Sudden Oak Death Update for Foresters and Landowners

Ukiah & Eureka, California

May 12-13, 2010

Biology and epidemiology of *P. ramorum*

Matteo Garbelotto, U.C. Berkeley

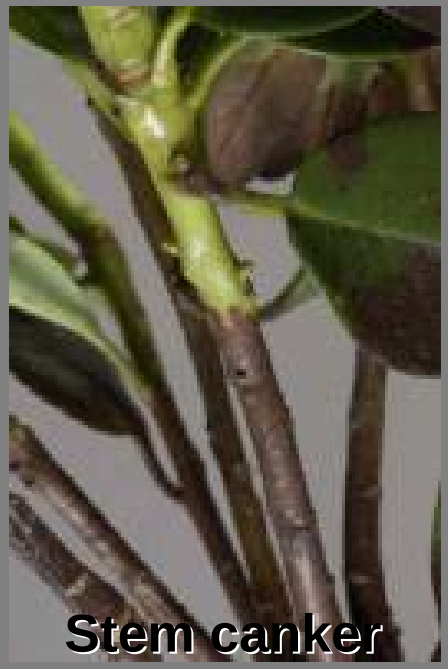
The year was…

70’s, 80s?

P. ramorum growing in a Petri dish

Organism new to science

- Origin unknown
- Biology unknown
- Symptoms caused unknown
- Immediately though highly regulated


Stem canker

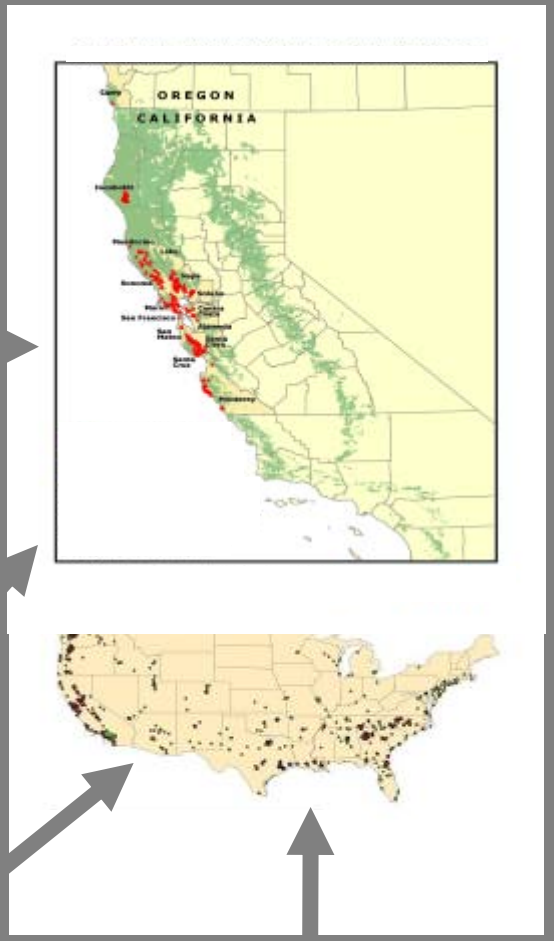
Rhododendron:

In EU mostly a nursery issue, but also present in nurseries in US and Canada


Leaf necrosis

Symptoms not always present

- Early stages of infection
- Cryptic infection in rhododendron roots
-Plants chemically treated
-Leaves plucked


OREGON
CALIFORNIA

Pathogen

- Q: Where does it come from?

  A: While area of origin is still unknown, commercial plant nurseries were unequivocally identified as sources of original introduction

NEW

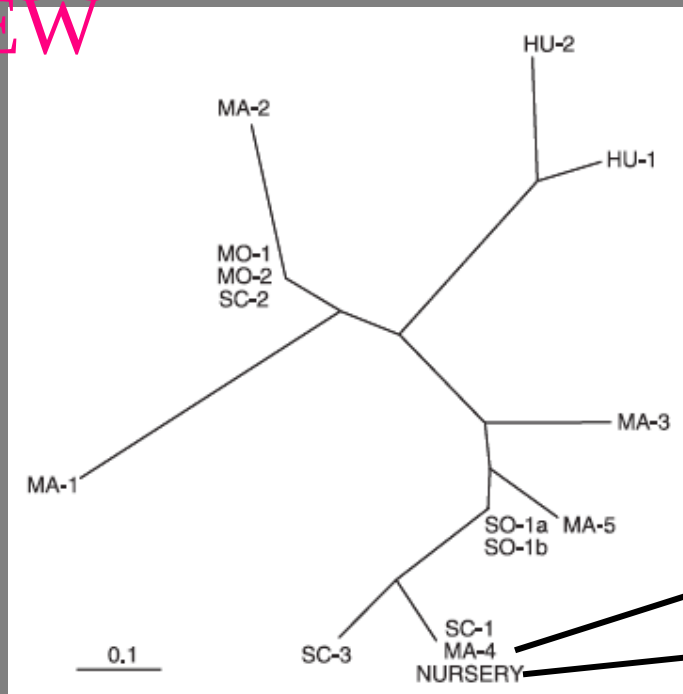
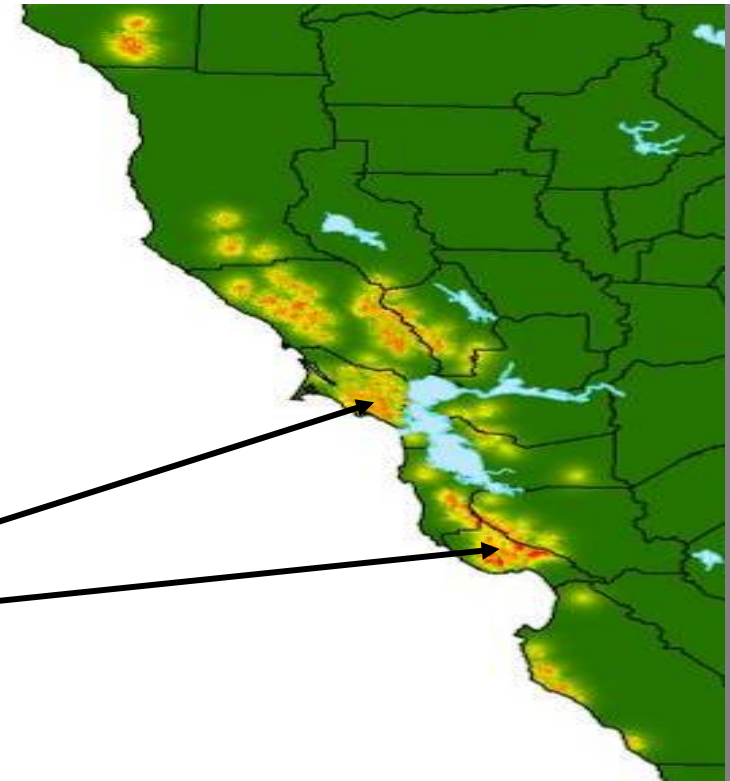


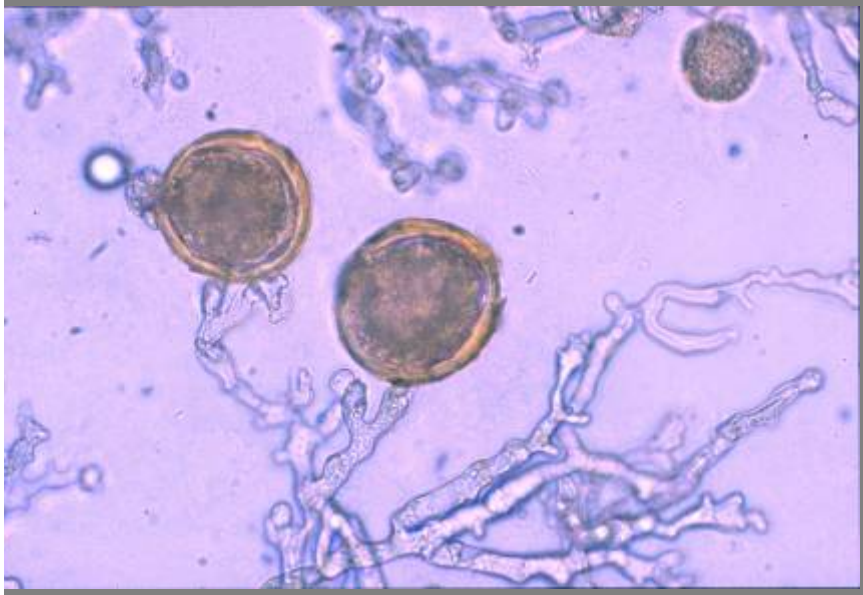
Fig. 3 Neighbour-joining tree illustrating the relationships between statistically significantly differentiated *Phytophthora ramorum* population samples and meta-samples, formed by clustering samples according to minimum Φ_{ST}.




Umbellularia

Phytophthora ramorum

Sporangia: produced when It is wet



Chlamydospores

How do sporangia move?

- Airborne
- Waterborne/soilborne/ movement of infected plants
- Can move 100-200 m, but in strong winds up to 2 km

Molecular Ecology (2008) doi: 10.1111/j.1365-294X.2008.03773.x

Reconstruction of the Sudden Oak Death epidemic in California through microsatellite analysis of the pathogen *Phytophthora ramorum*

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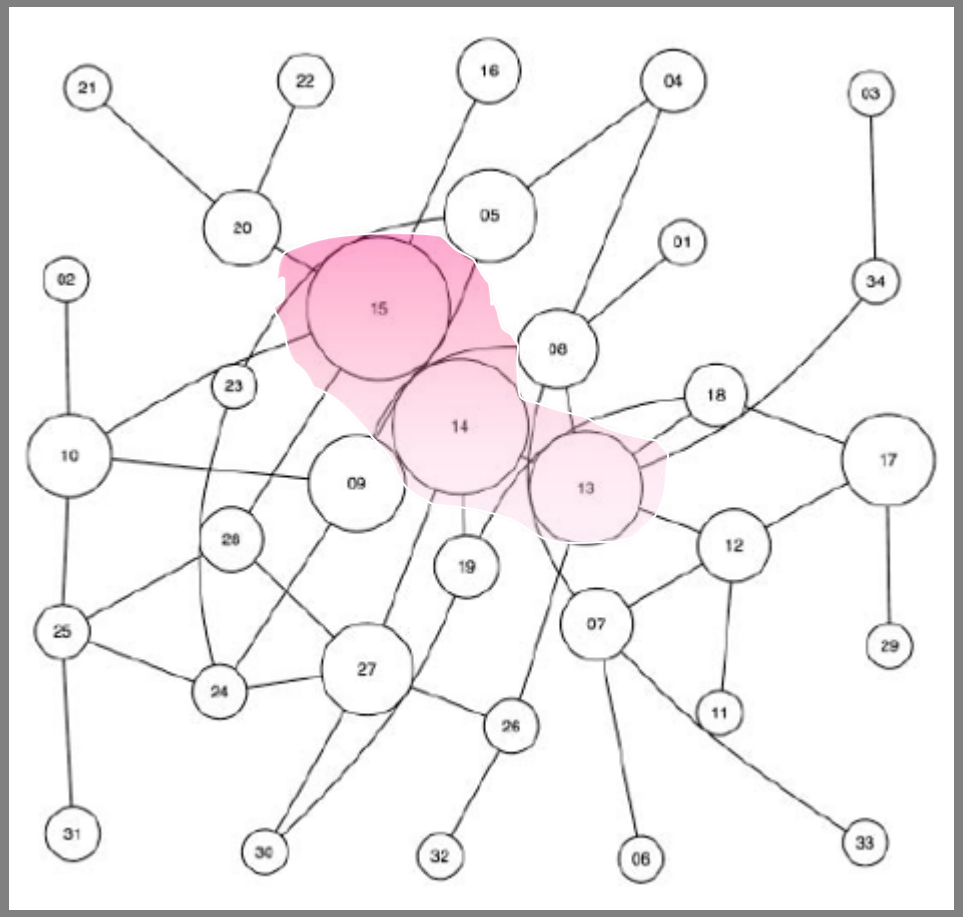


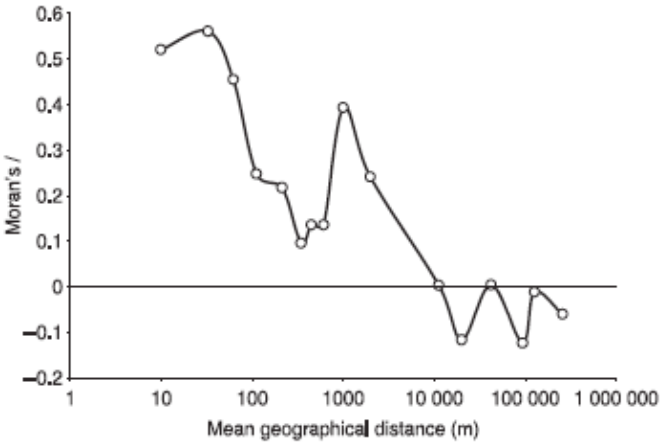
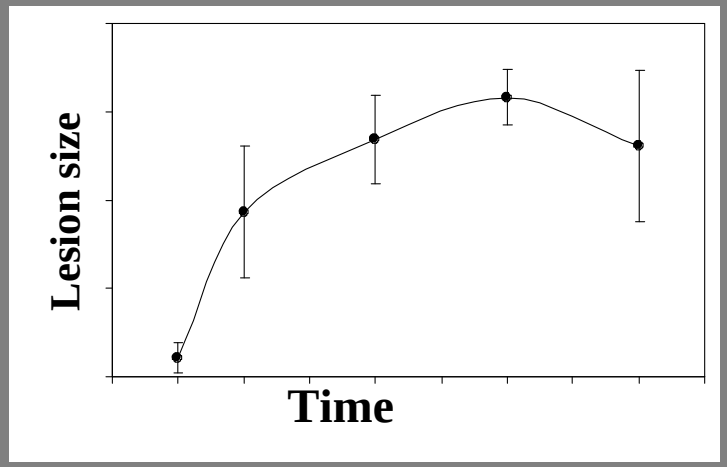


Fig. 4 Spatial autocorrelation analysis of genetic and geographical distance in *Phytophthora ramorum*. Moran's *I*-index, averaged over loci, was calculated from the repeat number at each of four variable microsatellite loci.

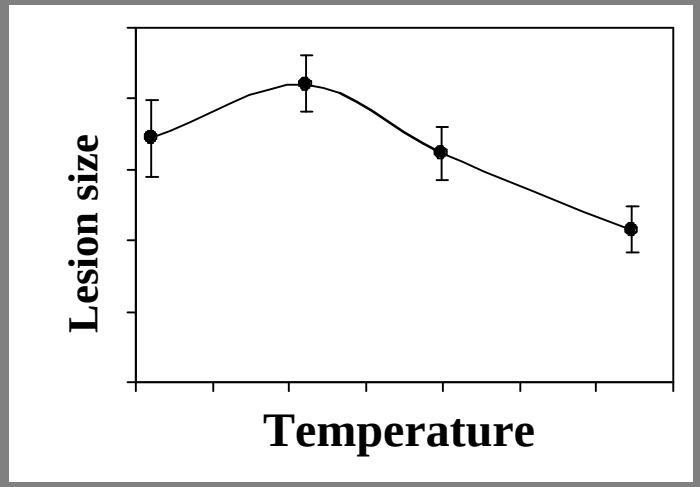
Circles represent genotypes: red shade indicates those that were introduced, are common in all infested sites, and are the progenitors of all other genotypes. Relatedness is indicated by connecting lines

When do sporangia infect new hosts?

- Temperature and leaf wetness



12 hours

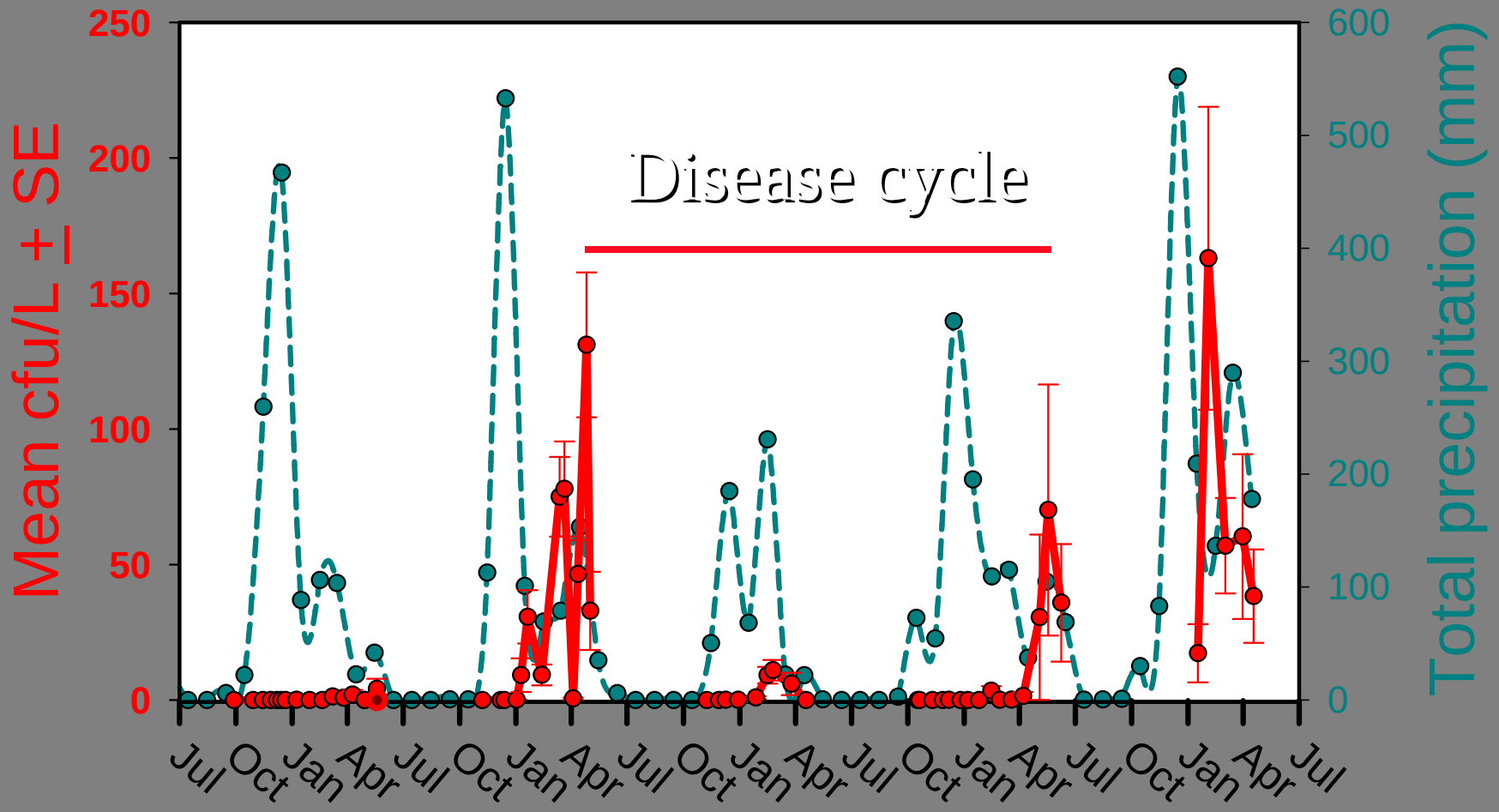


20 C

Infection occurs….

