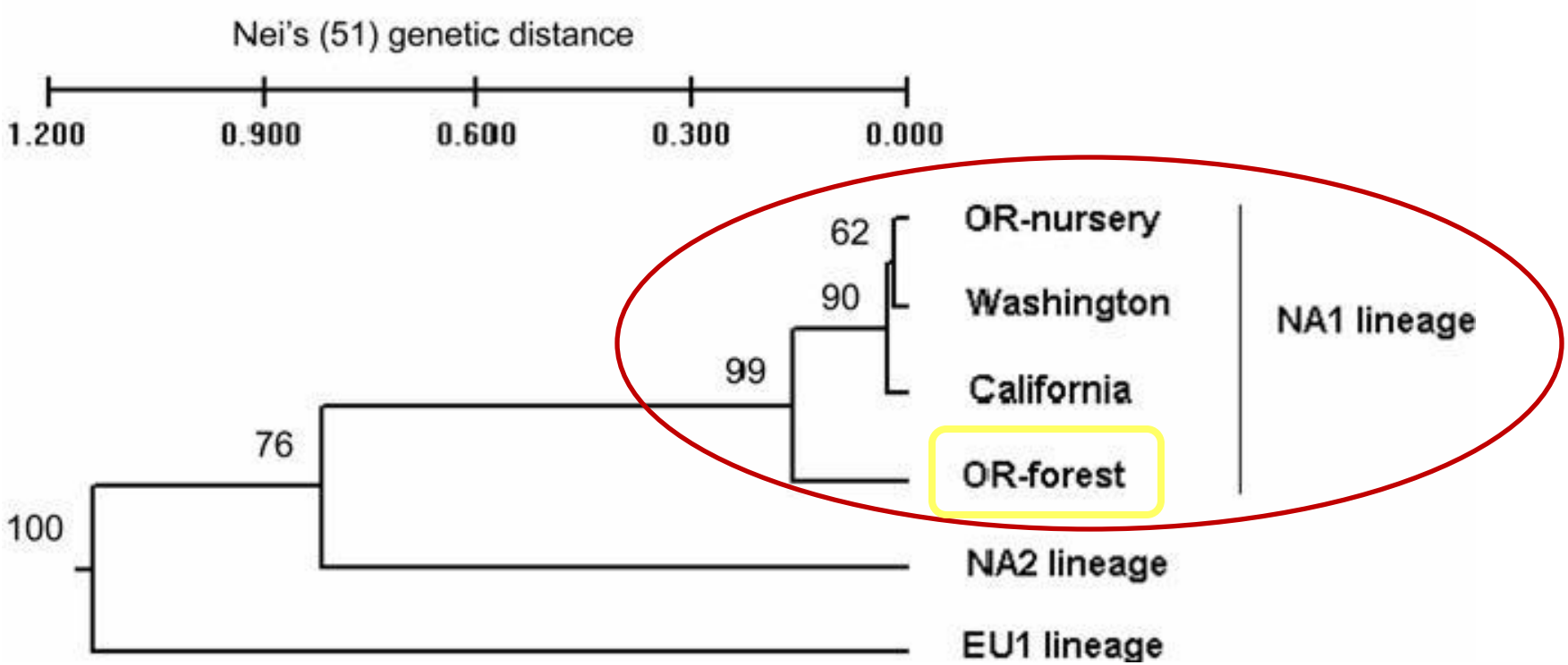

NA1
NA2
EU1

US forest populations

US forest populations

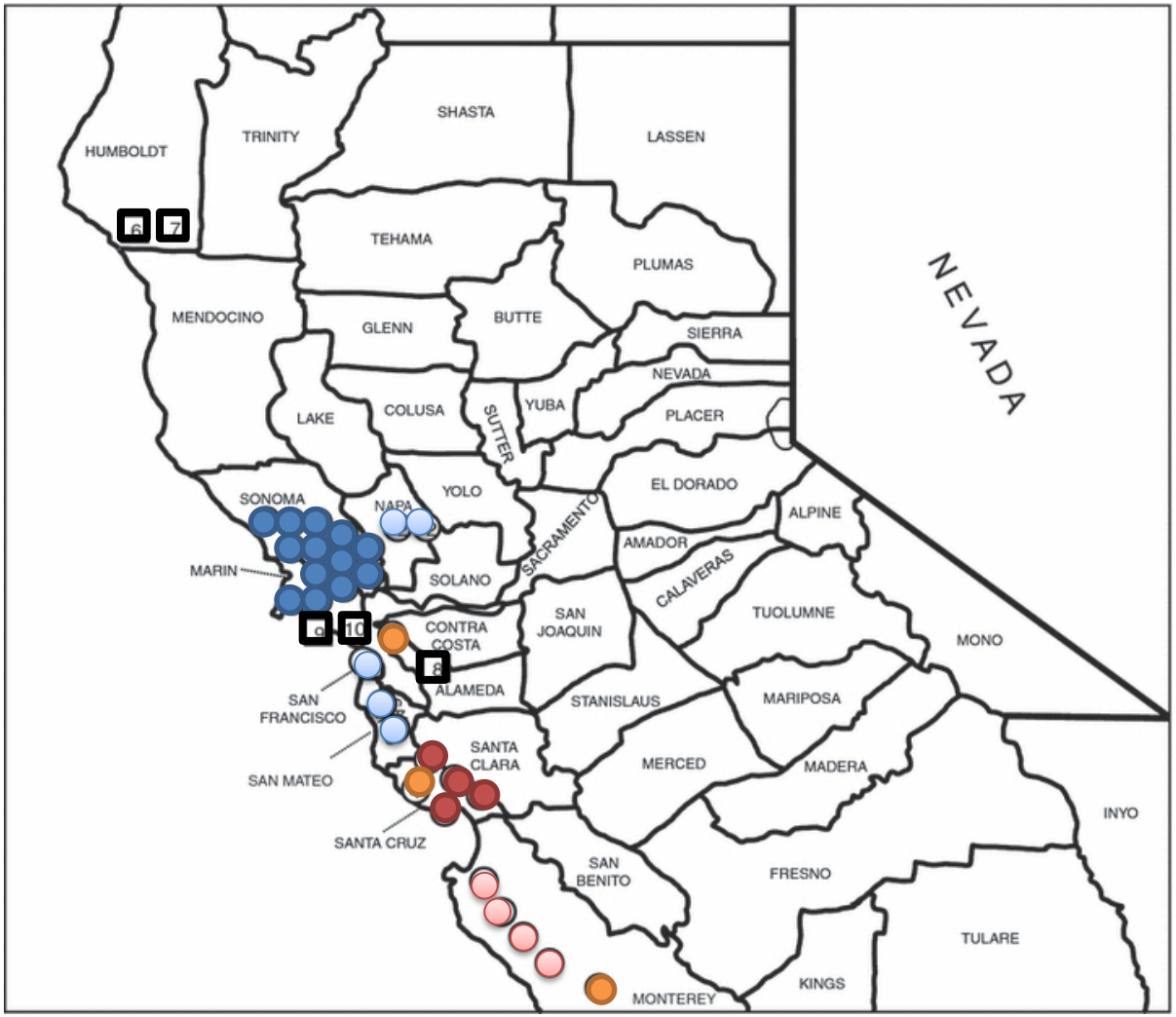


Potential for rapid differentiation of populations following dispersal



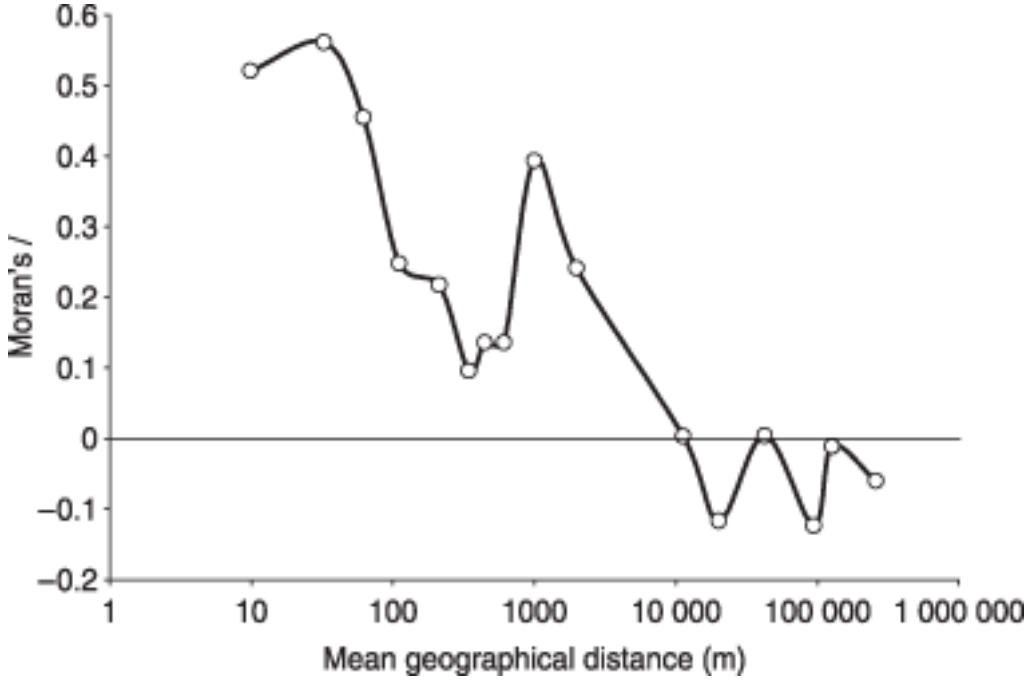
Prospero *et al*. 2009

Genetic diversity in California



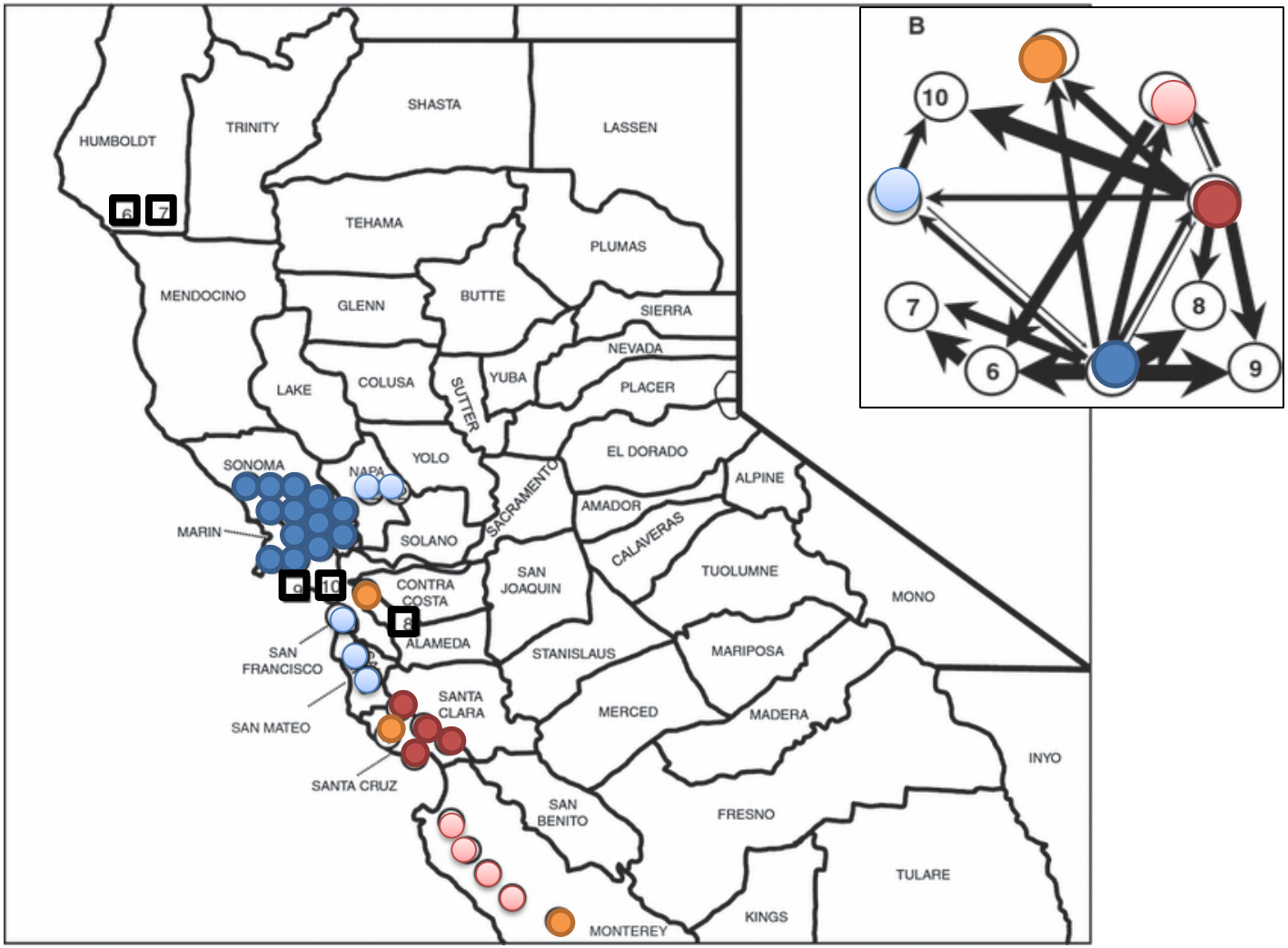
Mascheretti *et al*. 2009

Genetic autocorrelation with distance



Mascheretti *et al*. 2008