- Via zoospores produced by airborne sporangia…..
- Requires water: limited infection with fog, high with rain
- Needs warm temperatures

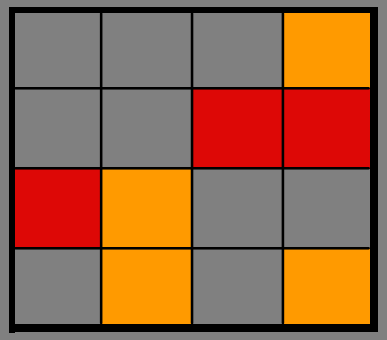
Spores in rainwater 2001-06



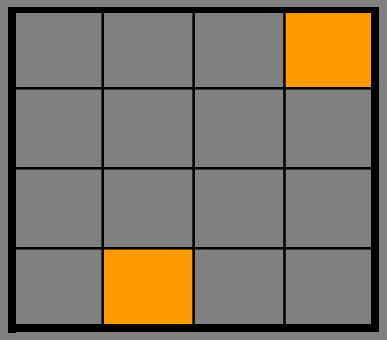
month

Buckets with water and healthy bay leaves as bait are placed on the vertices of a grid

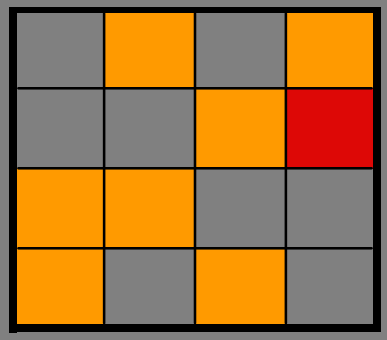
Medium (yellow) and high (red) inoculum levels in bucket baits in 8 plots in June



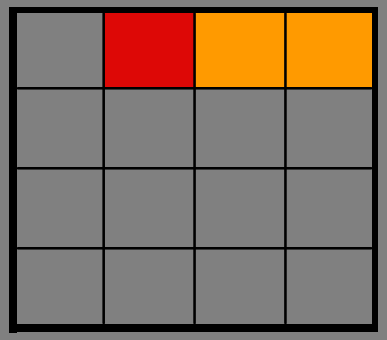
L1C



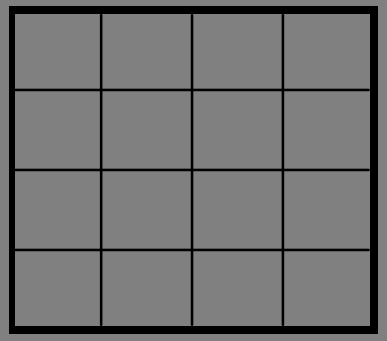
L1T



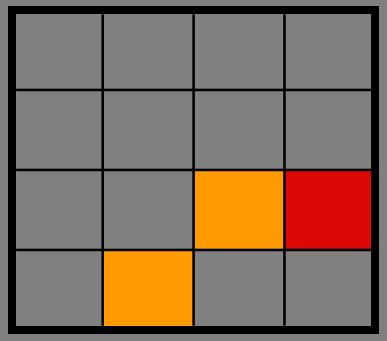
L2C



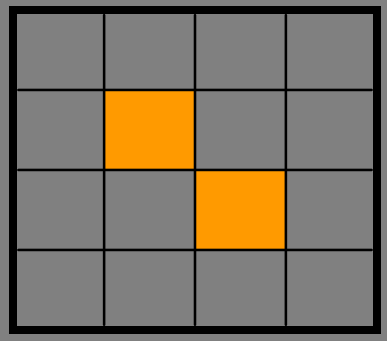
L2T



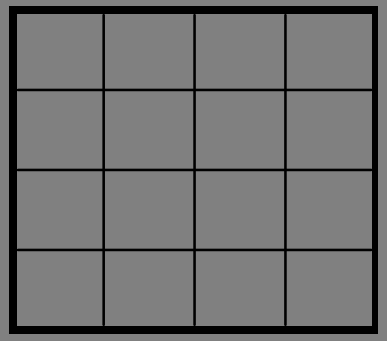
LT1C



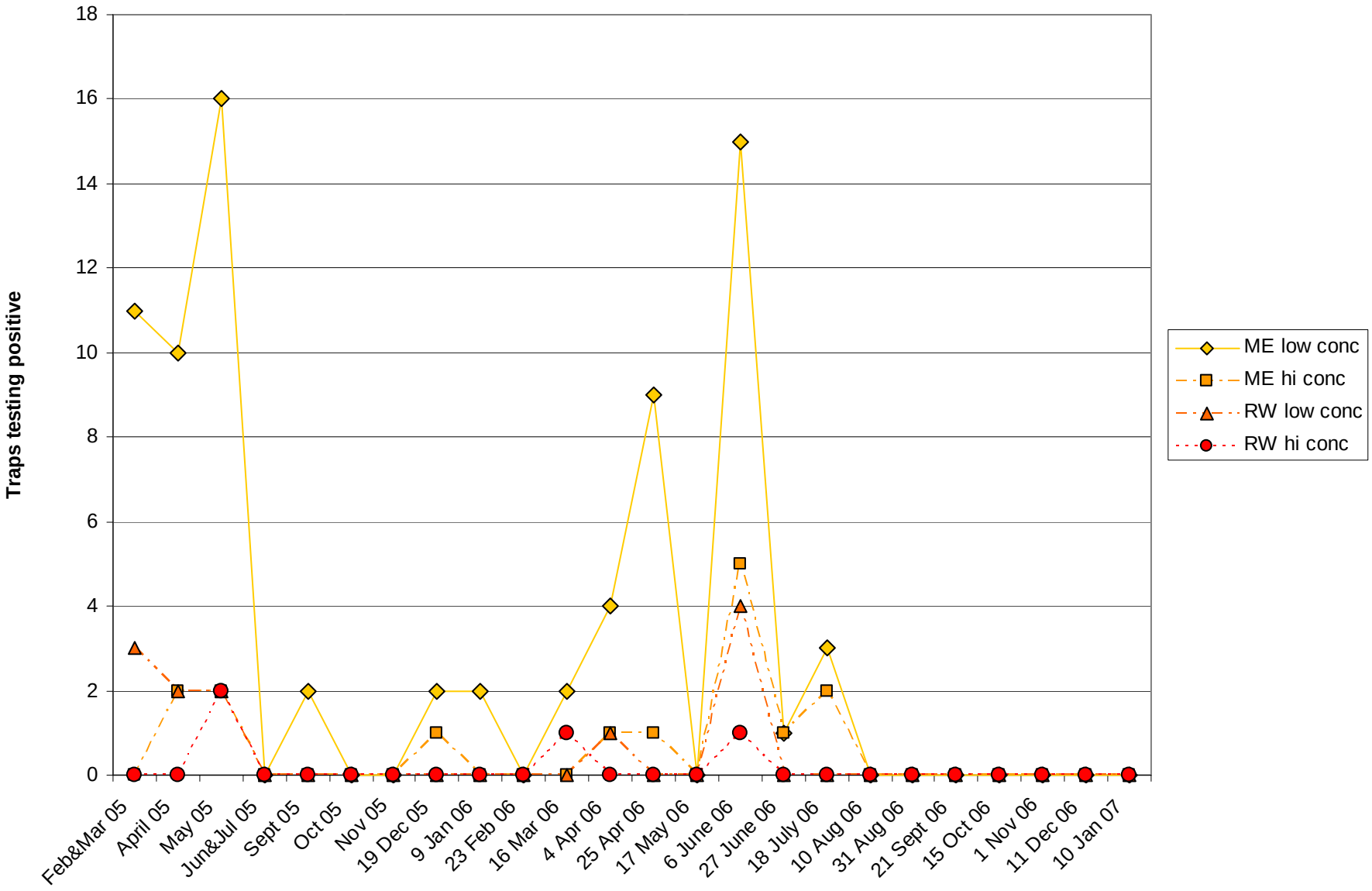
LT1T



LT2C

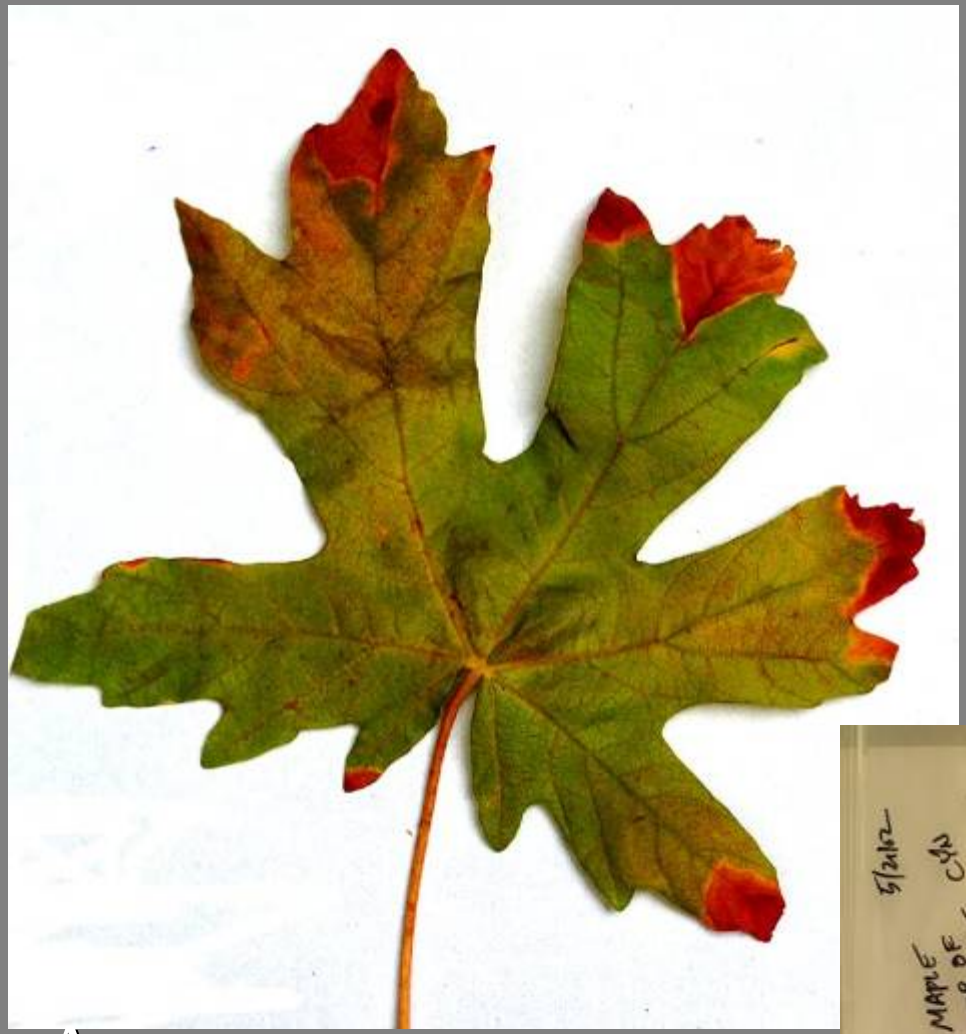


LT2T


Traps testing positive
18
16
14
12
10
8
6
4
2
0
Feb&Mar 05
April 05
May 05
Jun&Jul 05
Sept 05
Oct 05
Nov 05
19 Dec 05
9 Jan 06
23 Feb 06
16 Mar 06
4 Apr 06
25 Apr 06
17 May 06
6 June 06
27 June 06
18 July 06
10 Aug 06
31 Aug 06
21 Sept 06
15 Oct 06
1 Nov 06
11 Dec 06
10 Jan 07
ME low conc
ME hi conc
RW low conc
RW hi conc

Duglas-fir sapling branch tip wilted by *P. ramorum*

Symptoms on Buckeye leaves and petioles



Autumn

Scorching of maple leaves caused by *P. ramorum*

Spring

Most severe levels of disease and many plants species infected

- In proximity of infected bay laurels
- Tanoaks started were reported dead in 1995
- Coast live oak and black oaks in 2000

Girdling aerial ‘cankers’ removed from roots

Oaks

Quercus agrifolia

Black oak

Q. kellogii

Shreve's oak

Q. parvula* var. *shrevei

Canyon Live oak

Q. chrysolepis

Cankers end at soil line

Redwood-Tanoak forest

Tanoaks of all ages can be infected

Tanoaks mortality rate of adults can locally be 100%

Tanoaks can be infectious

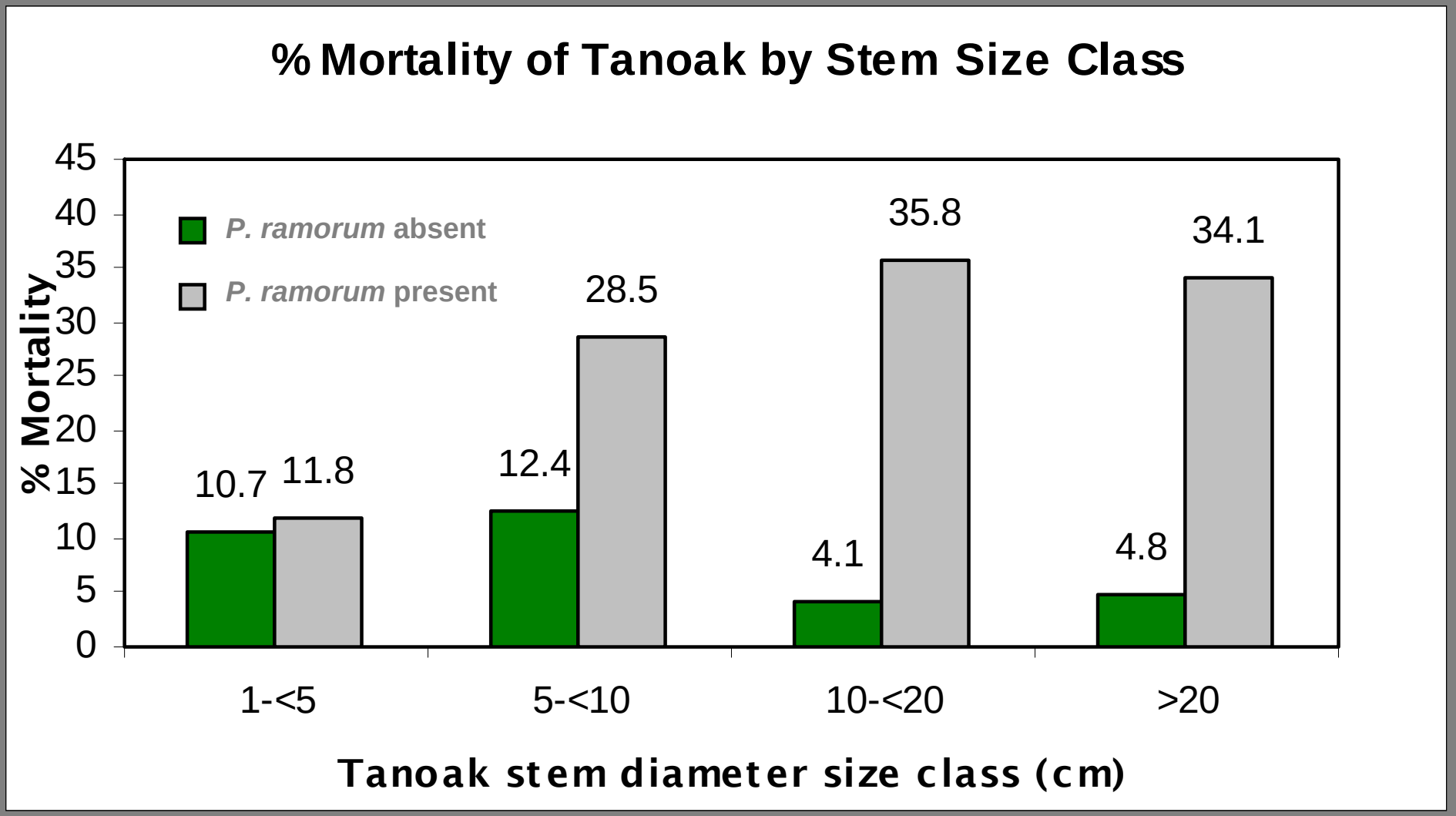
Mixed-evergreen forest

Only mature oaks are
Infected

Oak mortality still under 50%

Oaks are not infectious and their infection normally occurs near other infectious hosts and


Big Sur
2006
K. Frangioso


% Mortality of Tanoak by Stem Size Class
% Mortality
45
40
35
30
25
20
15
10
5
0
P. ramorum absent
P. ramorum present
10.7
11.8
12.4
28.5
4.1
35.8
4.8
34.1
1-<5
5-<10
10-<20
>20
Tanoak stem diameter size class (cm)


Warm wet weather


Umbellularia

Bay/Oak association

Bay

Sporangia

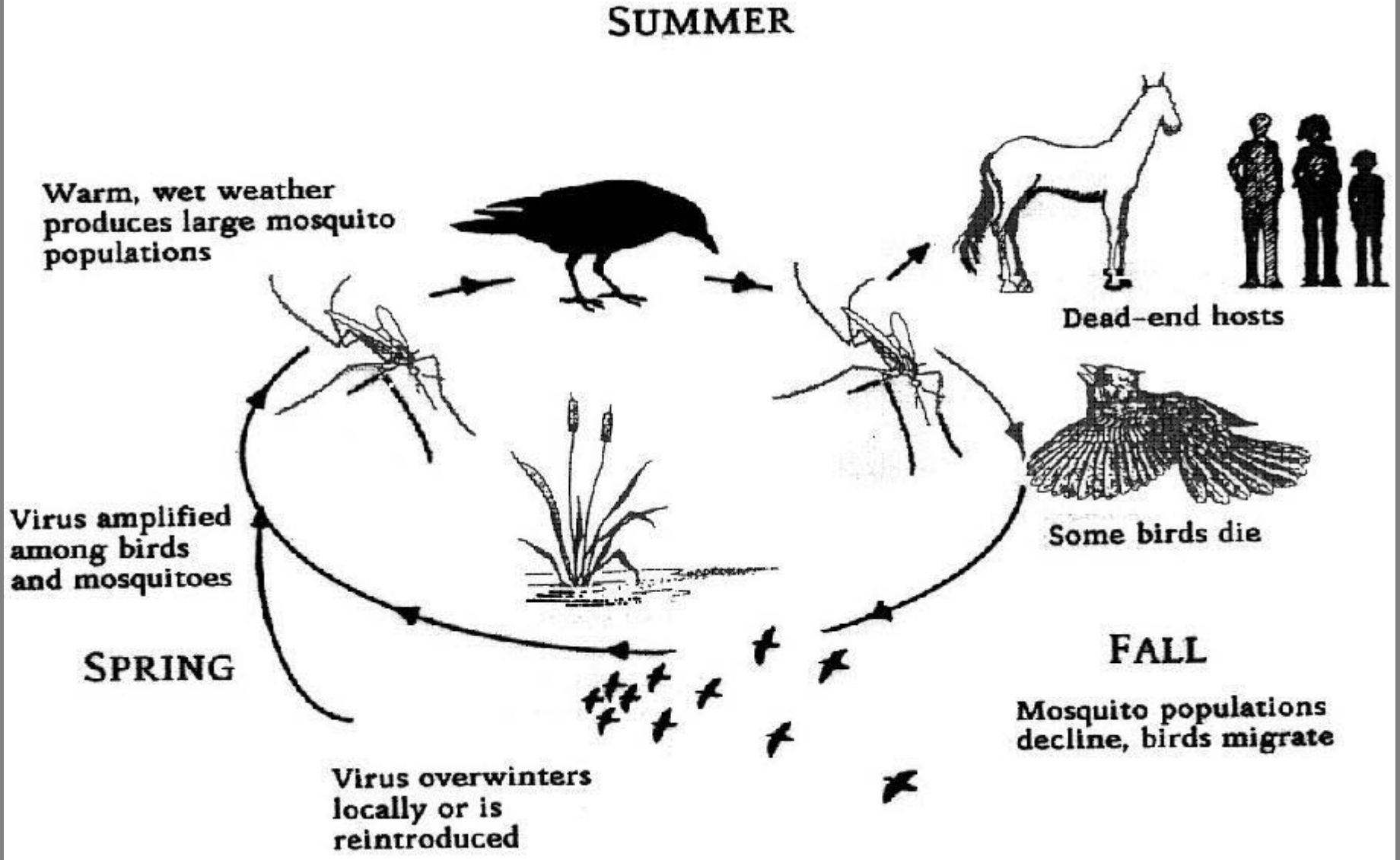
Coast Live Oak (no sporulation)