Repeated migration from old sites



Mascheretti *et al*. 2009

Origin of NA1

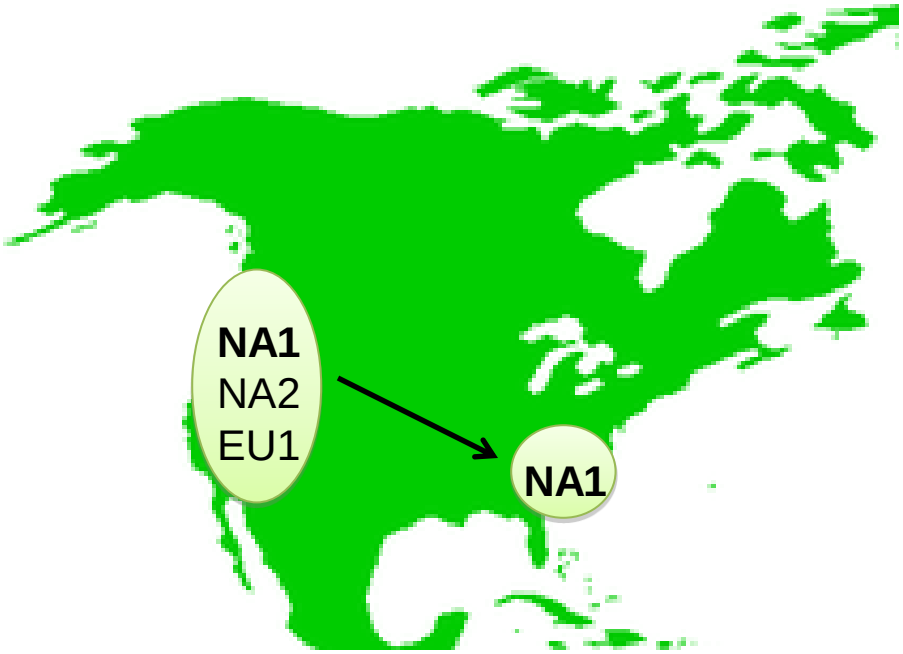
Mascheretti, S., et al. (2009) Genetic epidemiology of the sudden oak death pathogen *Phytophthora ramorum* in California. Mol Ecol 18, 4577-4590

Mascheretti, S., et al. (2008) Reconstruction of the Sudden Oak Death epidemic in California through microsatellite analysis of the pathogen *Phytophthora ramorum*. Mol Ecol 17, 2755-2768