Canker margin in phloem

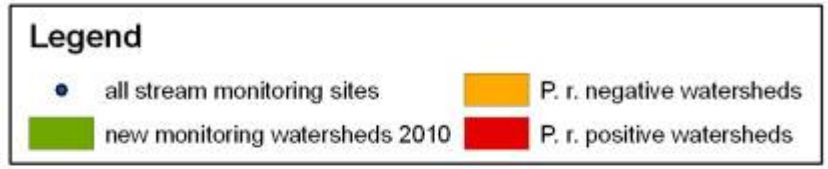
Bleeding canker

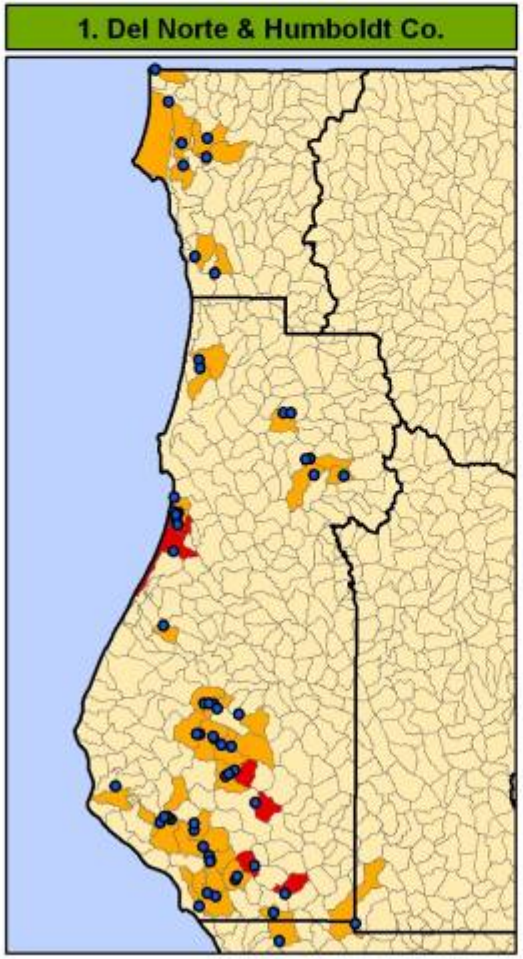
SOIL, WATER

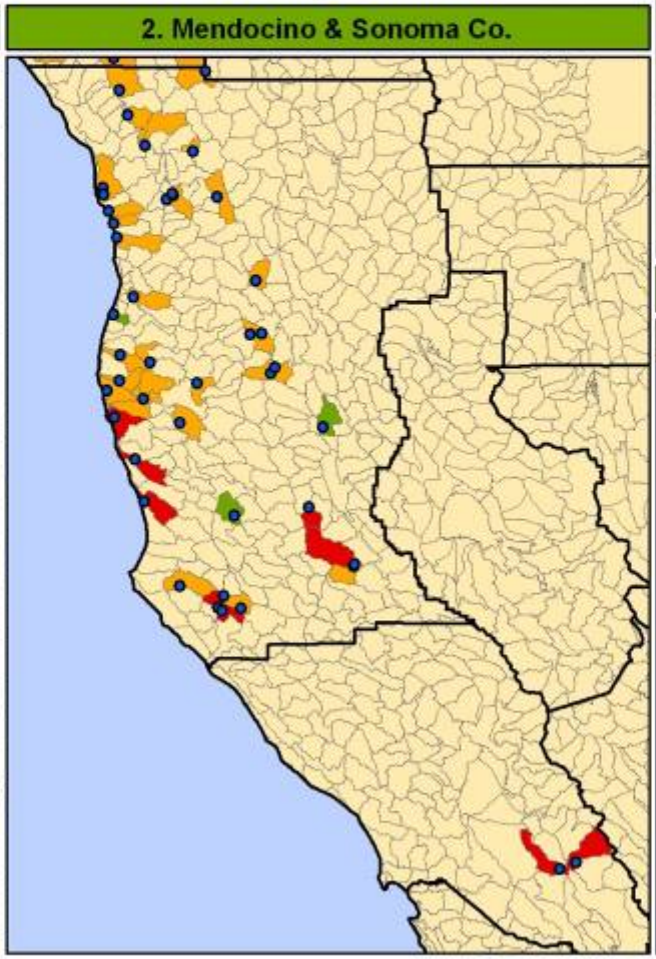
Life Cycle of the West Nile Virus

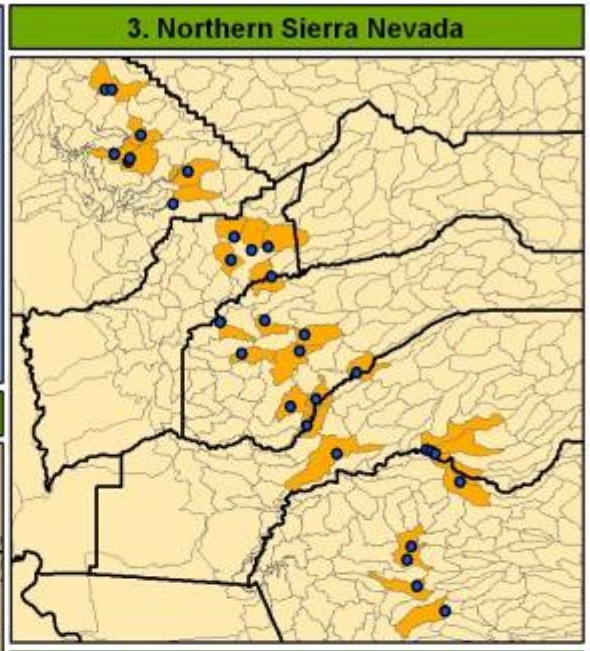


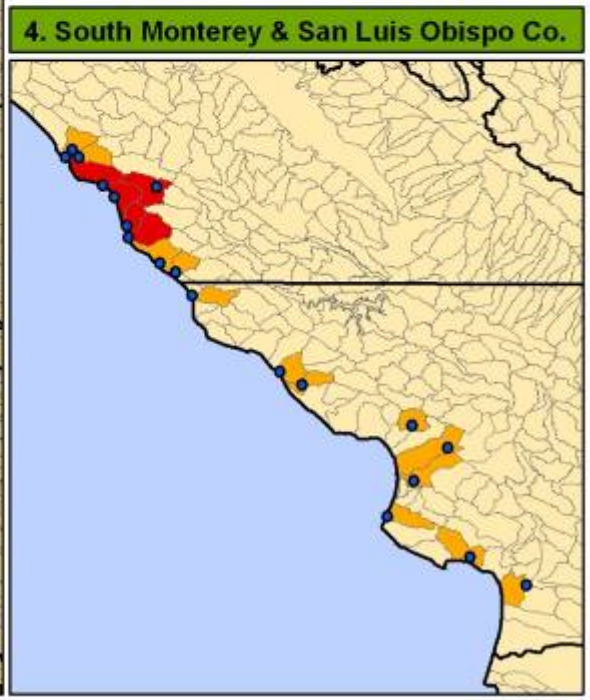
Stream Monitoring Detection of *Phytophthora ramorum* 2004-2009

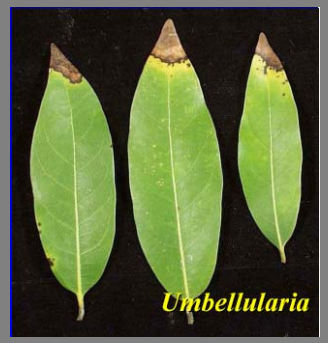












Host(s)

New Phytologist

Research

Evidence for the role of synchronicity between host phenology and pathogen activity in the distribution of sudden oak death canker disease

Richard S. Dodd[1], Daniel Hüberli[2], Waisima Mayer[1], Tamar Y. Harnik[1], Zara Afzal-Rafii[1] and Matteo Garbelotto[1]

[1]Department of Environmental Science Policy and Management, 137 Mulford Hall, University of California, Berkeley, CA 94720, USA; [2]Centre for Phytophthora Science and Management, School of Biological Sciences and Biotechnology, Murdoch University, Murdoch, WA 6150, Australia

Summary

P. ram active

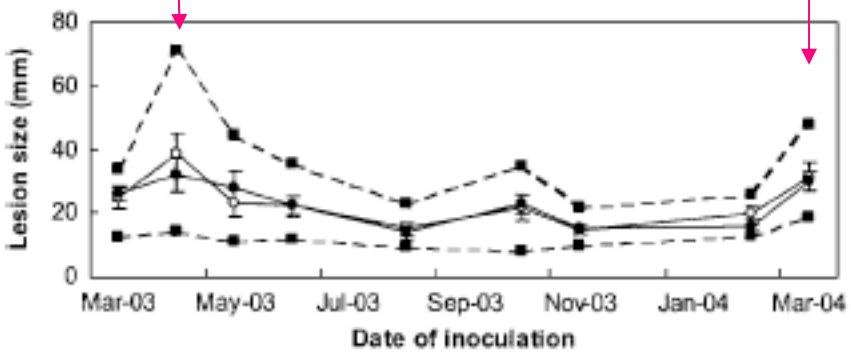


Fig. 1 Size of lesions at different inoculation dates in coast live oak (*Quercus agrifolia*) after inoculation with *Phytophthora ramorum*. Open circles, Chicken Coop site; closed circles, Miwok site. Overall maximum and minimum lesion sizes are shown as dotted lines with closed rectangles. Standard errors are shown as vertical bars.

Peaks of susceptibility correspond to peaks of cambial activity

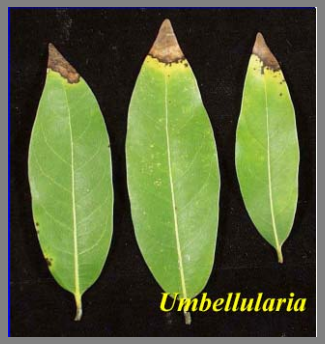
New Phytologist

Research

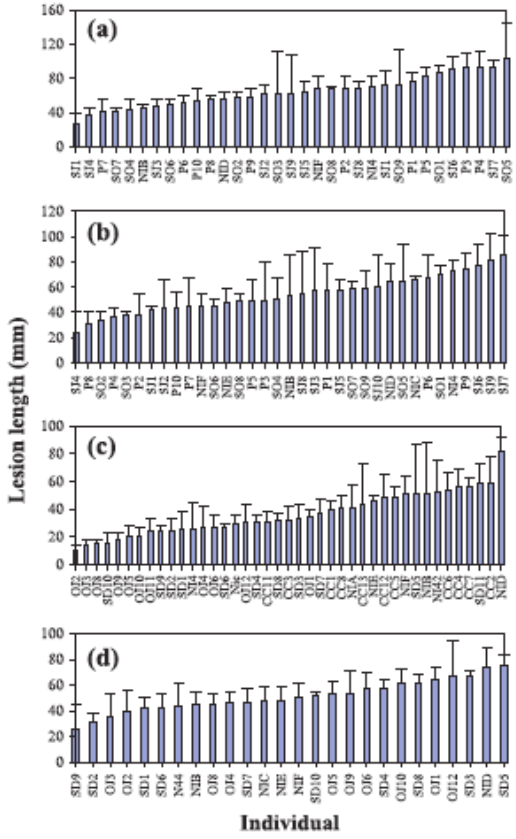
Is variation in susceptibility to *Phytophthora ramorum* correlated with population genetic structure in coast live oak (*Quercus agrifolia*)?

Richard S. Dodd[1], Daniel Hüberli[1], Vlad Douhovnikoff[1], Tamar Y. Harnik[1], Zara Afzal-Rafii[2] and Matteo Garbelotto[1]

[1]Department of Environmental Science Policy and Management, 151 Hilgard Hall, University of California, Berkeley, CA 94720, USA; [2]IMEP, Faculté des Sciences St. Jérôme, Université d'Aix-Marseille III, 13397 Marseille, France



Host(s)

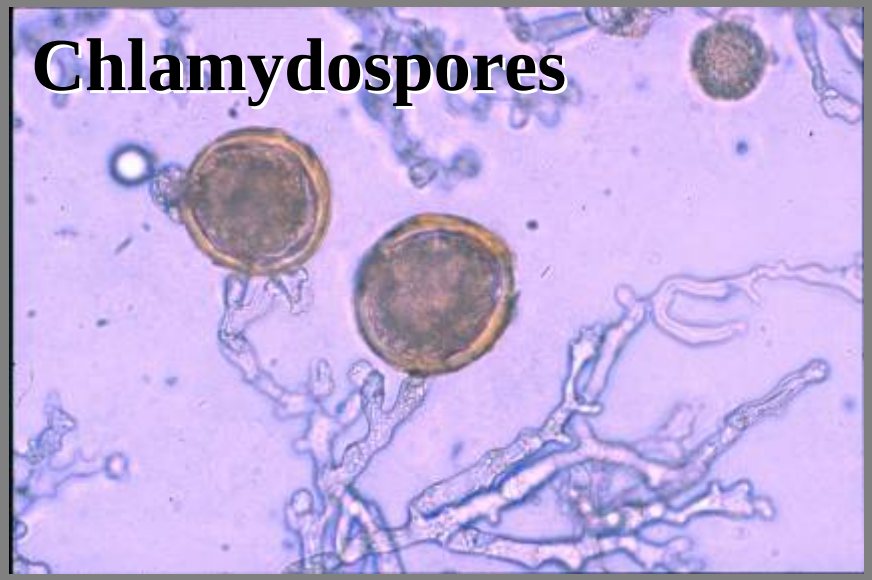


Significant variation in susceptibility (up to 20x) highlighted through inoculation studies

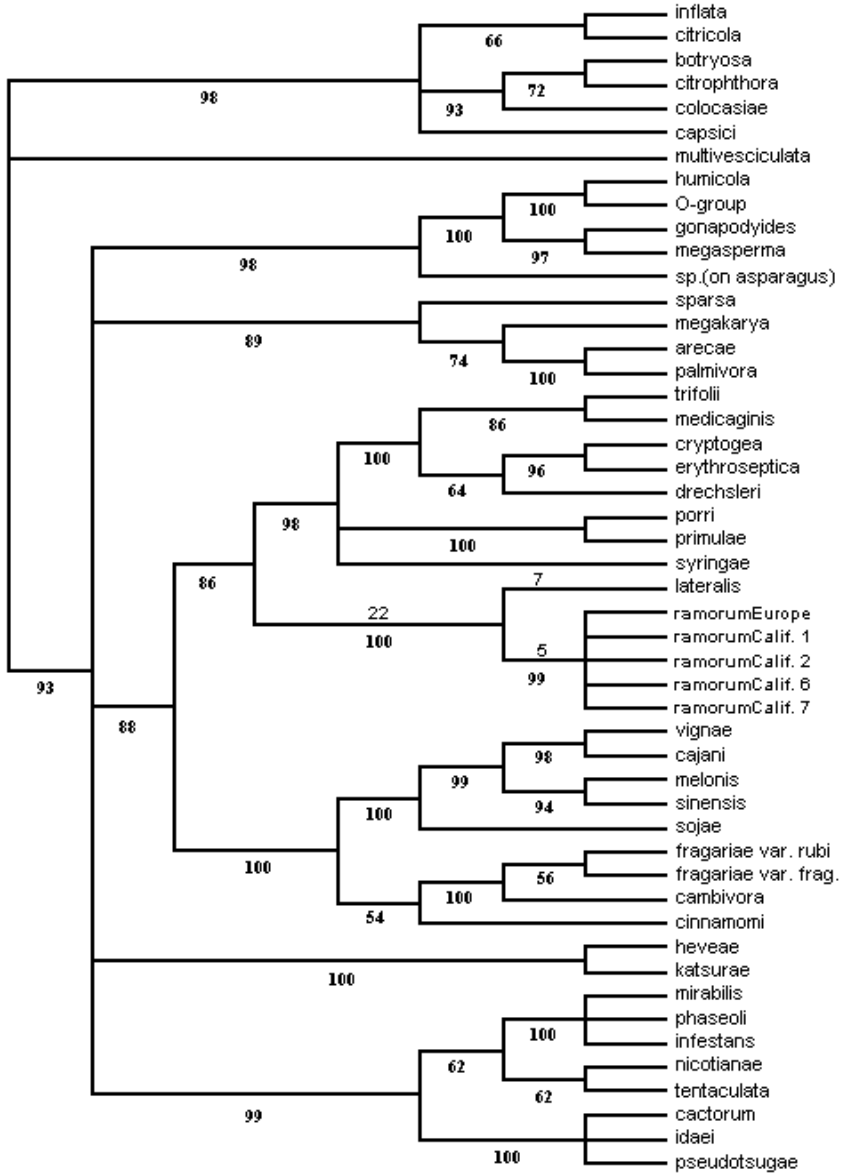
Although variation is mostly amongst individuals within a population, some populations differ as well. Population-level significance may allow us to predict local disease severity.

It is unclear what drives the observed difference (genetics vs. environment). First understanding of genetic structure of coast live oaks

Phytophthora ramorum



Phytophthora **- ITS**



Known Host Range of *Phytophthora ramorum*

Andrew's clintonia bead lily

Bigleaf maple
Blueblossom
California bay laurel
California black oak
California buckeye
California coffeeberry
California hazelnut
California honeysuckle
California maidenhair fern
California nutmeg
California wood fern
Camellia species
Camphor tree
Canyon live oak
Cascara
Chinese witchhazel
Coast live oak
Coast redwood
Douglas fir
Drooping leucothoe
European ash
European beech
European turkey oak
European yew
Evergreen huckleberry
False Solomon's seal
Formosa firethorn
Fetterbush
Goat willow
Grand fir
Griselinia
Holly olive
Holm oak
Horse chestnut
Hybrid witchhazel
Japanese evergreen oak
Laurustinus
Lilac
Madrone
Magnolia varieties
Manzanita
Michelia
Mountain laurel
Northern red oak
Oleander
Oregon ash
Osmanthus
Pacific yew
Persian ironwood
Pieris varieties
Planetree maple
Poison oak
Portuguese laurel cherry
Red fir
Red tip photinia
Redwood ivy
Rhododendron species
Roble beech
Rugosa rose
Salal
Salmonberry
Scotch heather
Sessile oak
Sheep laurel
Shreve oak
Southern red oak
Spicebush
Spreading euonymus
Star magnolia
Strawberry tree
Striped bark maple
Sweet bay laurel
Sweet chestnut
Sweet Cicely
Sweet olive
Tanoak
Toyon
Viburnum varieties
Victorian box
Vine maple
Western maidenhair fern
Western starflower
White fir
Winter's bark
Witch hazel
Wood rose
Yew

Problems

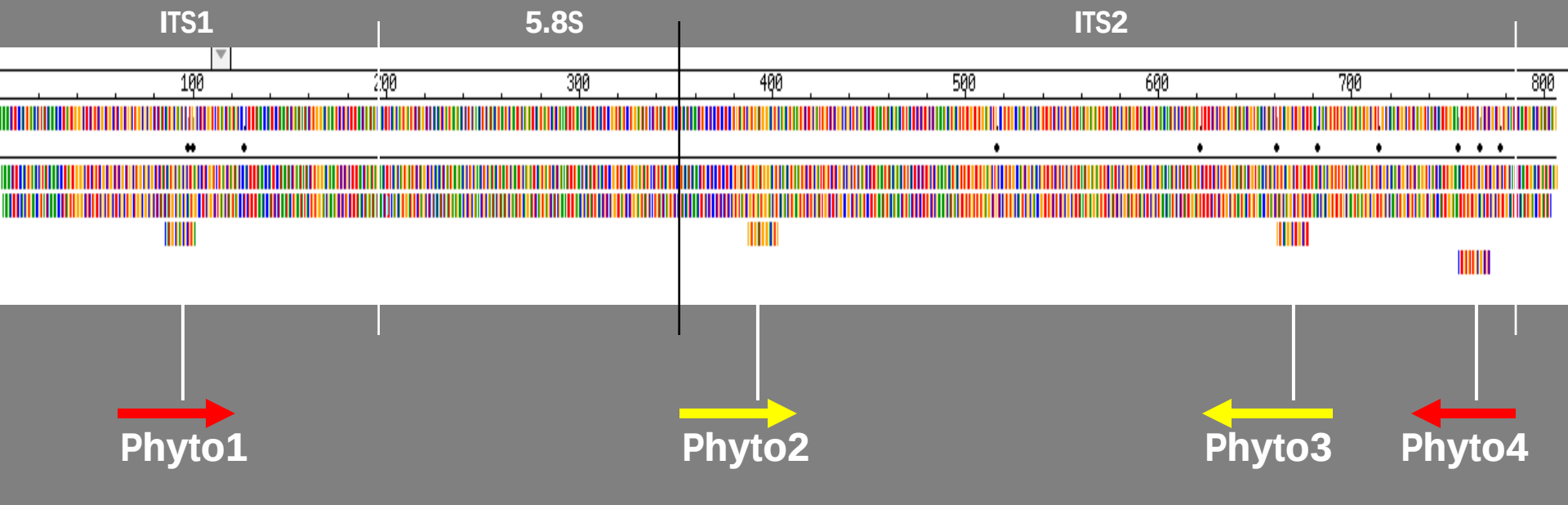
- Host lists started expanding (now over 100) in all plant families and ferns
- Symptoms looked extremely different on different hosts
- Isolation of organism from symptomatic tissue often not possible
- Isolation success extremely different in different seasons

DNA-based diagnostics

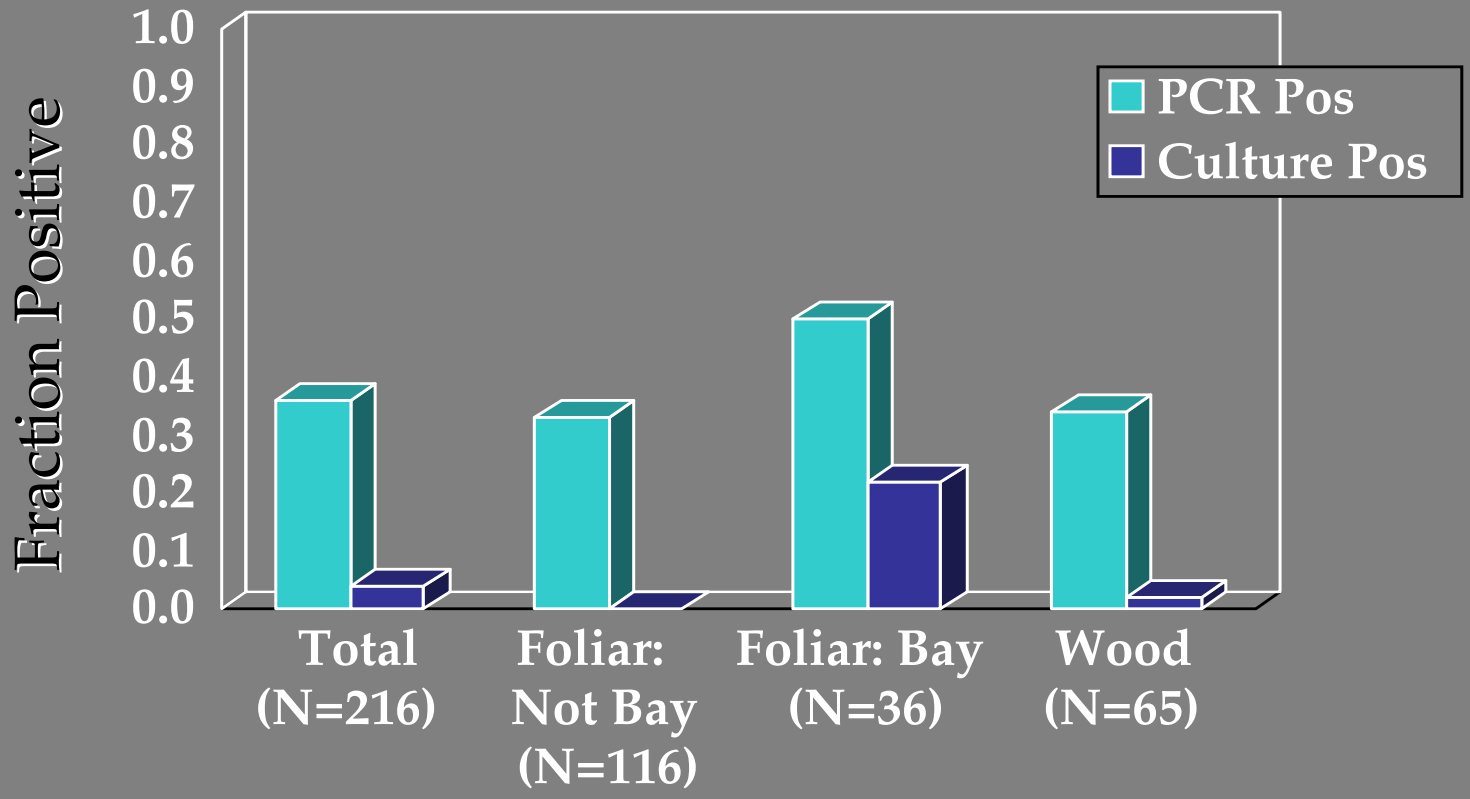
Designed 2 sets of *P. ramorum* specific primers (www primer3 software)

- **phyto1-phyto4 (1st round PCR)**
  - **highly specific for *P. ramorum***
    - **687 bp fragment (in between red arrows)**

- **phyto2-phyto3 (2nd round PCR)**
  - **nested in phyto1-4 amplicon; specific for *Phytophthora* spp.**
    - **291 bp fragment (in between yellow arrows)**



Culture versus nested PCR

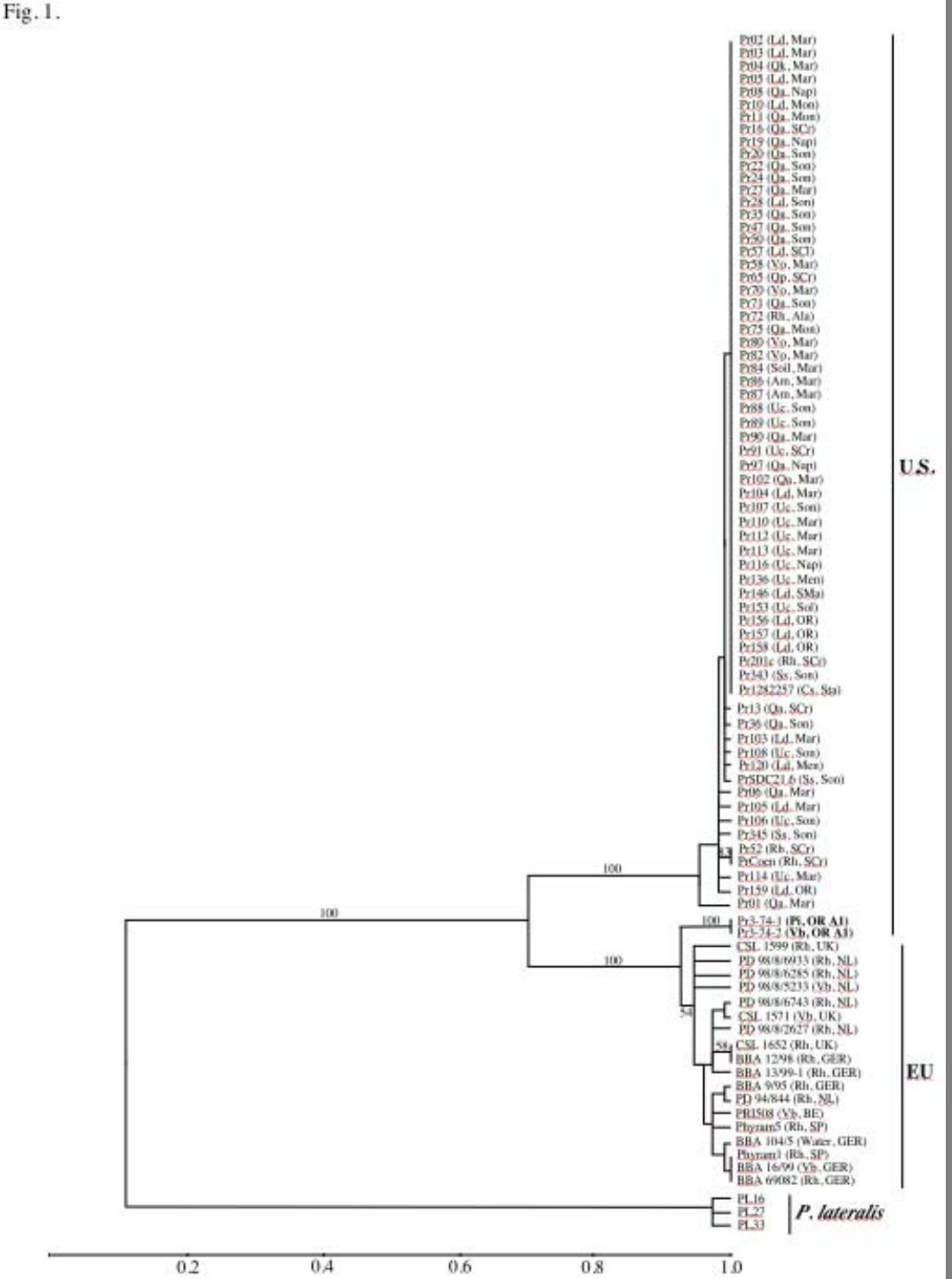


Significant effect of diagnostic type (P <0.001) and sample type (P=0.0036)

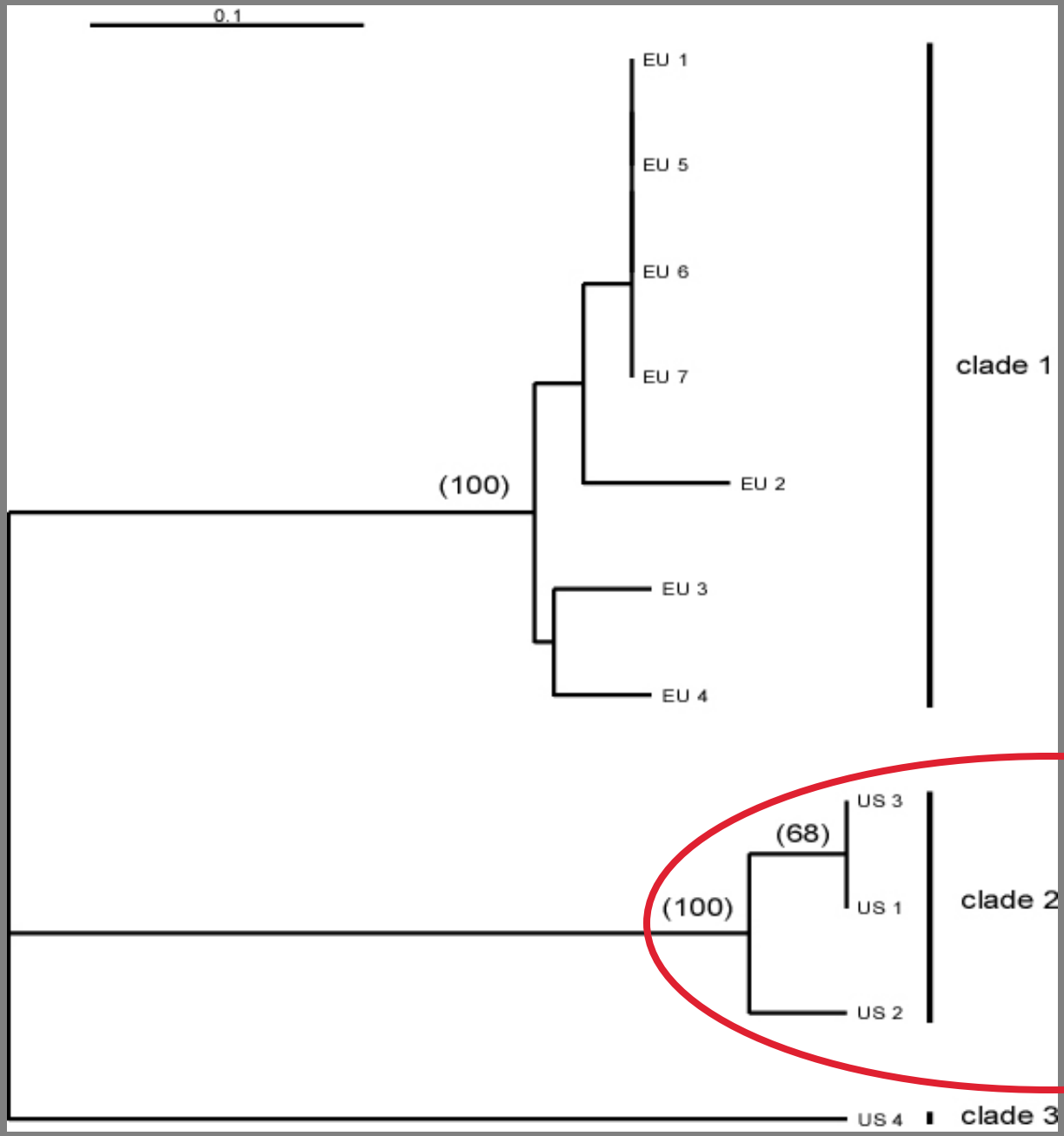
The assay we developed became the first DNA assay to diagnose non viral plant pathogens. Now diagnosis of most microbes will be DNA based

What else have we learned thanks to DNA analysis

- P. ram is introduced
- P. ram reproduces clonally in CA forests
- P. ram comes in three “varieties”
- P. ram in CA forests is not the same “variety” as in European nurseries
- P. ram is evolving through mutations
- P. ram was introduced multiple times in California from the same nursery source
- P. ram is “breathing” even if it does not grow



- US forest isolates clearly distinct from EU nursery isolates, also have different mating type
- Isolates from nurseries in WA, OR, & BC both of the US and EU types
- Potential for XXX sex and recombination in US nurseries
- US forest population is genetically very homogeneous, trademark of an introduced species



	Mating Type	Growth Rate
clade 1	A1	Fast
clade 2	A2	Slow
clade 3	A2	Fast


Forest structure


Wildlife


Fire


Microorganisms

EFFECTS OF SOD

- Ecological and sociological impacts: tanoaks at risk of extinction: change in forest structure and composition
- Biota linked to vanishing trees highly impacted
- Hydrogeological impact
- Climate and nutrient cycle impact
- Hazard to humans and properties
- Added cost because of intense regulation of pathogen: cleaning, prescriptions, testing
- Affecting trade

Outlook

- Pathogen
  - No clear trade- off between virulence and transmission. Predict an increase in virulence, already supported by some preliminary data
- Host
  - Bays: seem to be favored by SOD, their presence likely to increase
  - Oaks: climate change predicted to lengthen the window of maximum susceptibility
  - If resistance present it will take thousands of years to become significant, hampered by long distance host gene flow
- Environment
  - Warmer winters may mean infection may be rampant in winter

Yana Valachovic
UC Cooperative Extension

Sudden Oak Death in Forestlands: Management Options?

Outline

- What you can expect from this disease
- Is there hope
- Results of management trials
- Stand-scale management approaches
- Landscape management approaches

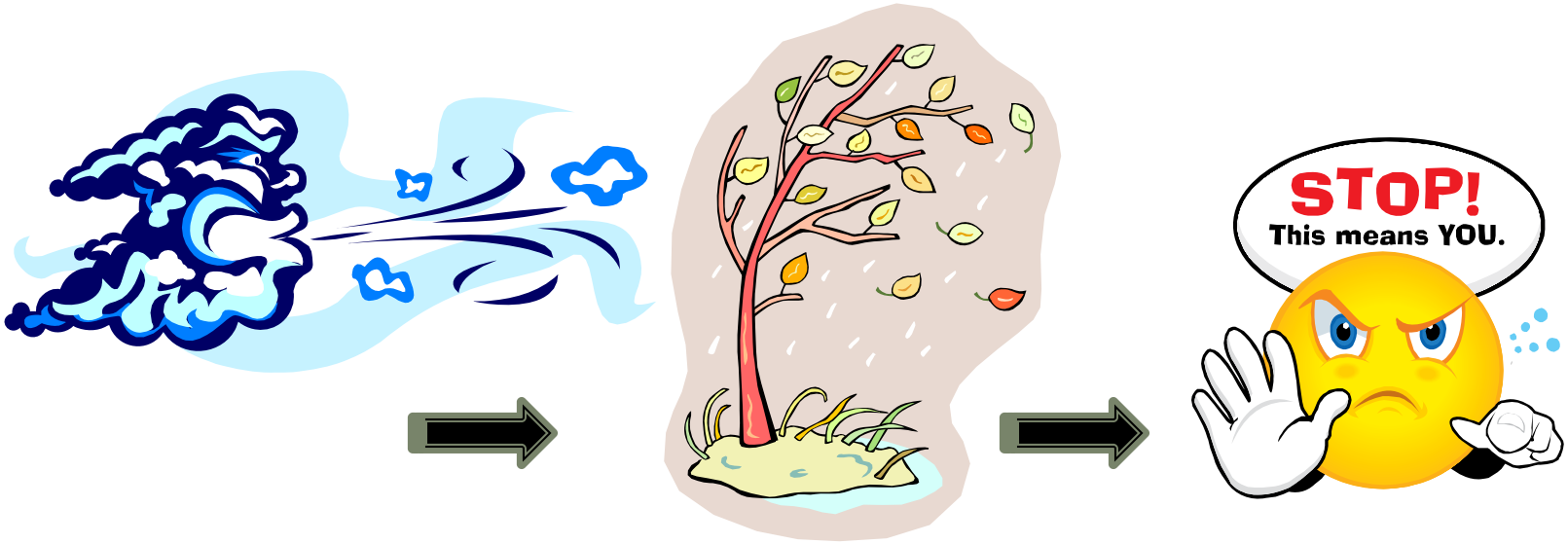
What you can expect

Tanoak mortality in high numbers

- Fuels and fire risk problems
- Regeneration problems?
- Market restrictions?
- Wildlife habitat and forage loss, how will this affect listed species?
- Loss of cultural resources
- Restrictions on movement of plant materials/ soils
- Costs to businesses for regulatory compliance and sanitation
- Aesthetic issues
- Continued spread unless management occurs

Is there hope?

(infected tree)

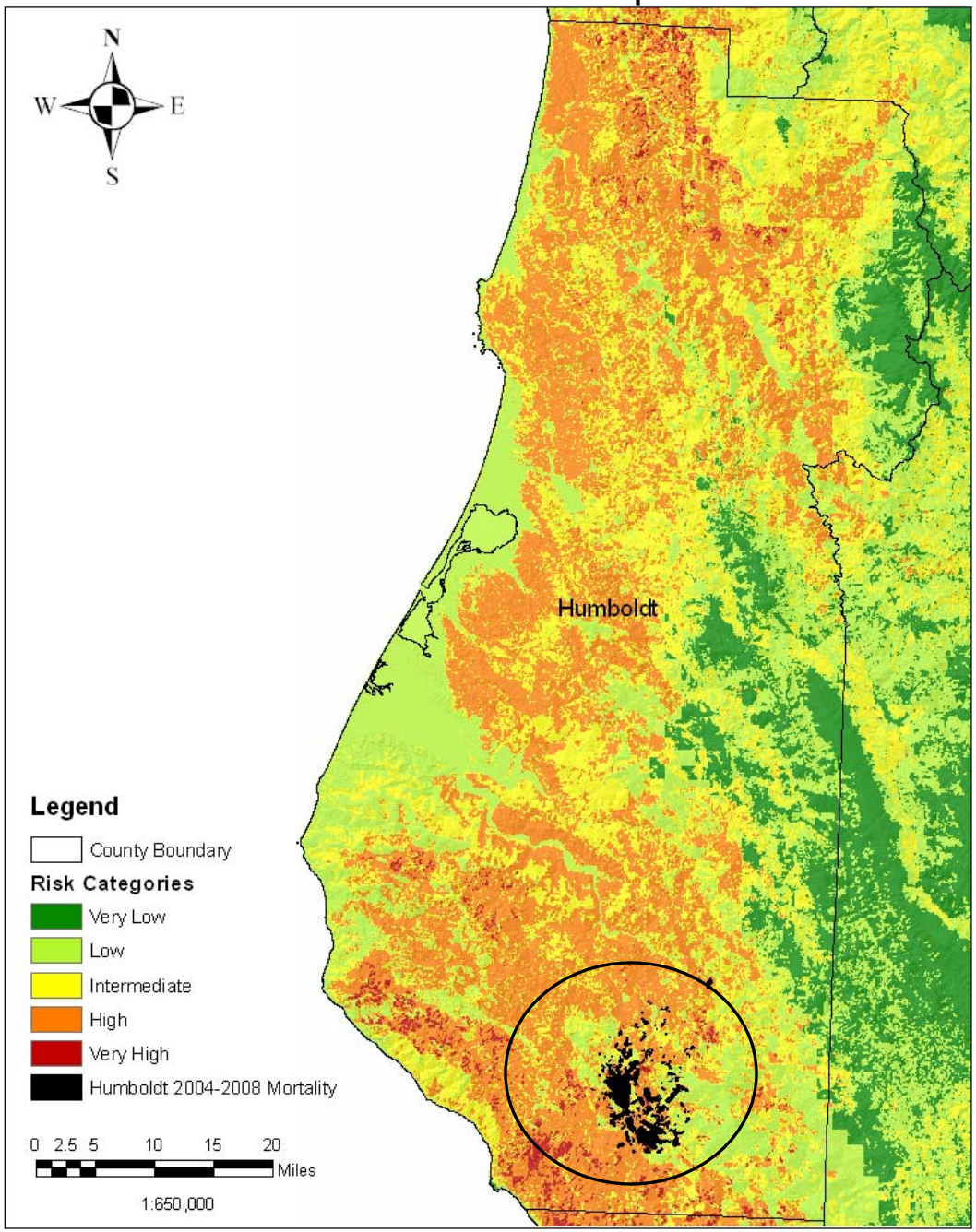


It depends, on what you are trying to achieve . Requires an understanding of the stand and the landscape dynamics .