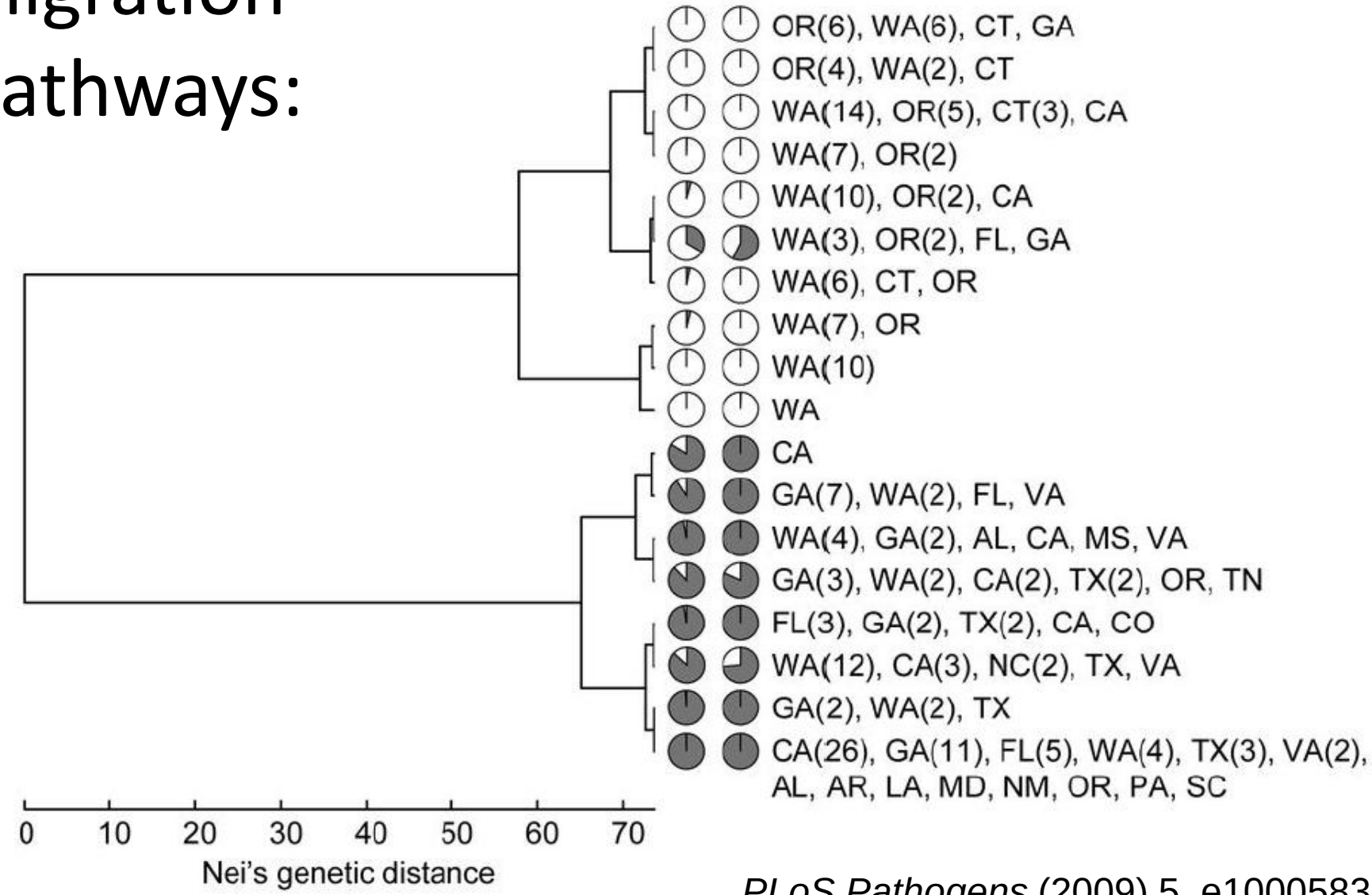
Trends in Microbiology (2012)

Migration in North American nursery trade

Can we infer migration pathways?

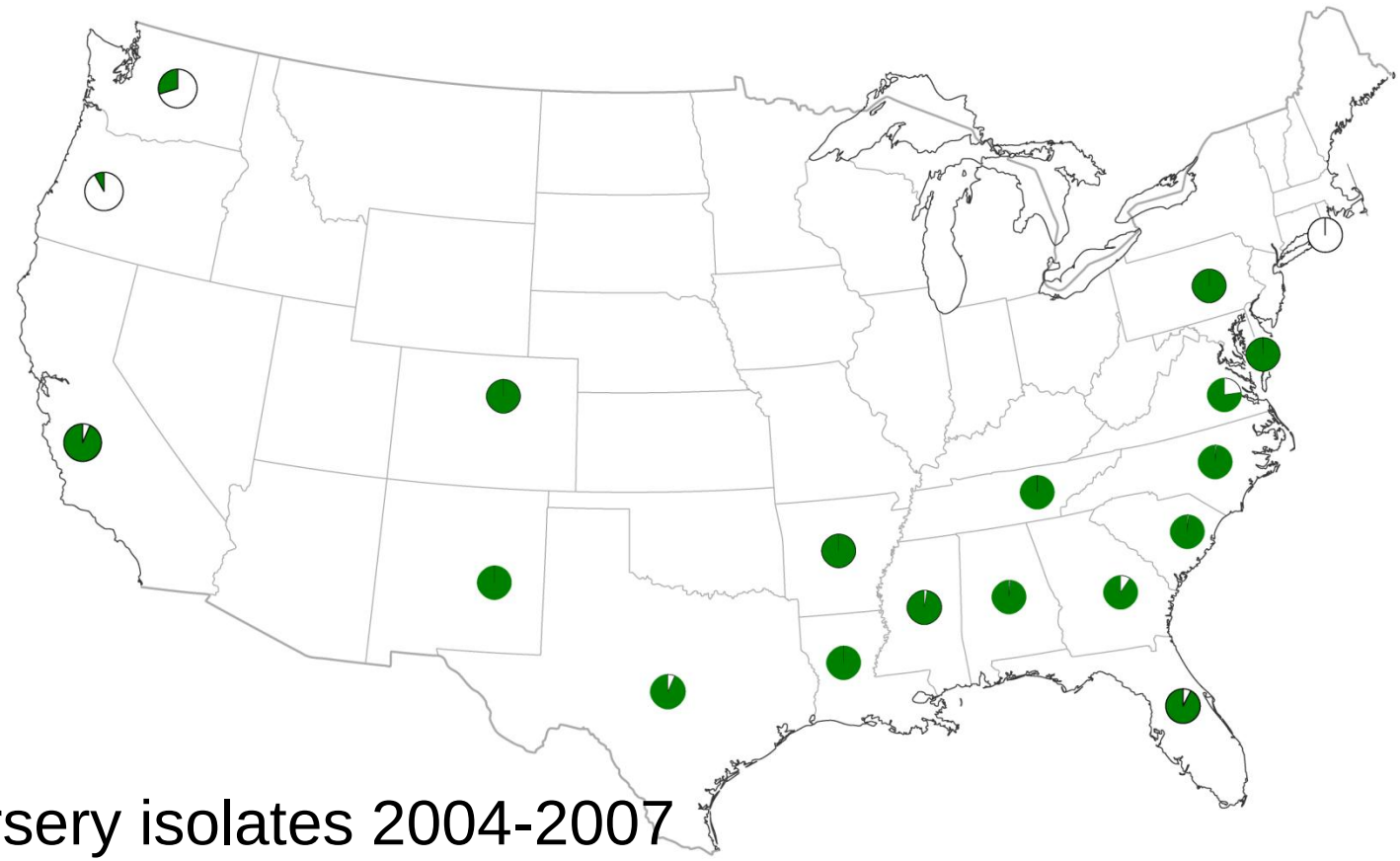


Two major migration pathways:



PLoS Pathogens (2009) 5, e1000583

NA1 isolates cluster into 2 groups



Nursery isolates 2004-2007

Goss *et al*. 2009 PLoS Path

Compare to APHIS investigation results

From shipping records:

Trace back

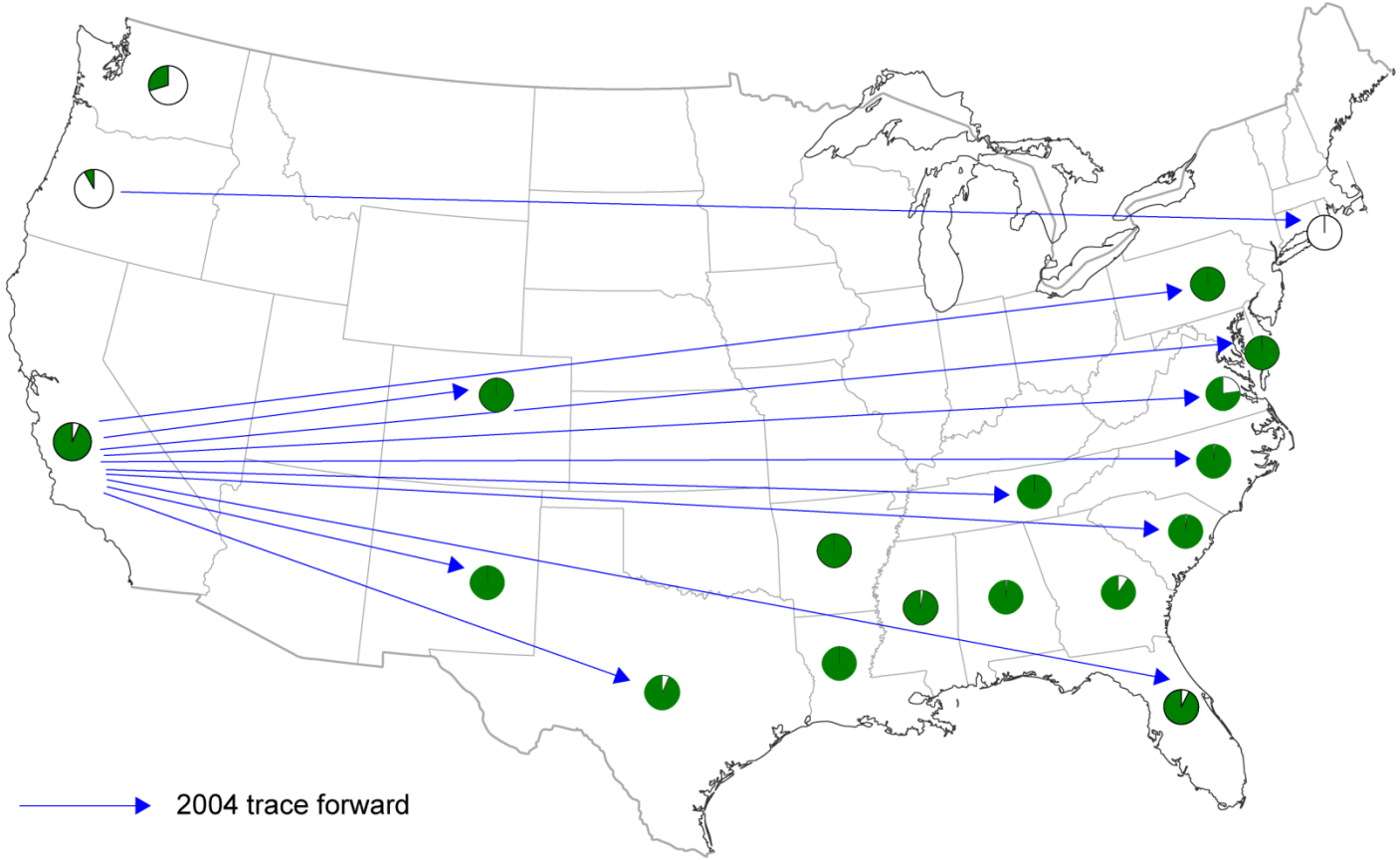
Trace forward

Source of pathogen

Infected nursery

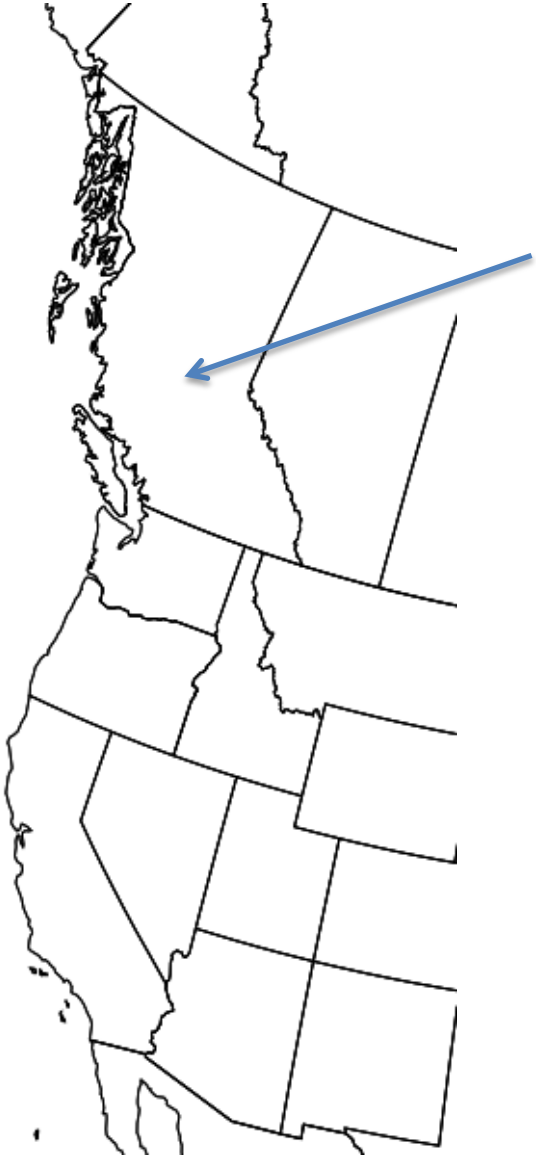
Infection of receiving nursery or landscape