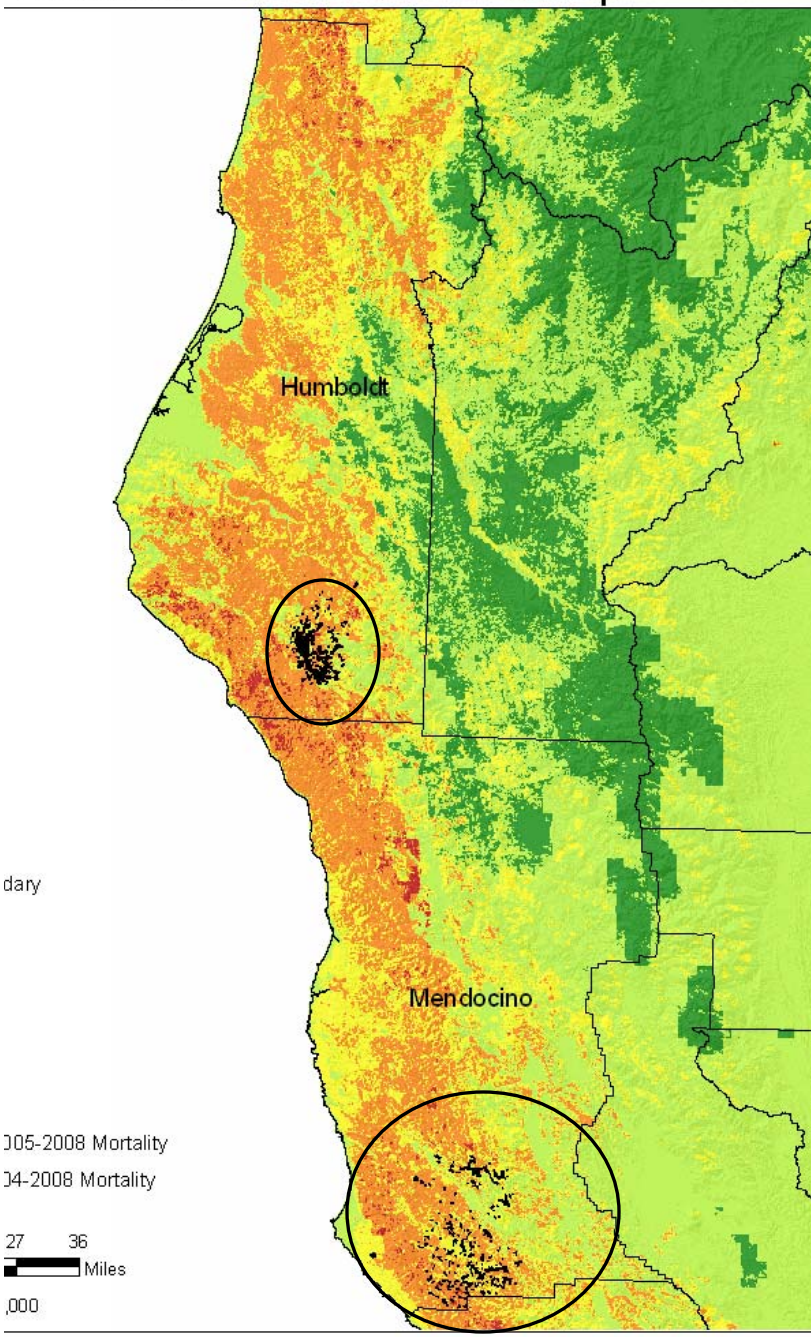
Is there hope?

- More options outside of the infested area
- Some tools are emerging within the infested areas
- Always risk and uncertainty in any treatment effort
- Not much time to take action
- Only 10% of at-risk area in CA has been impacted and much less in the north coast

Humboldt Risk Map



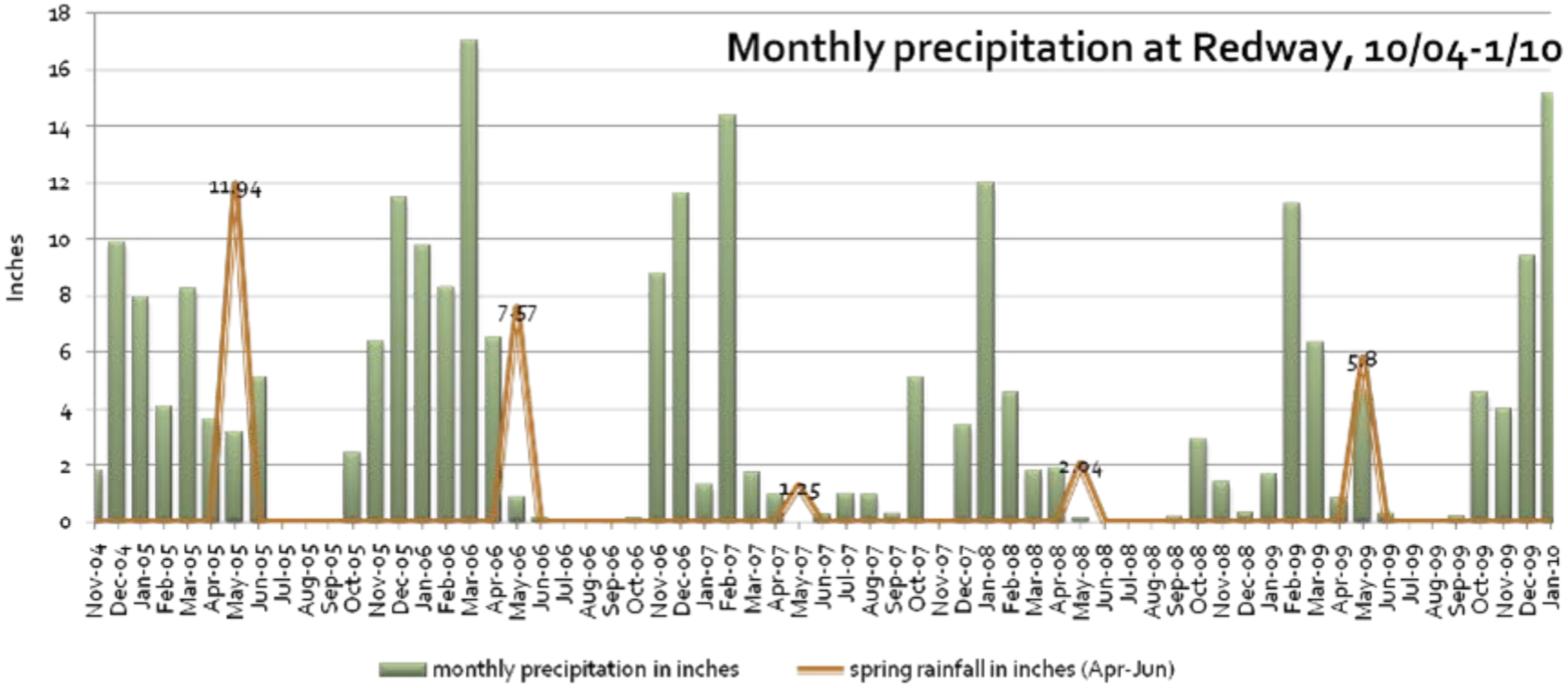
Humboldt - Mendocino Risk Map



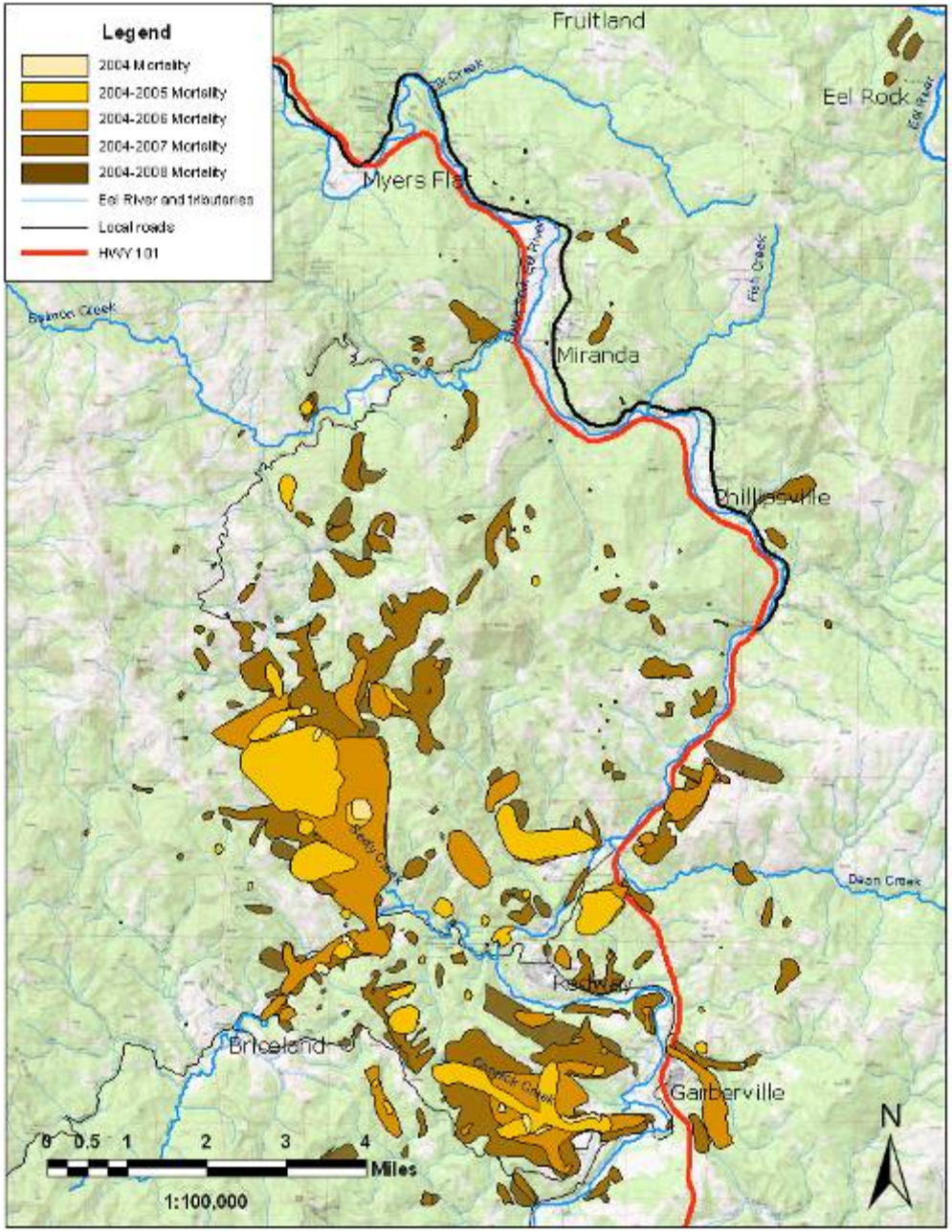
P. ramorum Management Considerations

- Treatments have to be designed to address:
  - Stand structure: pathogen needs moisture to survive
  - Species composition: favors bay and tanoak, which serve as reproductive platform (aka- seed head)
- Treatments must be responsive
  - Disease expands rapidly during wet spring conditions
- Monitoring is critical
  - Small infestations can grow rapidly
- Long-term habitat needs
  - No tanoak resistance observed to date

2005 and 2006 were highly supportive for pathogen spread, what will happen this year?



Southern Humboldt Tanoak Mortality -2004-2008



Outline

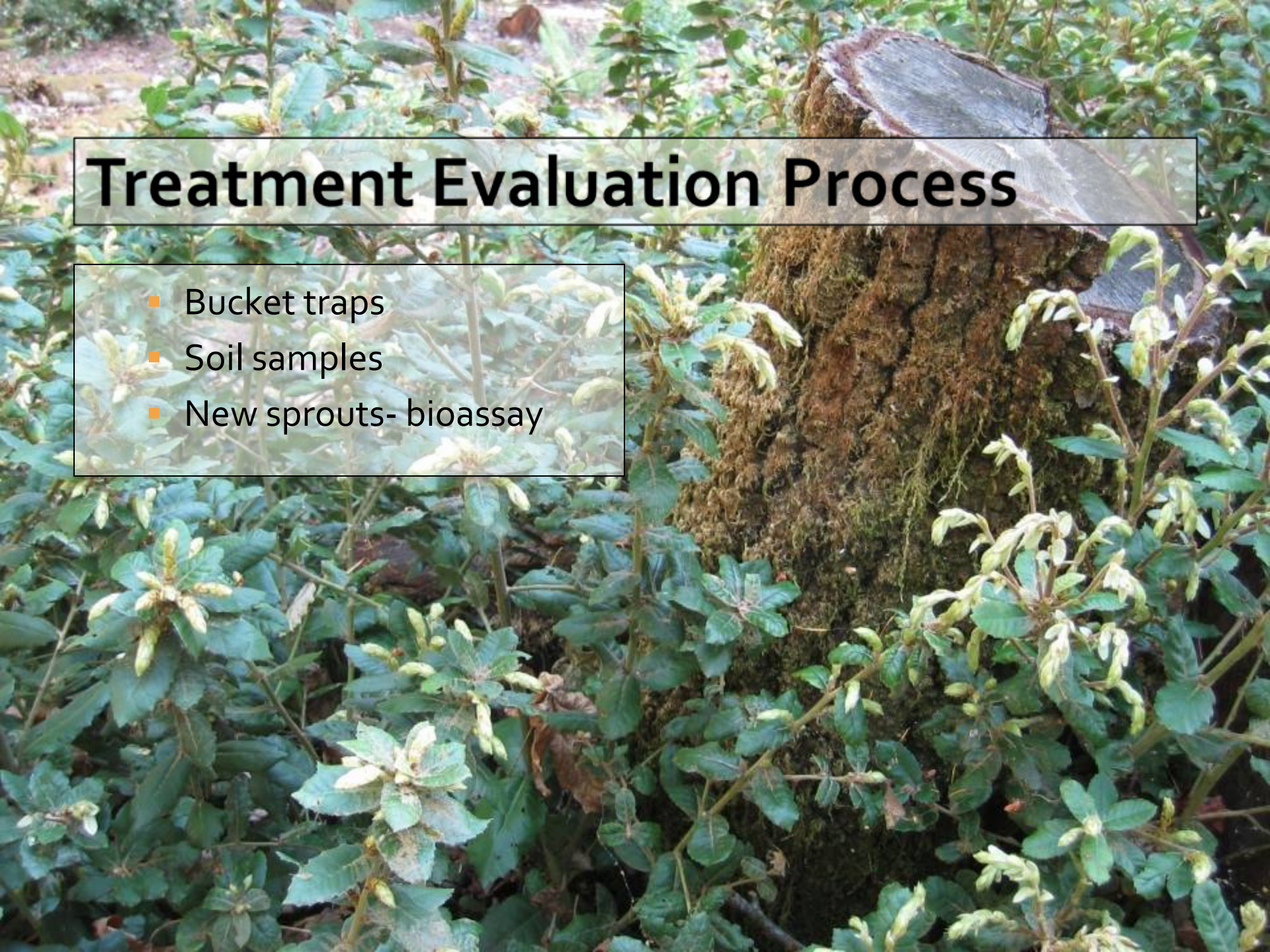
- What you can expect from this disease
- Is there hope
- Results of management trials
- Stand scale management approaches
- Landscape management approaches

Management Tools

- Tree/ plant removal by:
  - chainsaw
  - herbicides
  - fire
  - girdling
- Reforestation
  - planting
  - promoting seed trees
- Agri-Fos
- Creativity

Treatment Evaluation Process

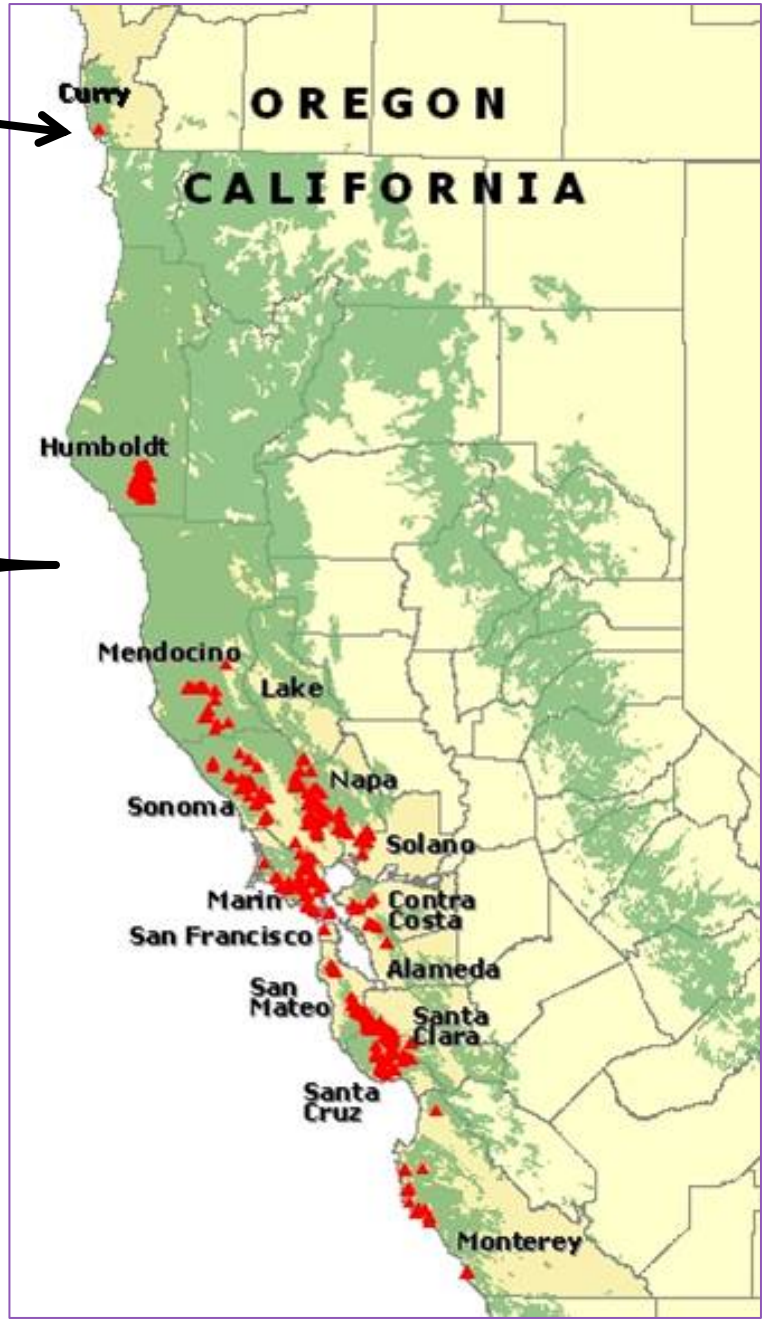
- Bucket traps
- Soil samples
- New sprouts- bioassay



Oregon:
-Eradication

Humboldt and Mendocino:
- Hot spot approach
- Slow the spread
- Tanoak survival

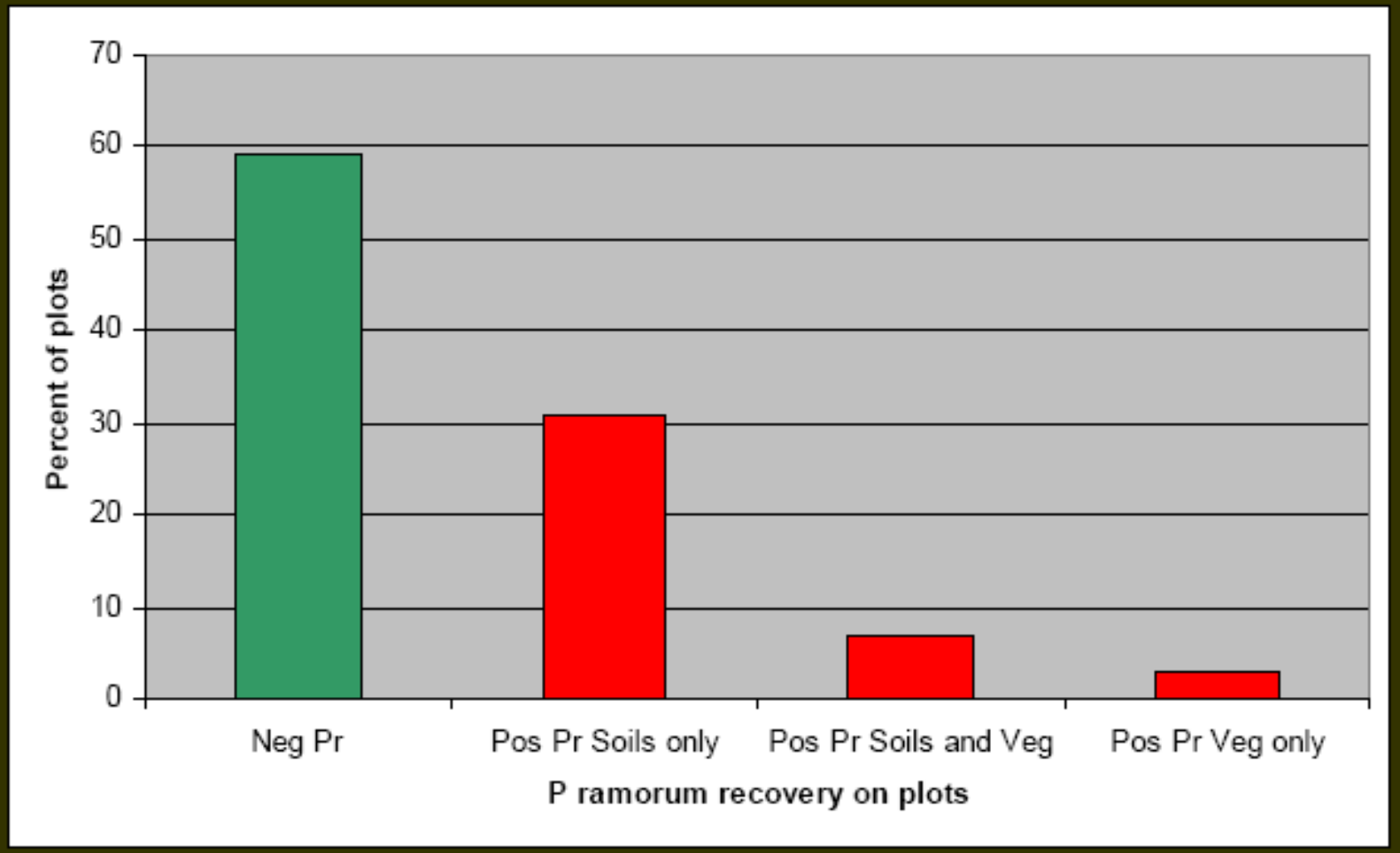
Greater bay area:
-Impact management
-Tanoak/ oak survival



Treatment

1. Hack & squirt tanoak to prevent stump sprouting (except on BLM land)
2. Cut tanoak, rhododendron, huckleberry, sometimes myrtle.
3. Burn (piles or broadcast)
4. Plant, follow-up treatments

All Plots on Sites Treated 2001-2007
(n = 119)

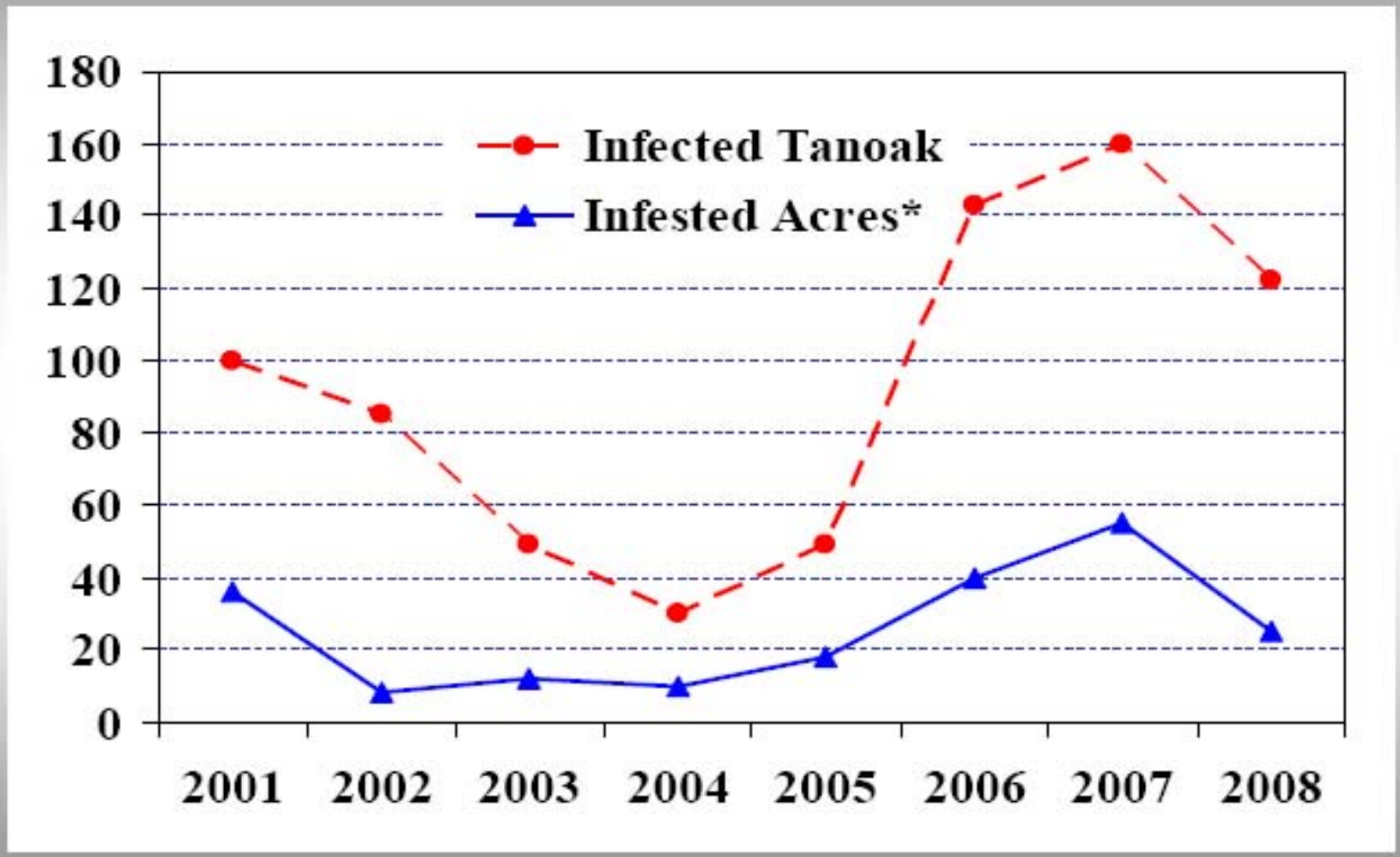


59 percent plots No *Pr* detected
31 percent *Pr*+ soils* only
7 percent *Pr*+ soils* and vegetation
3 percent *Pr*+ vegetation only

*OSU soil baiting only

Sudden Oak Death in Oregon Forests

31 December 2008



California Approaches

Goal	**Minimizing Property Impacts from Sudden Oak Death**	**Strategic Protection of Tanoak Islands, Old-Growth Tanoak, or Particular Geographic Areas**	**Suppression of *Phytophthora ramorum* and Limitation of Spread**
Treatment	Dead tree removal	Manual removal of bay laurel only	Manual removal of bay laurel and tanoak (+/- prescribed underburning)
	Reforestation	Agri-fos® application	Modified fuel hazard reduction removal (+/- bay girdling)
	Maintain some tanoak with thinning (manual or by Agri-fos®)	Combination of manual removal of bay laurel and Agri-fos® application	Herbicide host removal (bay laurel and tanoak)
	Combination treatments to address site specific goals		

Known hosts in north coast

- Bigleaf maple
- Blue blossom ceanothus
- California bay
- California black oak
- California buckeye
- California hazel
- Canyon live oak
- Coast redwood
- Coffeeberry
- Evergreen huckleberry
- Hairy and common manzanita
- Inside-out flower
- Maidenhair fern
- Pacific yew
- Salmonberry
- Sweet cicely
- Tanoak
- Toyon
- Vine maple
- Western star flower
- Wood rose

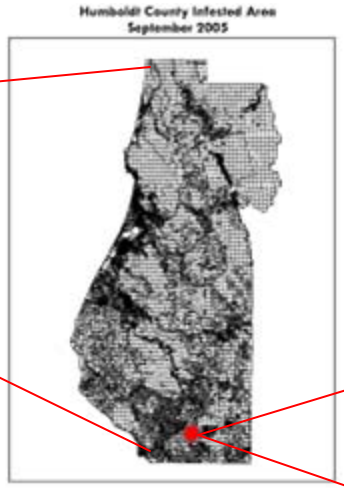
<u>Mendocino Only</u>

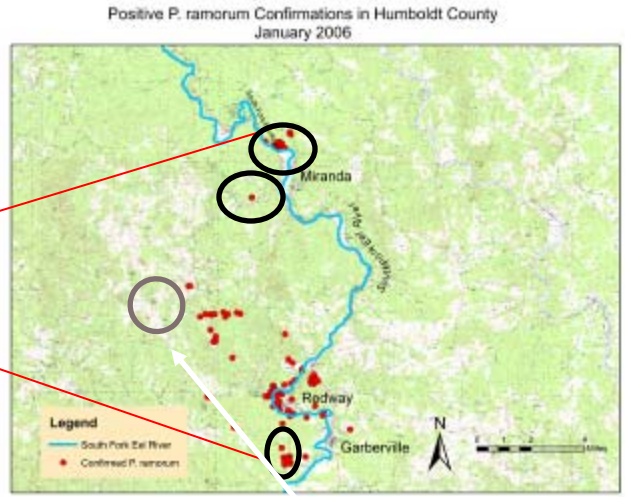
- Pacific Yew,
- Coast Live Oak
- Shreve Oak


Example of mortality observed in Southern Humboldt

Hot Spot Treatment Strategy

"Fire Control Model"





7 mi

Forth project tied to a community fire protection project

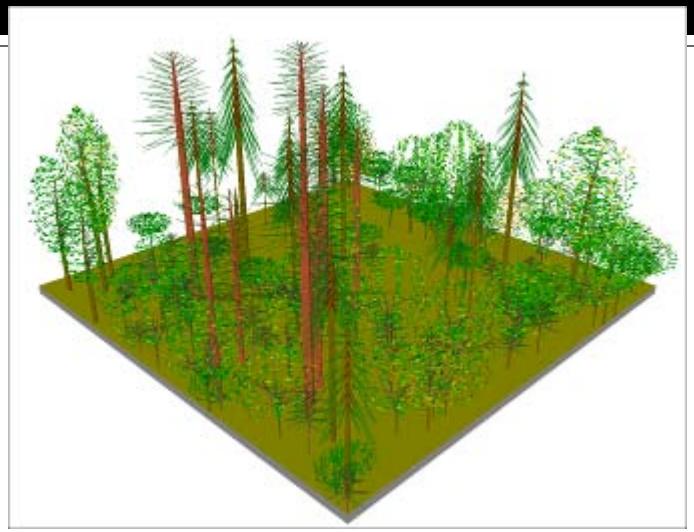

Before


Before

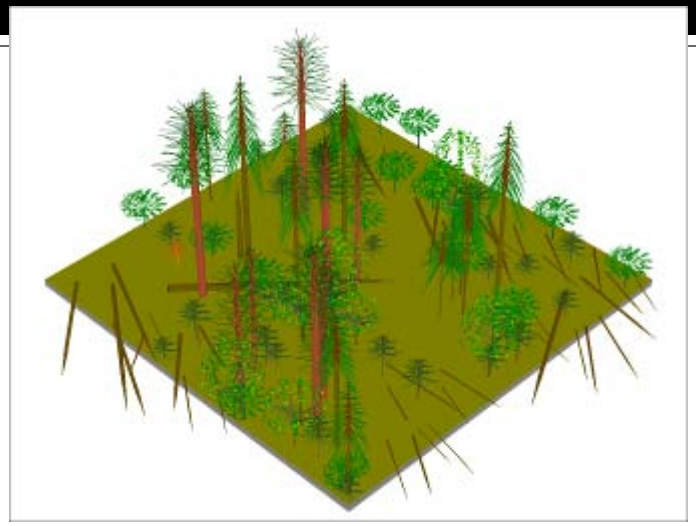

After


After

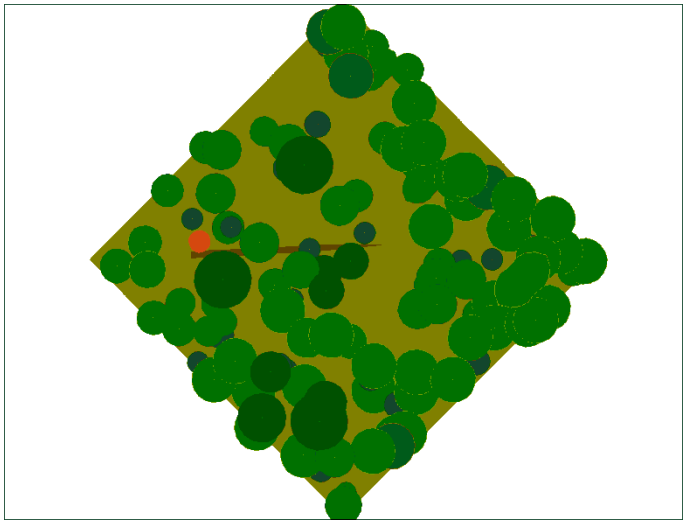
P. ramorum management

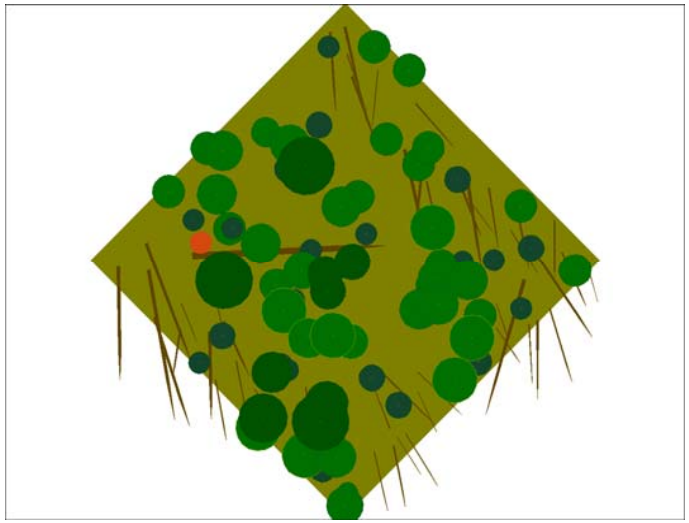


156 TPA, 187 Ft^2 BA, 61% Canopy Cover



108 TPA, 131 Ft^2 BA, 51% Canopy Cover





Bay's miracle

What does it take?

Humboldt Summary

- Data after 4 seasons post-treatment
  - Significant re-sprouting, but few symptoms observed
  - Prescribed burn sites had the most material consumed, likely more effective
  - No spread observed north of bay removal zone on Ave of the Giants
  - Evidence mounting to be able to control the pathogen at the backyard to smaller site scale
  - Bay removal appears most effective (though not appropriate in all situations). Herbicide bay removal is questionable. Imazapyr + glophosate.
  - Results are very weather dependent
  - Recommendations still very site specific and reflect landowners long-term goals.

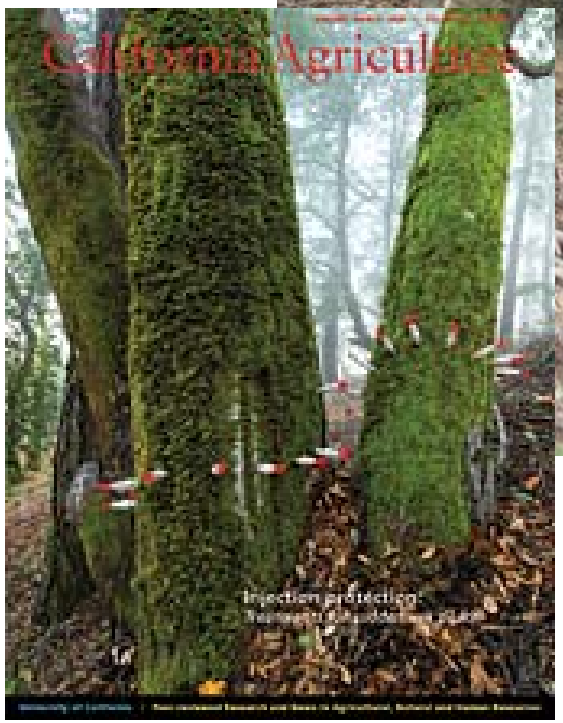

IMG_0040


048

Agri-Fos

<u>Wildland trials</u>
Six counties, treatment by Agri-Fos versus control

<u>Island treatment strategy</u>, assessing treatment in two old-growth stands of tanoak



Outline

- What you can expect from this disease
- Is there hope
- Results of management trials
- Stand-scale management approaches
  - What is practical?
- Landscape management approaches

Stand-scale approaches

- Prioritize your property
- What is most at risk, least at risk?
- Are you inside or outside of the infested area?
- Work strategically
- Don’t bring it home

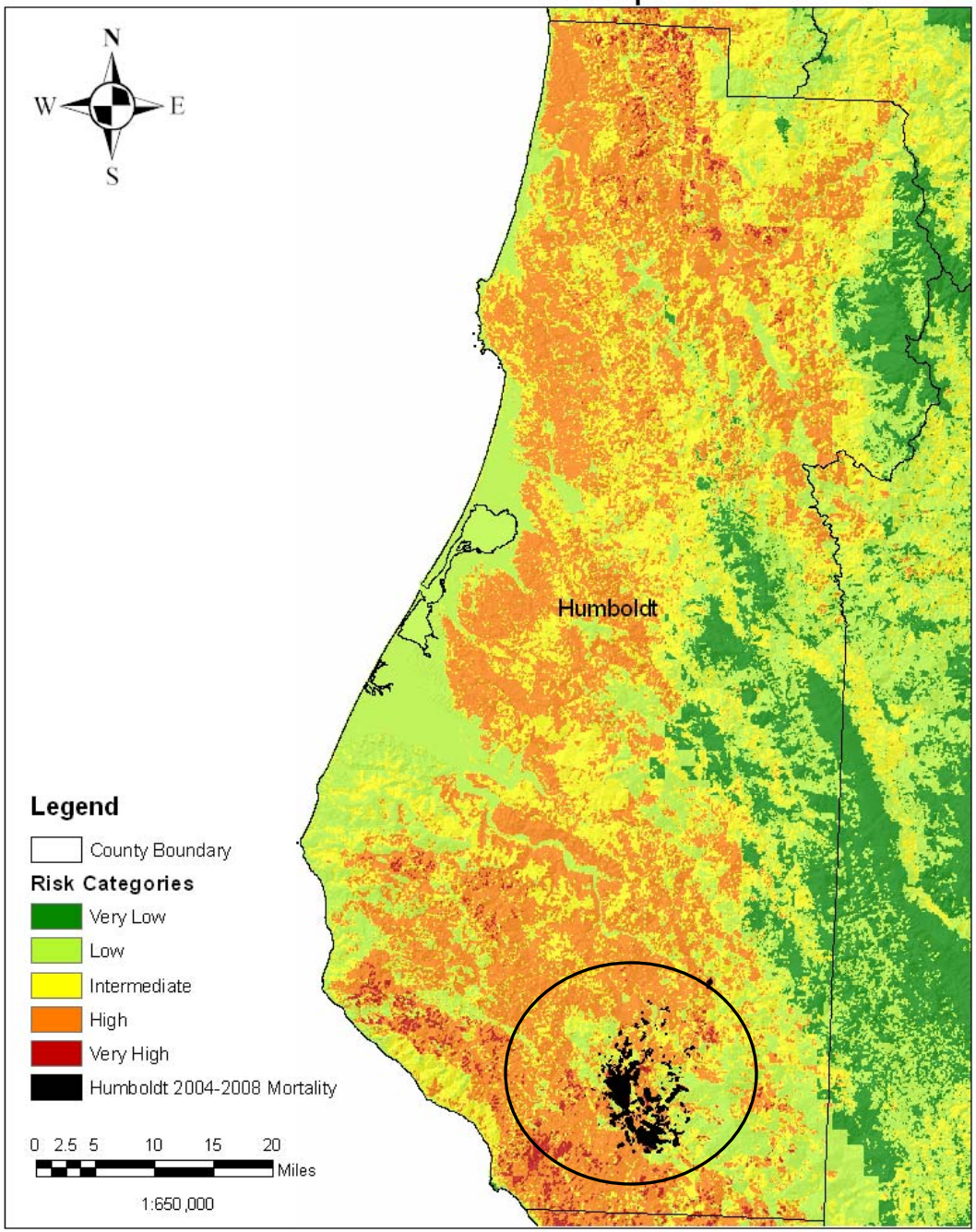
Management options depend on goals and stand conditions