Genetic groups were consistent with shipping records

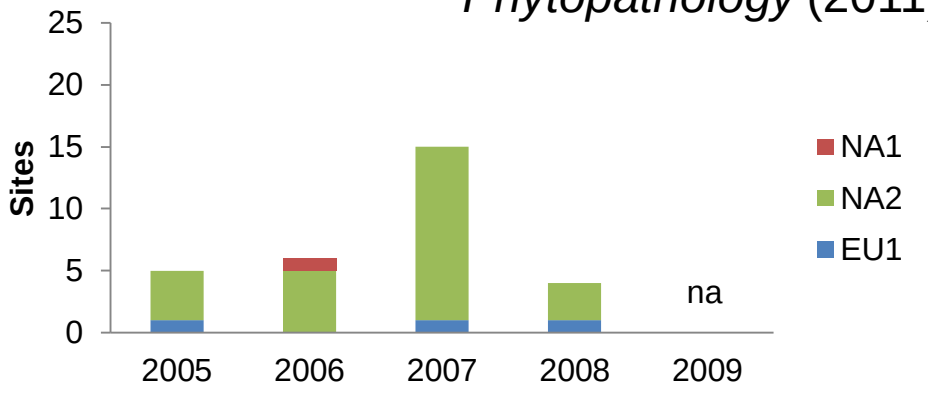


Goss *et al*. 2009 PLoS Path

Changes in West Coast nurseries

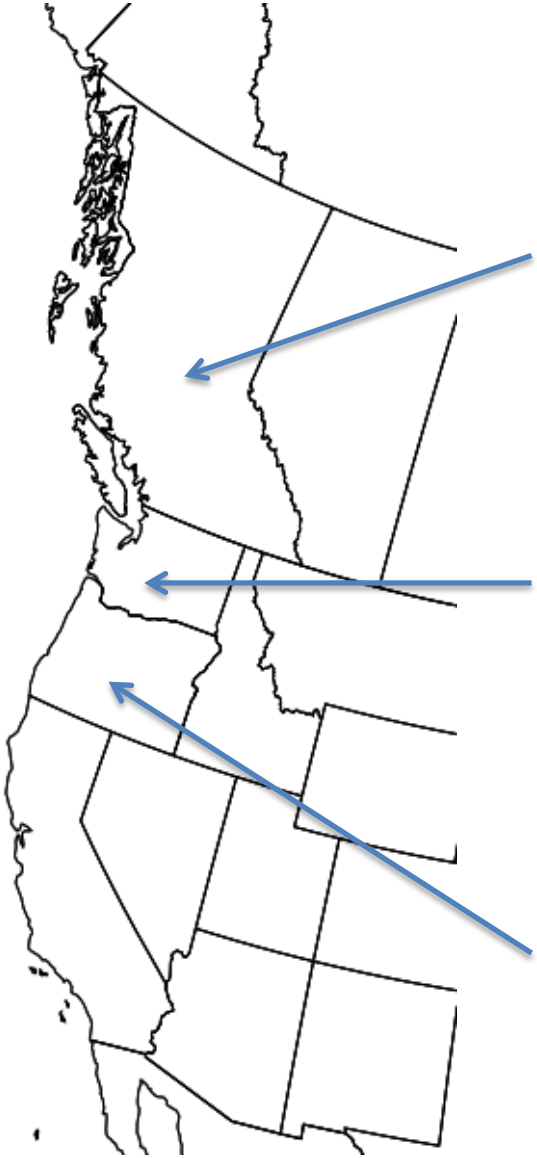


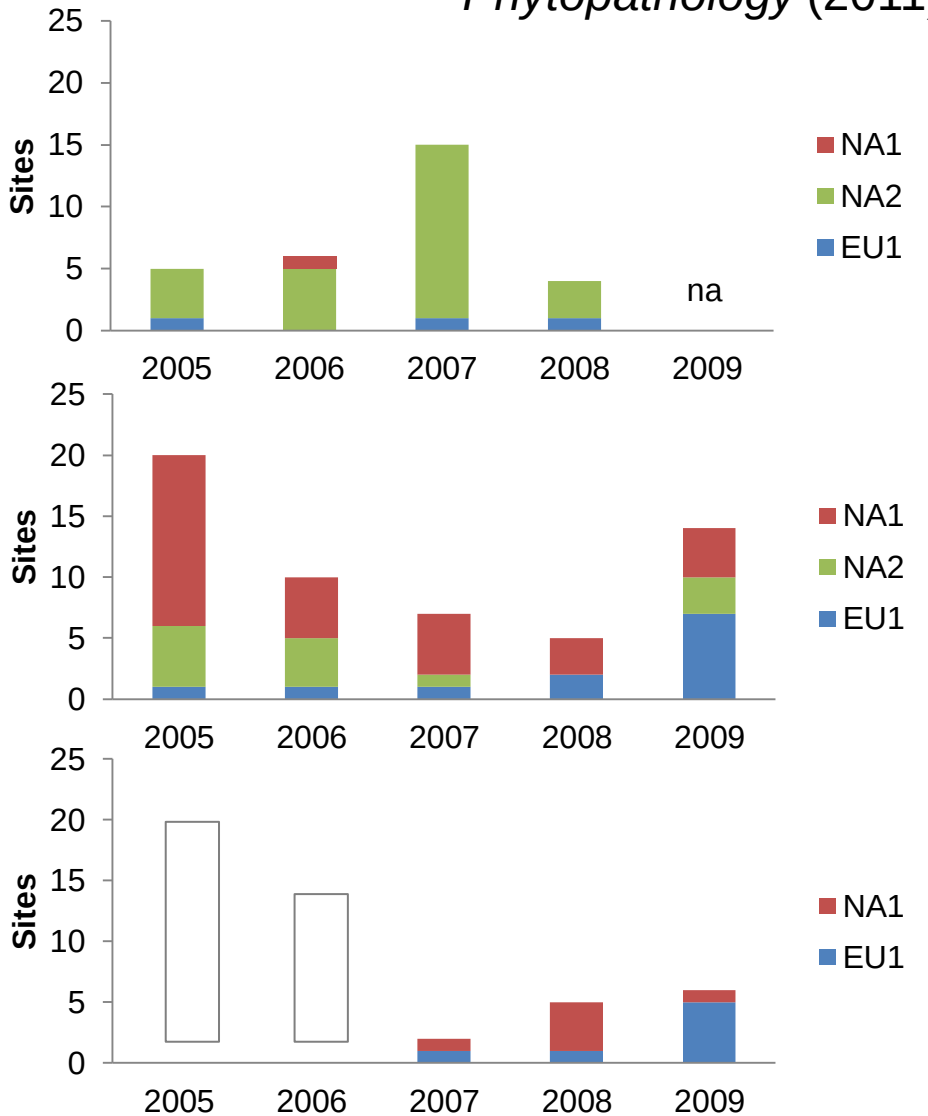
Phytopathology (2011) 101, 166-171

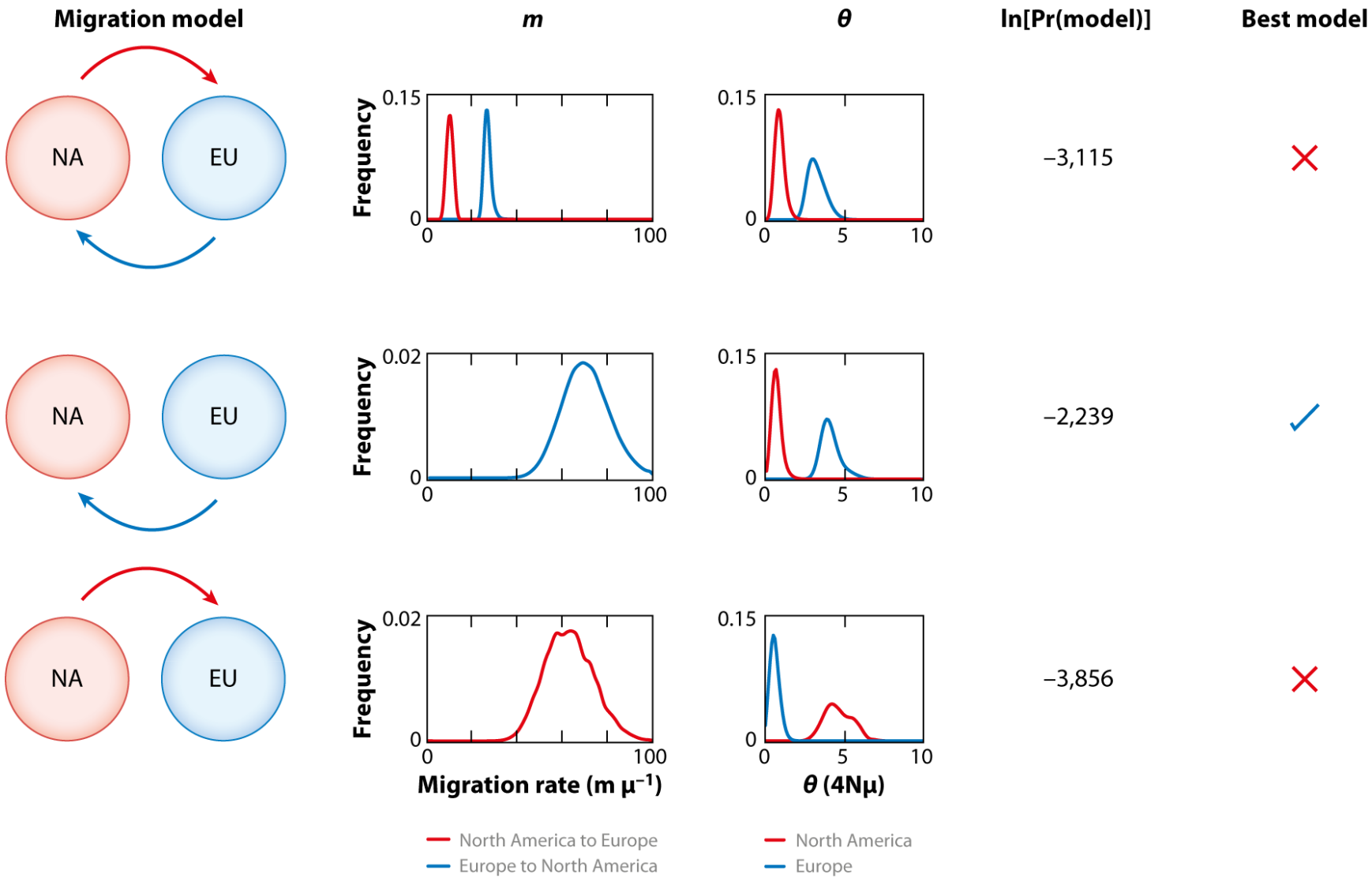


Changes in West Coast nurseries

Phytopathology (2011) 101, 166-171

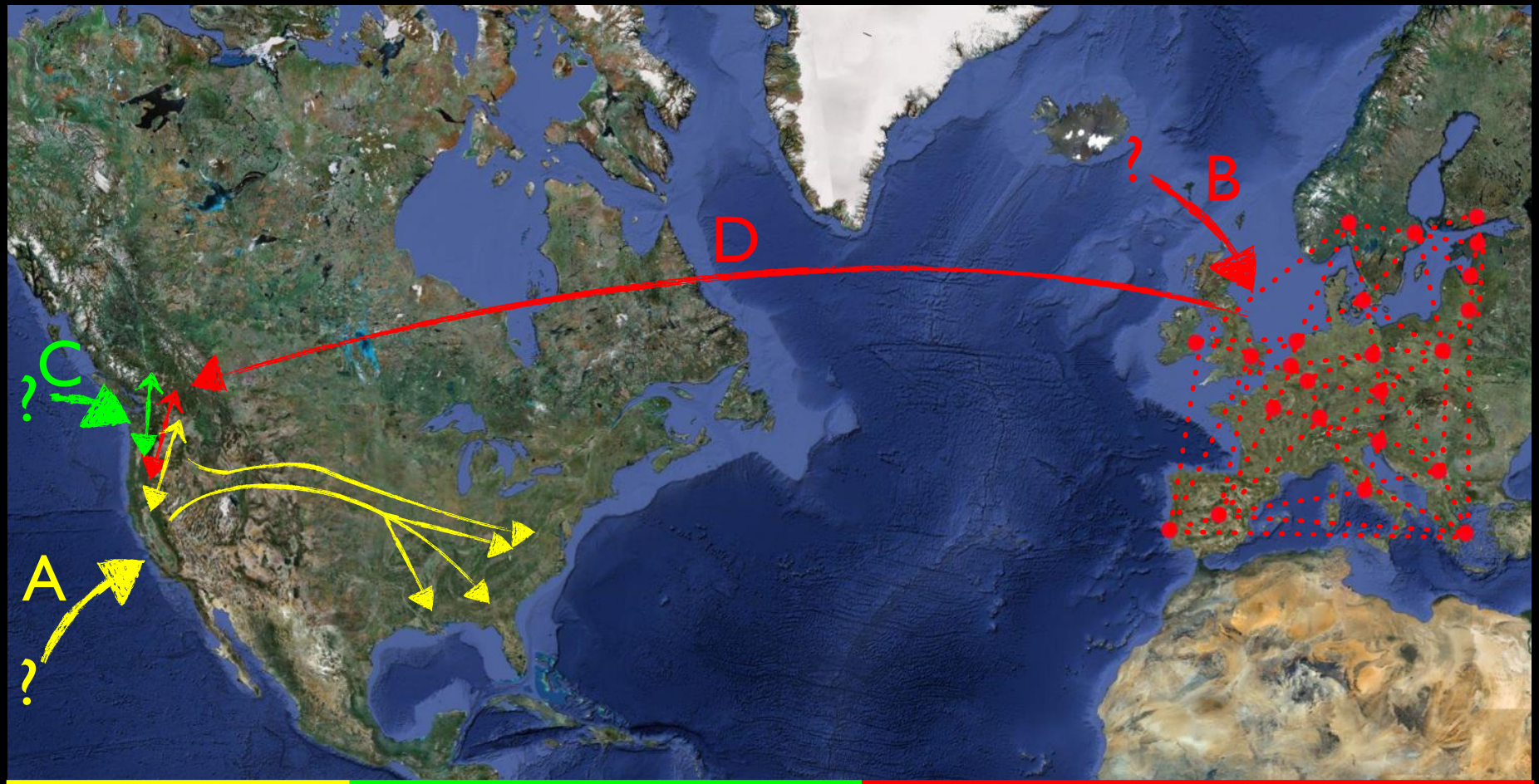






Grünwald NJ, Goss EM. 2011.
Annu. Rev. Phytopathol. 49:249–67

Phytopathology (2011) 101, 166-171



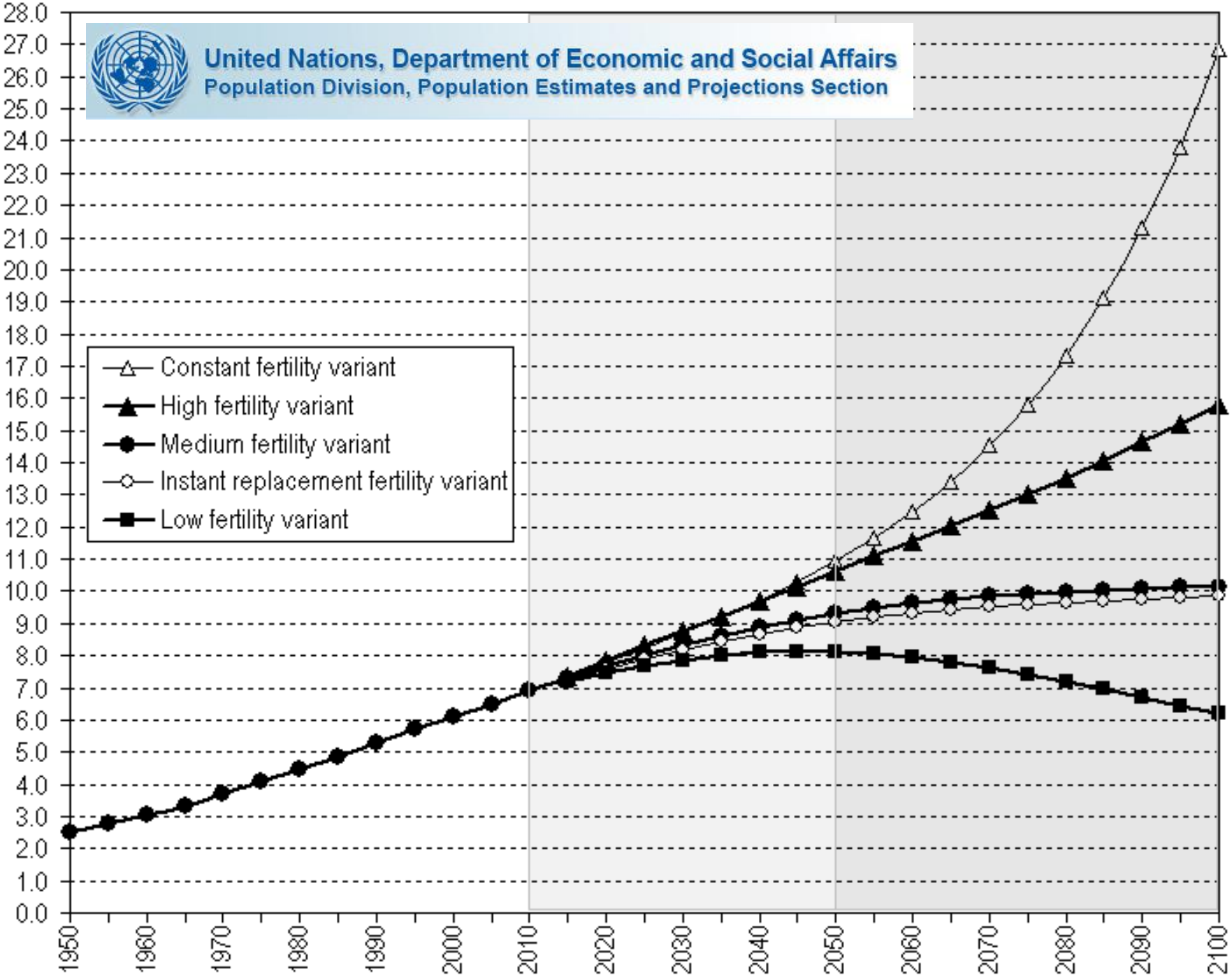
NA1	**Migration A:** **source**: ? **sink**: California	NA2	**Migration B:** **source**: ? **sink**: Washington, USA; British Columbia, Canada	EU1	**Migration C:** **source**: ? **sink**: Europe **Migration D:** **source**: Europe **sink**: Washington, USA; British Columbia, Canada

Trends in Microbiology (2012)

Outstanding questions

- Where is the center of origin of the sudden oak death pathogen?
- Will *P. ramorum* eventually reproduce sexually?
- Can *P. ramorum* hybridize, like *P. alni* and *P. andina*?
- How was *P. ramorum* introduced into Europe and what was the pattern of spread?
- Will there be further new epidemics, as observed for the recent Japanese larch epidemic in the UK? Can we predict them?
- Introduction of the EU1 or NA lineages into US forests? Introduction of NA1 or NA2 lineages into Europe?
- Can breeding for resistance help the management of sudden oak death on oaks and tanoak and related epidemics on larch?
- How do we improve the current biosecurity protocols to reduce further spread of *P. ramorum* and how can we avoid further pathogen introductions?
- How will climate change affect the sudden oak death epidemic?

In my own opinion


United Nations, Department of Economic and Social Affairs
Population Division, Population Estimates and Projections Section
Constant fertility variant
High fertility variant
Medium fertility variant
Instant replacement fertility variant
Low fertility variant
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
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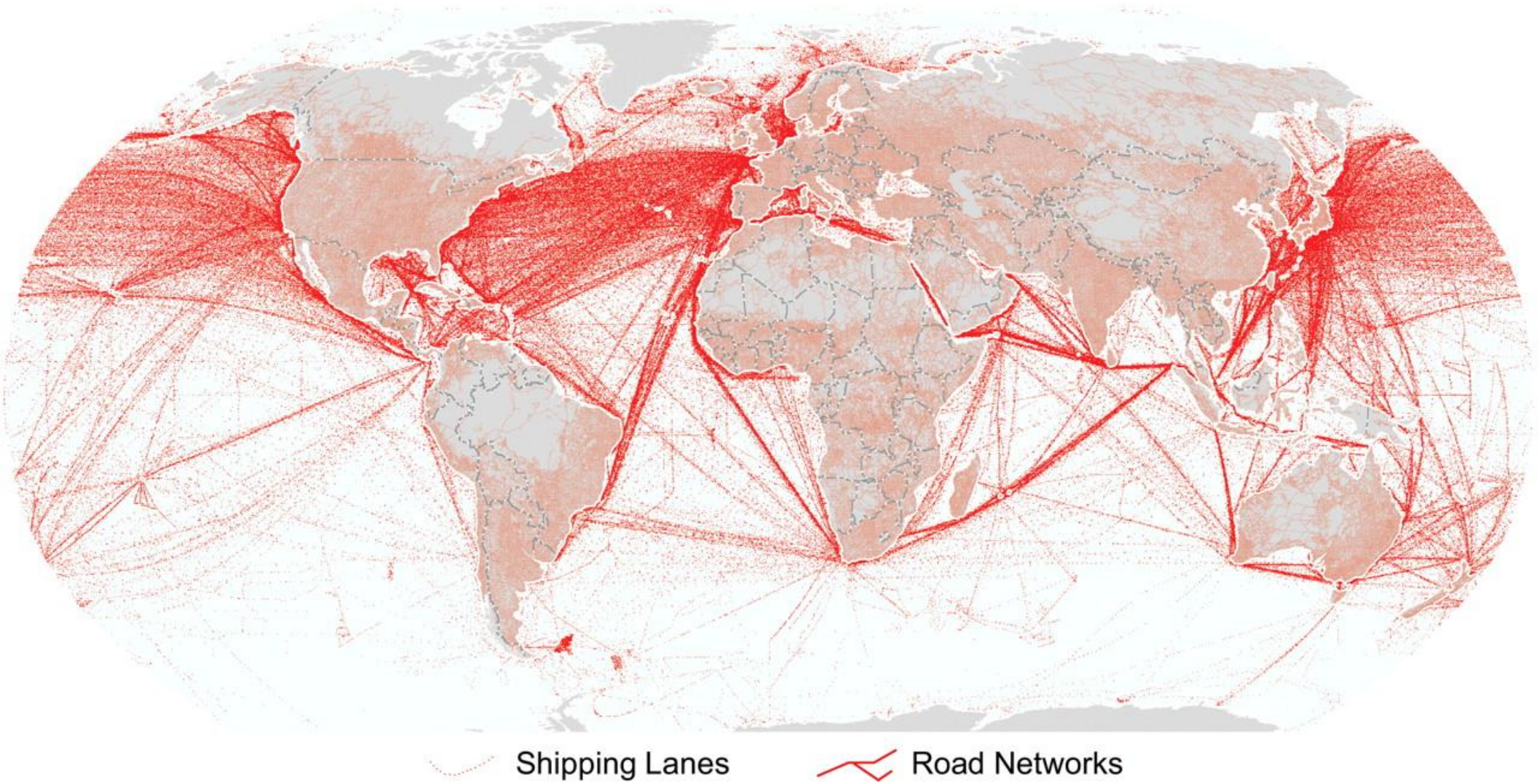
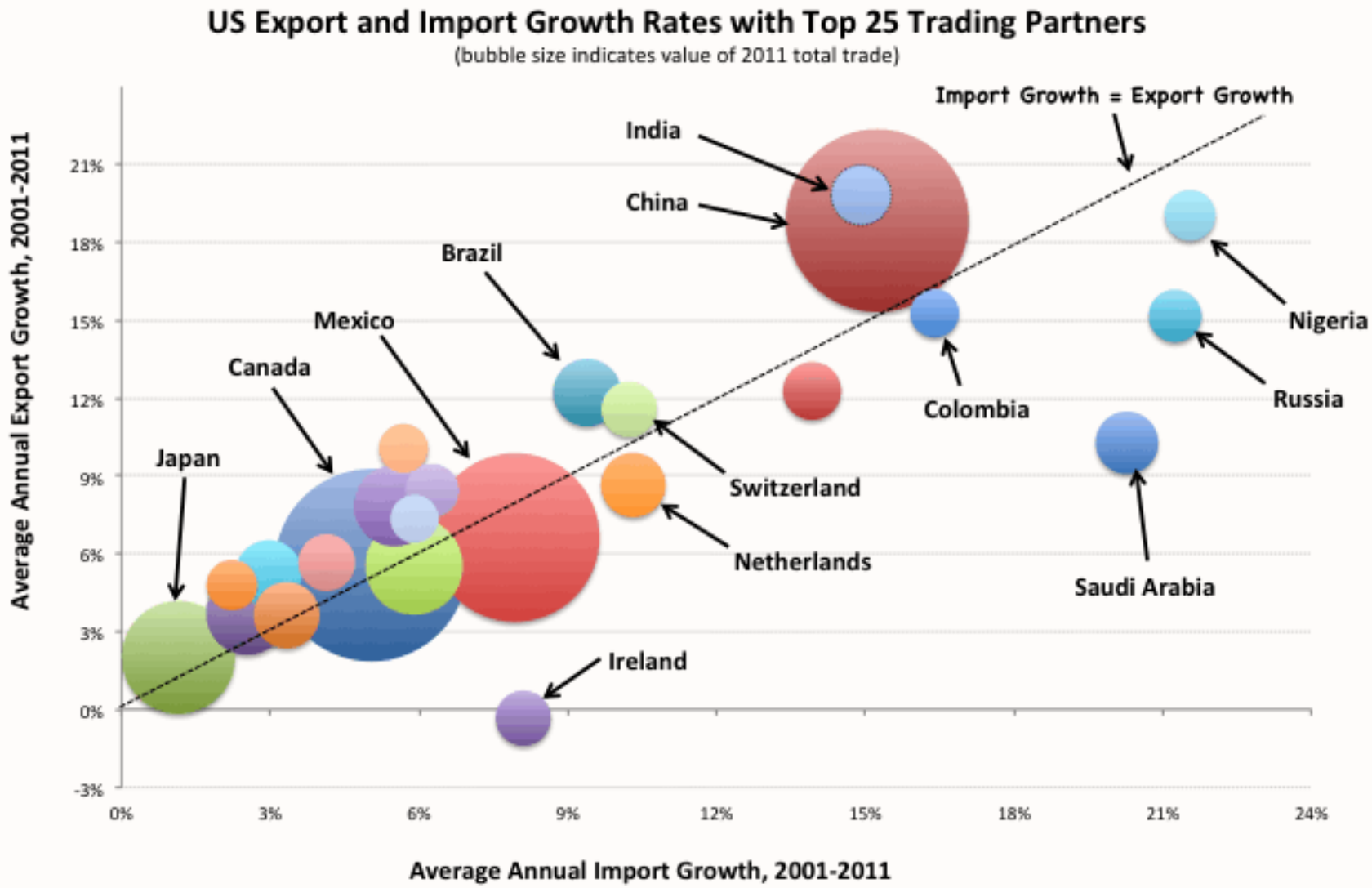
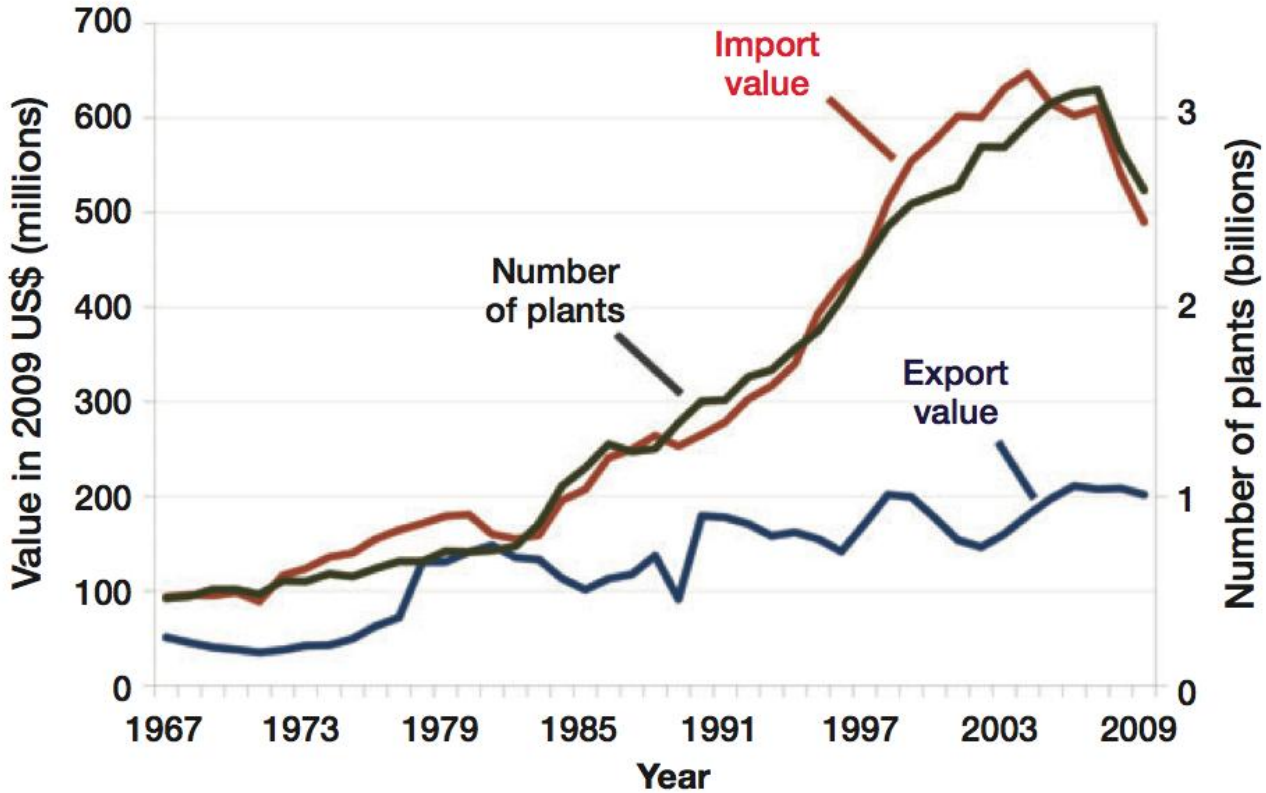


http://billjaquette.net/top-major-shipping-lanes-and-ports-in-the-world



Source: The Trade Partnership (Washington, DC) from U.S. Bureau of the Census data