- Remove infected hosts to stop spore production
- Change species composition
- Change stand structure and canopy cover, to dry a location
- Use Agri-fos to protect high value tanoak or oak trees
- Remove bay adjacent to high value tanoak or oak trees, stump treat bay to prevent sprouting
- Install a reduced or no-host zone to prevent tree to tree spread
- Integrate SOD management into other activities

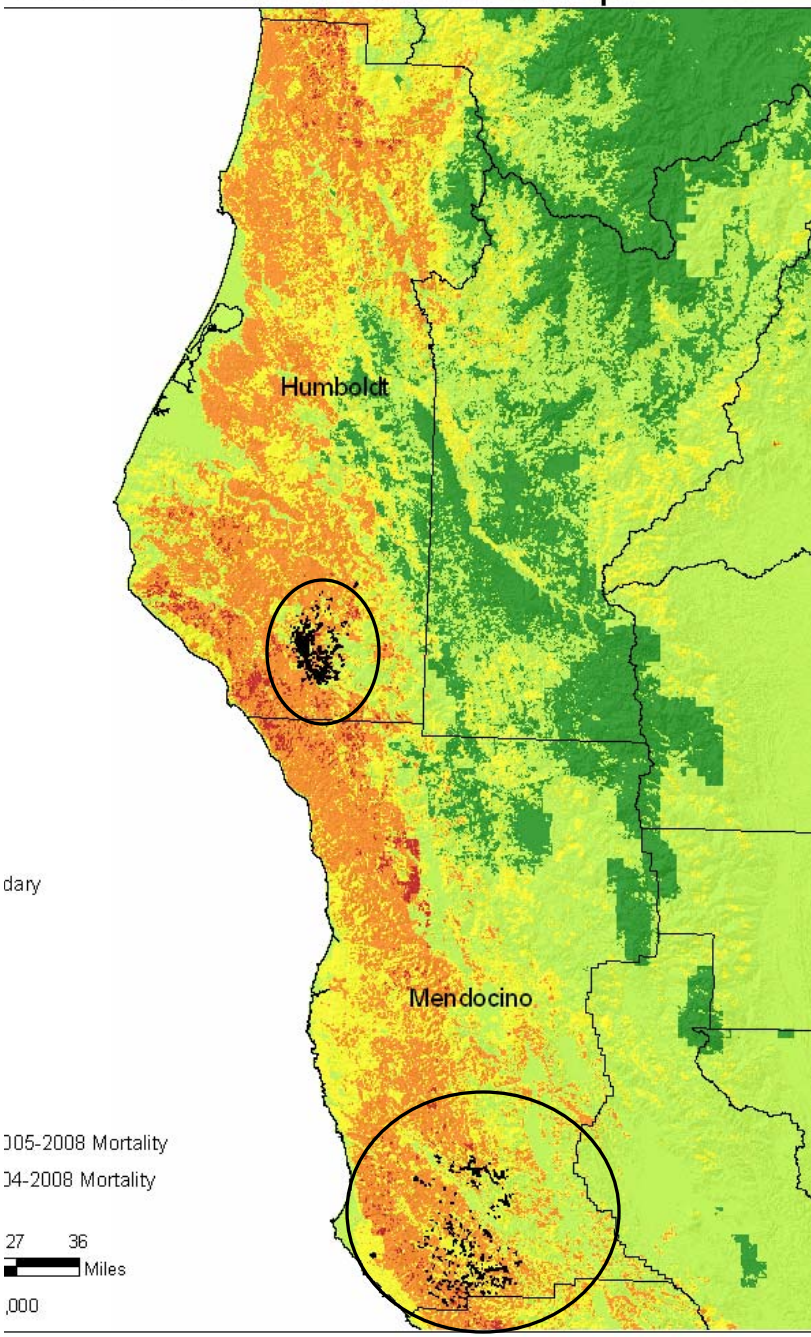
Outline

- What you can expect from this disease
- Is there hope
- Results of management trials
- Stand scale management approaches
- Landscape management approaches
  - Hot-spot approach?
  - Coordinated action?
  - Regulatory support for action?

Humboldt Risk Map



Humboldt - Mendocino Risk Map



Tools in the Tool Box

Goal	**Minimizing Property Impacts from Sudden Oak Death**	**Strategic Protection of Tanoak Islands, Old-Growth Tanoak, or Particular Geographic Areas**	**Suppression of *Phytophthora ramorum* and Limitation of Spread**
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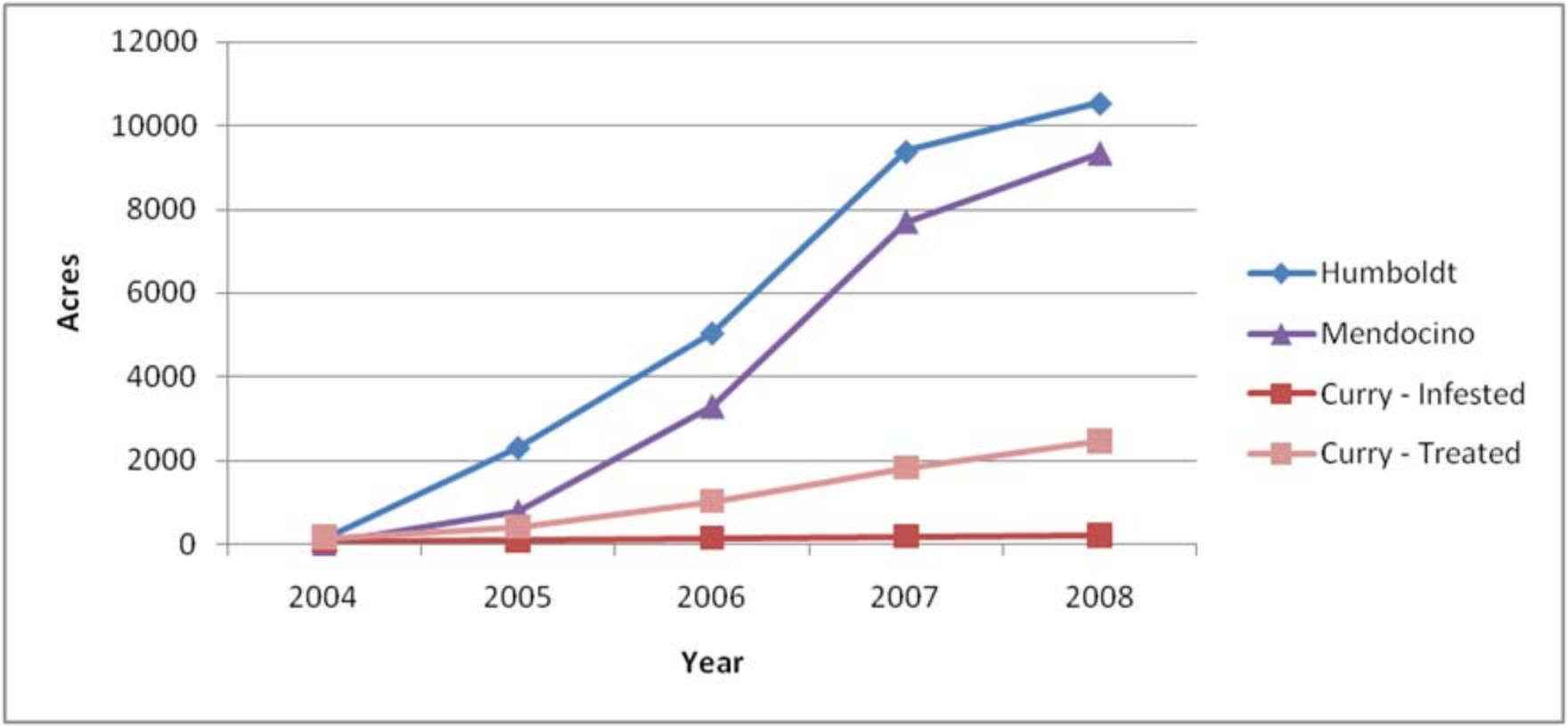
	Combination treatments to address site specific goals		

Curry, Humboldt and Mendocino Acres



P. ramorum management

- Remember that it has mostly been a disease of the unmanaged landscape!
- Coordinated action in Oregon is producing results
- We still have options in the north coast
- We need to work together to have regulatory support to take action
- Monitoring disease development is essential
- We are developing forecasting tools, to help managers make decisions

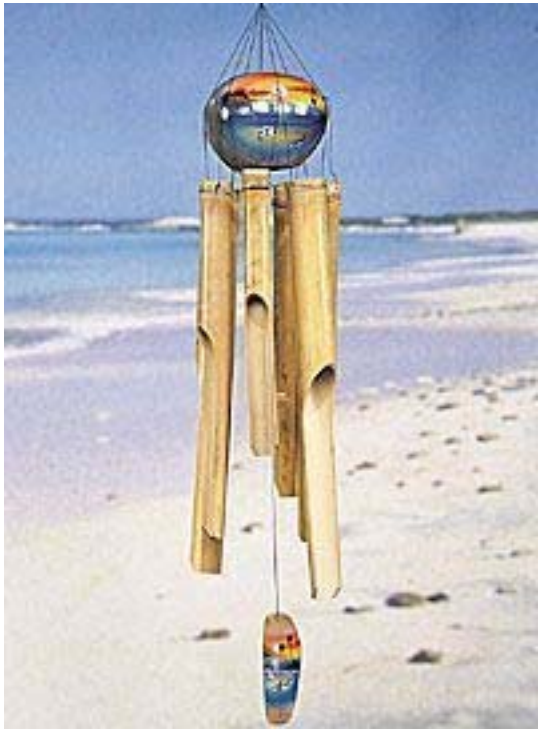
Acknowledgements

- Funding
  - USDA FS State and Private Forestry; PSW Research Station
  - CDF's California Forest Improvement Program and Vegetation Management Program
  - Bureau of Land Management
- In kind donations of labor and technical expertise
  - Cal Fire, UCCE, DPR, Cal Trans, and several small landowners.
- Organizations Involved
  - Treatment- Southern Humboldt Fire Safe Council/Institute for Sustainable Forestry, USFS State and Private aerial detection staff, DFG, USFWS, several private vegetation management contractors, and consulting foresters
  - Monitoring- Hoopa and Yurok Tribes, Redwood National Park, Bureau of Land Management, Mattole Restoration Council, UC Davis, UC Berkeley, Sonoma State

Ways that are being investigated to control *P. ramorum*

- Wind Chimes
- Holy Water
- Banning cell phone use
- Using dark energy from outer space
- Hugging trees

- **Chemicals**
- **Natural resistance**



Ways that were suggested to us to control *P. ramorum*

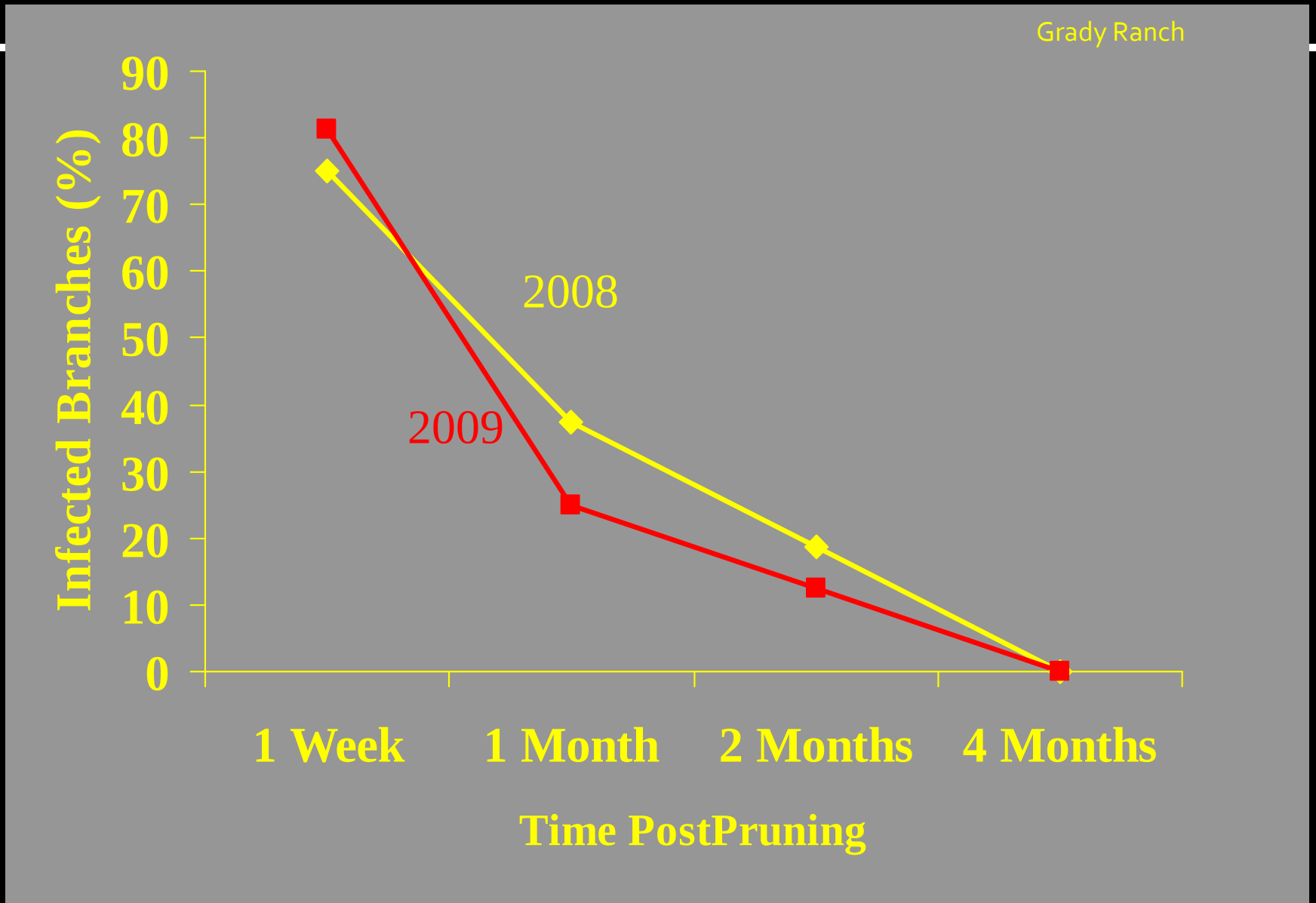
- Diagnosis
- Predictions/modeling
- Sanitation: soil/water/plant material
- Reducing risk: pruning and wounding
- Stand composition: removal of bays
- **Preventive chemical treatment**
- **Natural resistance**

Transmission of SOD through pruning:

- Does tree pruning introduce SOD infection?
- Is the timing of cutting a factor?