REVIEWS REVIEWS REVIEWS

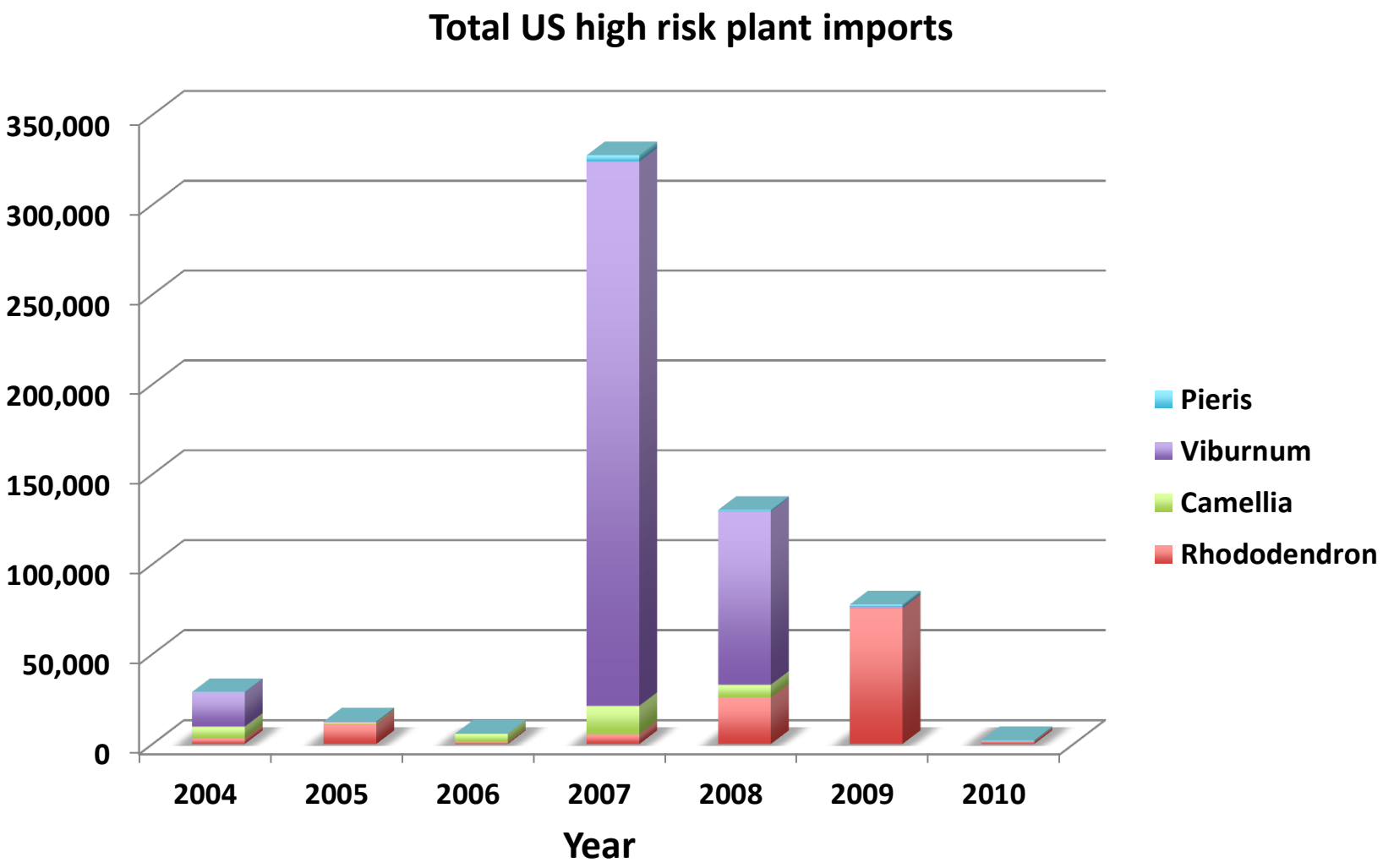
Live plant imports: the major pathway for forest insect and pathogen invasions of the US

Andrew M Liebhold[1*], Eckehard G Brockerhoff[2], Lynn J Garrett[3], Jennifer L Parke[4], and Kerry O Britton[5]

Front Ecol Environ 2012; 10(3): 135–143, doi:10.1890/110198 (published online 5 Mar 2012)

Conclusions (Liebhold et al. 2012)

- Importation of live plants is most common pathway for introduction of non-native forest pests and pathogens
- Plant imports in US increased 33% per decade over past 43 years
- Practical limitations to finding pests through inspections
- Estimate that in fiscal year 2009, about 72% of infested plant shipments passed through US ports undetected



Source: USDA APHIS

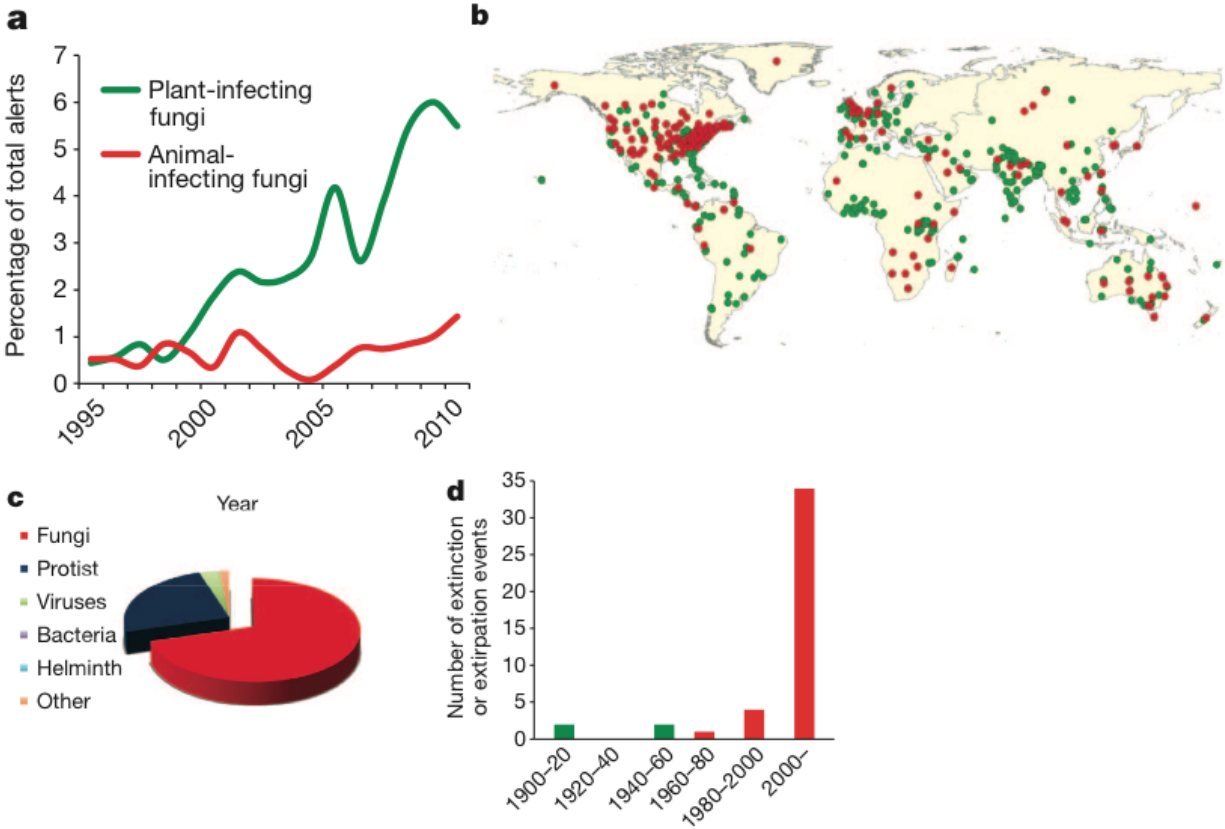


Figure 1 | Worldwide reporting trends in fungal EIDs. **a**, **b**, Disease alerts in the ProMED database for pathogenic fungi of animals and plants (**a**), and the spatial location of the associated reports (**b**). **c**, **d**, Relative proportions of species extinction and/or extirpation events for major classes of infectious disease agents (**c**) and their temporal trends for fungal pathogens (**d**). Primary data sources are given in the Supplementary Information.

REVIEW

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Emerging fungal threats to animal, plant and ecosystem health

Matthew C. Fisher[1], Daniel. A. Henk[1], Cheryl J. Briggs[2], John S. Brownstein[3], Lawrence C. Madoff[4], Sarah L. McCraw[5] & Sarah J. Gurr[5]

Participating institutions:

- USDA Agricultural Research Service
- Department of Environmental Science, Policy and Management, UC Berkeley
- Emerging Pathogens Institute, University of Florida
- Institute for Agricultural and Fisheries Research (ILVO), Plant Sciences Unit – Crop Protection, Belgium
- Swiss Federal Institute for Forest, Snow and Landscape Research WSL

- And many other unnamed colleagues

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- NNCRC
- USFS PSW
- USDA APHIS
- USDA ARS

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