Skywalker / Grady Ranch Site

Transmission of SOD Through Pruning



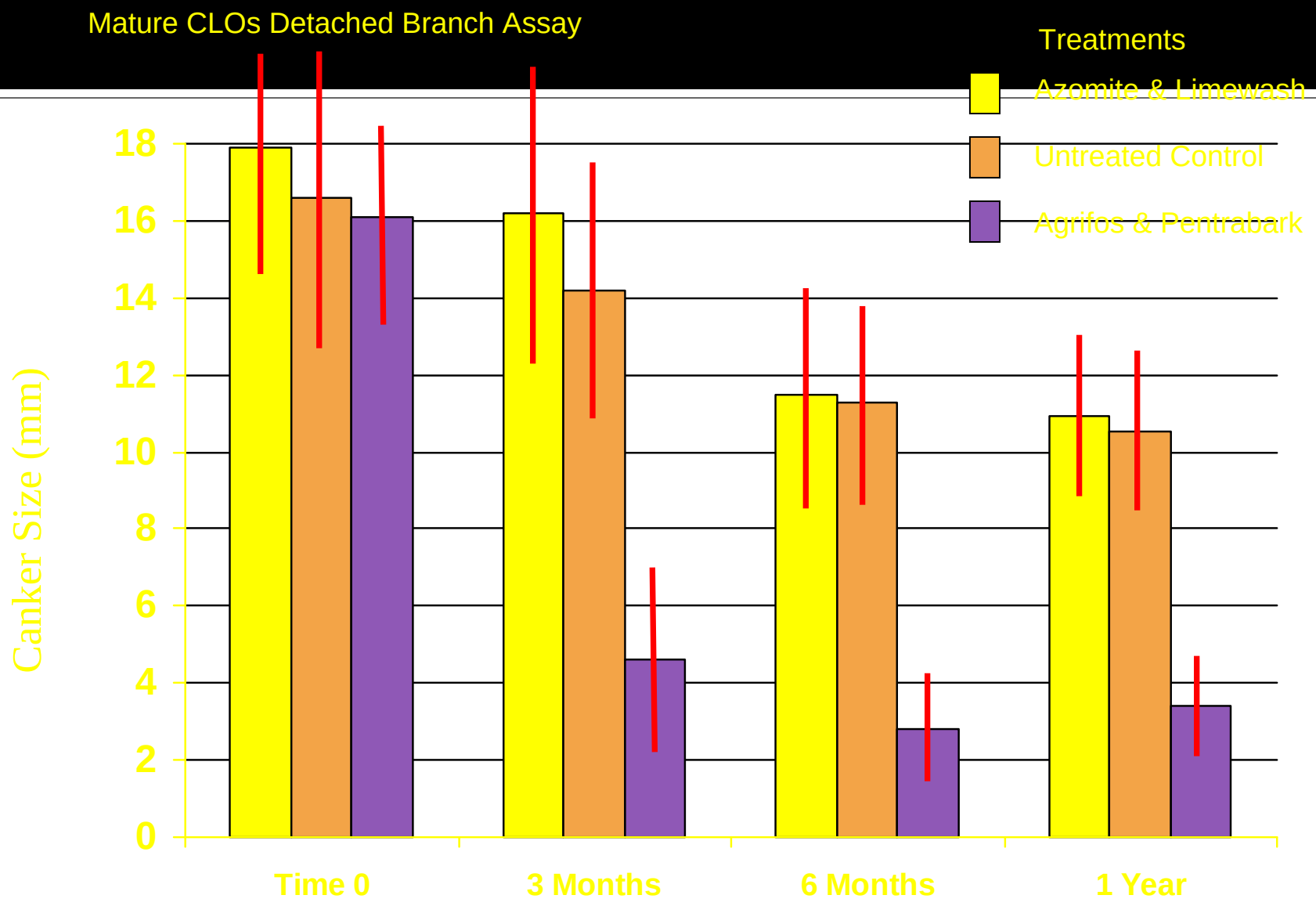
AgriFos and PentraBark

Topical Application

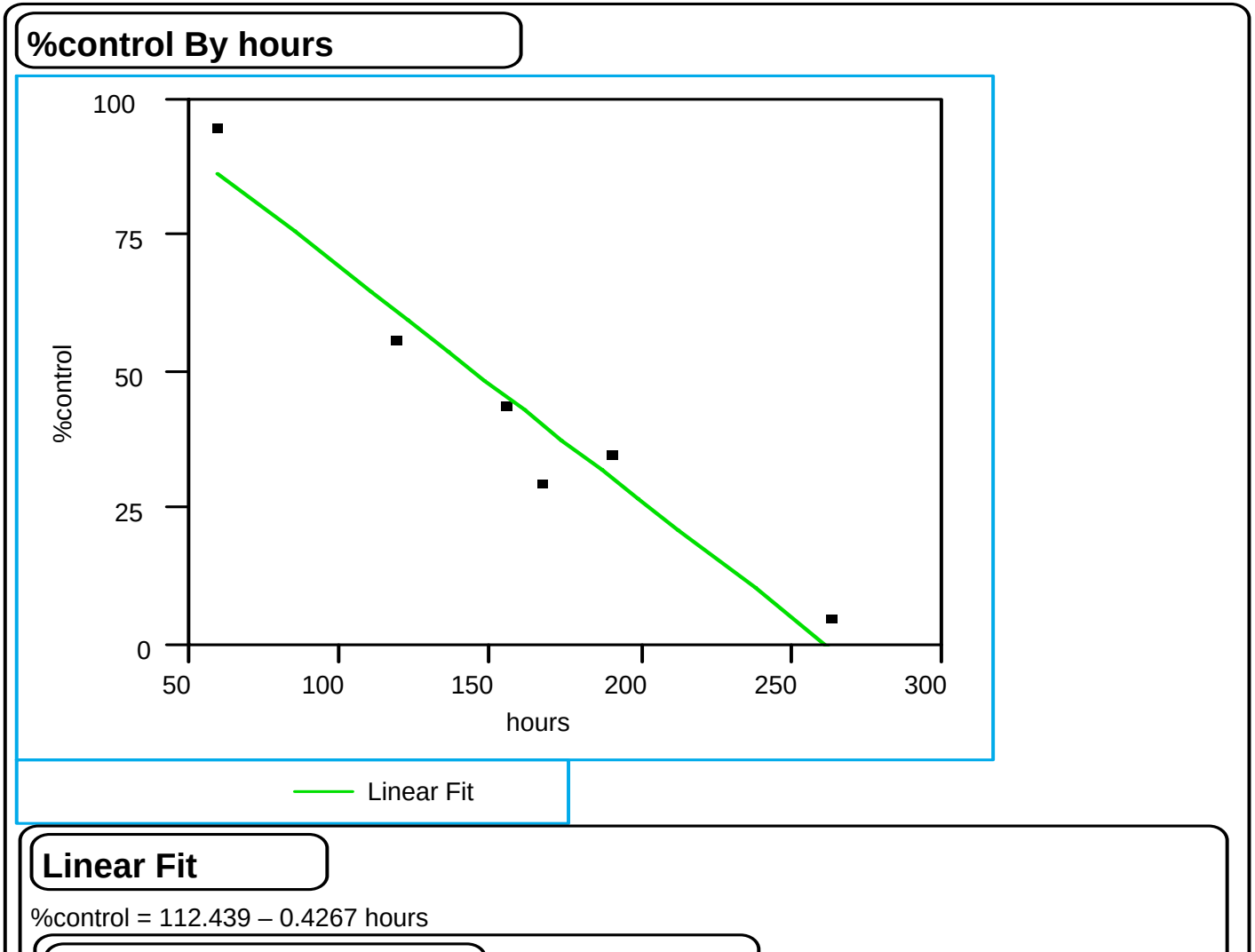
Azomite Soil

Sweetener and Limewash Application

Agrifos vs. Azomite Treatments



Efficacy of curative treatments (% control) plotted against time elapsed between inoculation and application of treatment

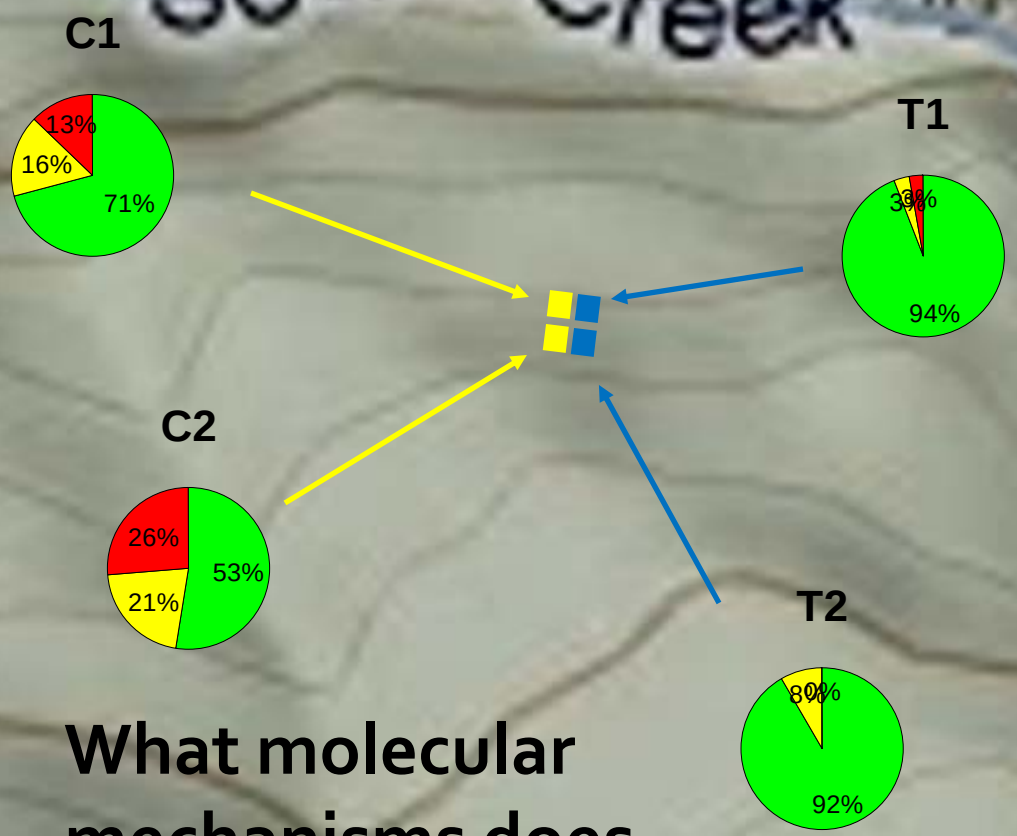


Long Term Treatment of Tanoaks

- 32 Field Plots
- 6 Sites in 3 Counties
- 672 Tanoaks > 8cm DBH

Long Term AF Treatment of Tanoaks

% Asymptomatic Control	56.5312	t-Ratio	-4.50771
% Asymptomatic treatment	74.9062	DF	15
Mean Difference	-18.375	Prob > |t|	0.0004
Std Error	4.07635	Prob > t	0.9998
Upper95%	-9.6865	Prob < t	0.0002
Lower95%	-27.064		
N	16		
Correlation	0.86547		



Soquel Site A

Soquel Demonstration State Forest

What molecular mechanisms does treatment trigger? Are

11/2009

Bicycles for Cargo Transport

Sanitation

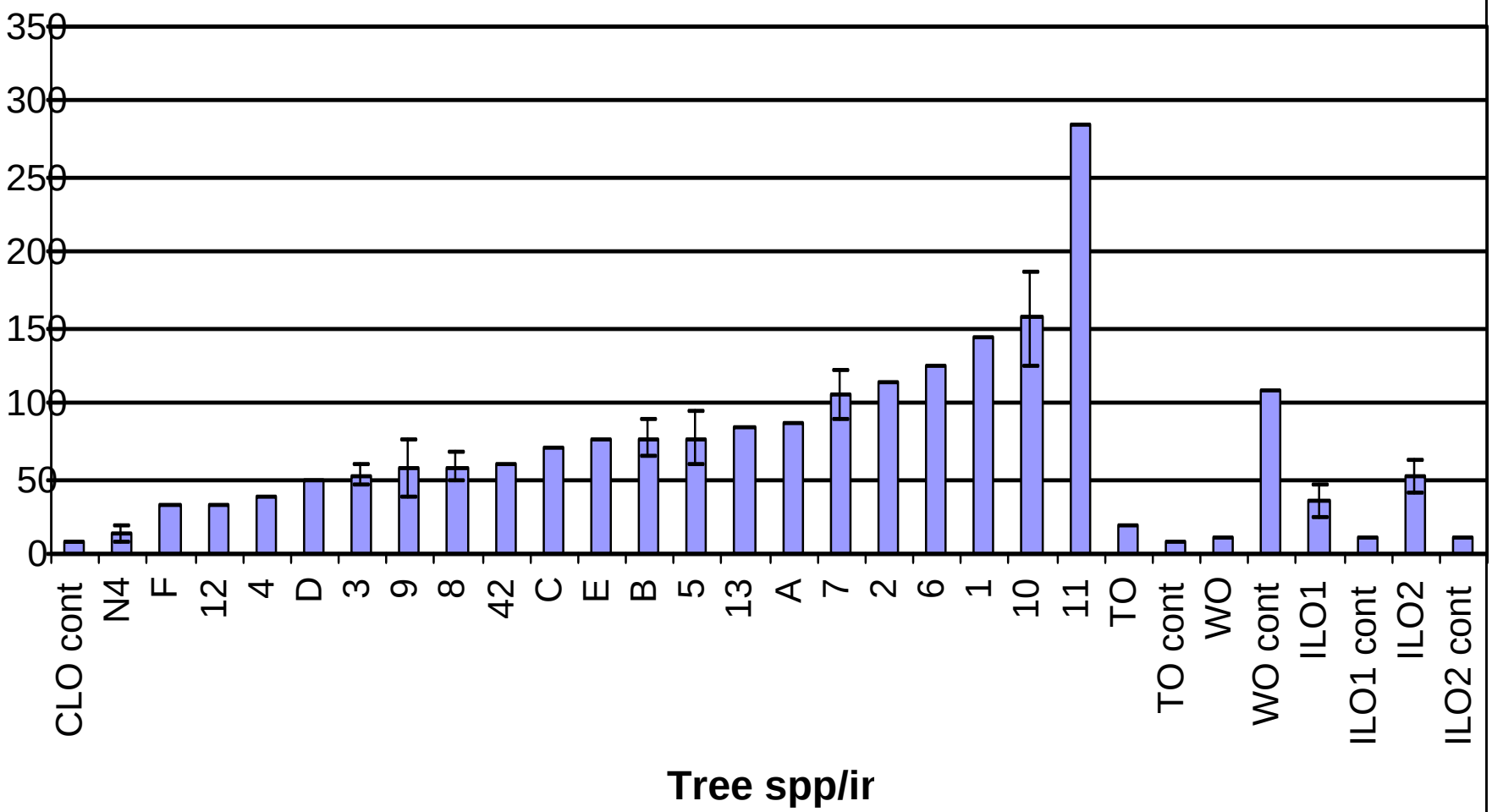
Drying plant woody debris fast

Composting

Chemical treatment of water

Diagnosis of wood decay agents may be of use for so called green tree failures

NATURAL RESISTANCE?



Population genetics of host can help determine nature, frequency, and distribution of possible resistance

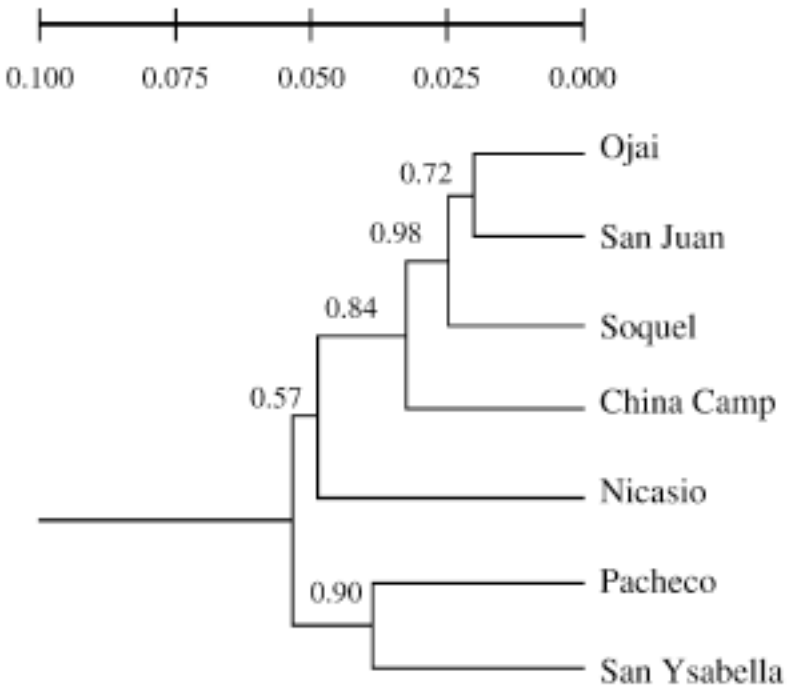


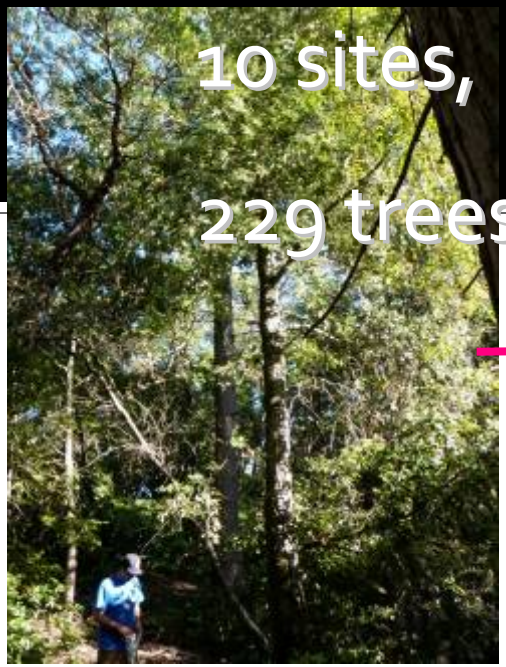
Fig. 5 UPGMA tree based on distances between populations estimated from Nei's unbiased genetic distance of amplified fragment length polymorphism (AFLP) fragments. Support for branches is given by bootstrap percentages for recalculated genetic distances from 1000 bootstrap replicates.

Table 5 Mantel R correlation coefficients between amplified fragment length polymorphism molecular similarity classes of *Quercus agrifolia* and Euclidean distances in lesion size of *Q. agrifolia* after inoculation with *Phytophthora ramorum* for each of four trials

Molecular similarity	Trial 1	Trial 2	Trial 3	Trial 4
Up to 99%				
Lesion × genotype	0.022	0.040	−0.019	−0.04
Up to 95%				
Lesion × genotype	−0.05	0.03	−0.102*	0.05
Up to 90%				
Lesion × genotype	−0.05	−0.01	−0.053	0.070
Up to 75%				
Lesion × genotype	0.04	−0.04	0.05	−0.04
Up to 50%				
Lesion × genotype	0.01	0.02	0.02	0.10*

*, $P < 0.05$.

common population membership remained significant for the 25% small lesion size class for all trials.

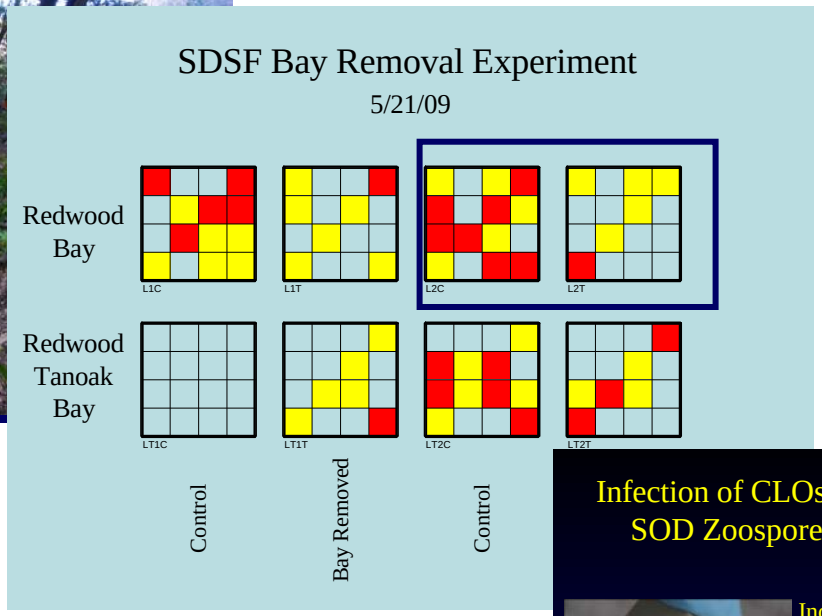

10 sites,
229 trees


13,000


800

Bay removal reduces but does not eliminate inoculum

California Bay Laurel Removal for SOD Control



Is this reduction sufficient?

→

Infection of CLOs by SOD Zoospores

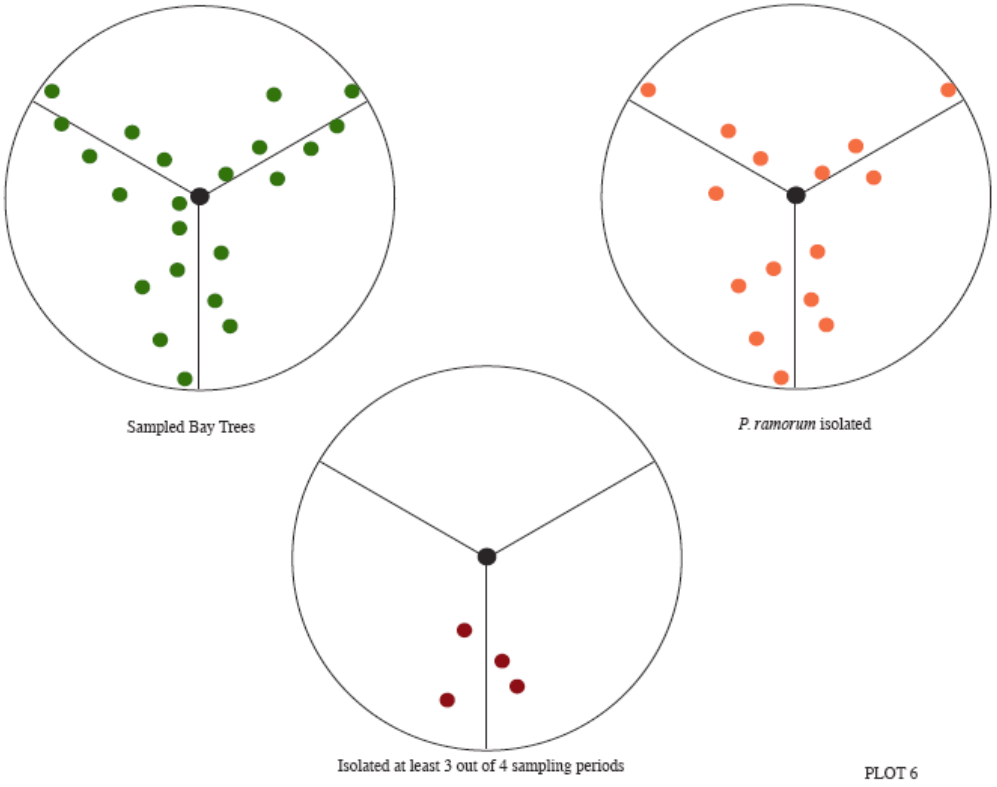
Inoculator & Grafting Wax

Pipetting Zoospore Suspension

Elimination of all bays not feasible or desirable:

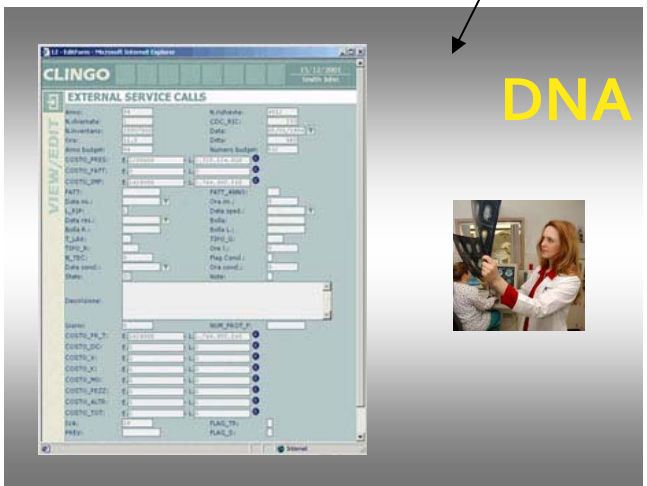
- Eliminate bays near oaks

- Eliminate bays identified as hotspots



PREVENT: Diagnose

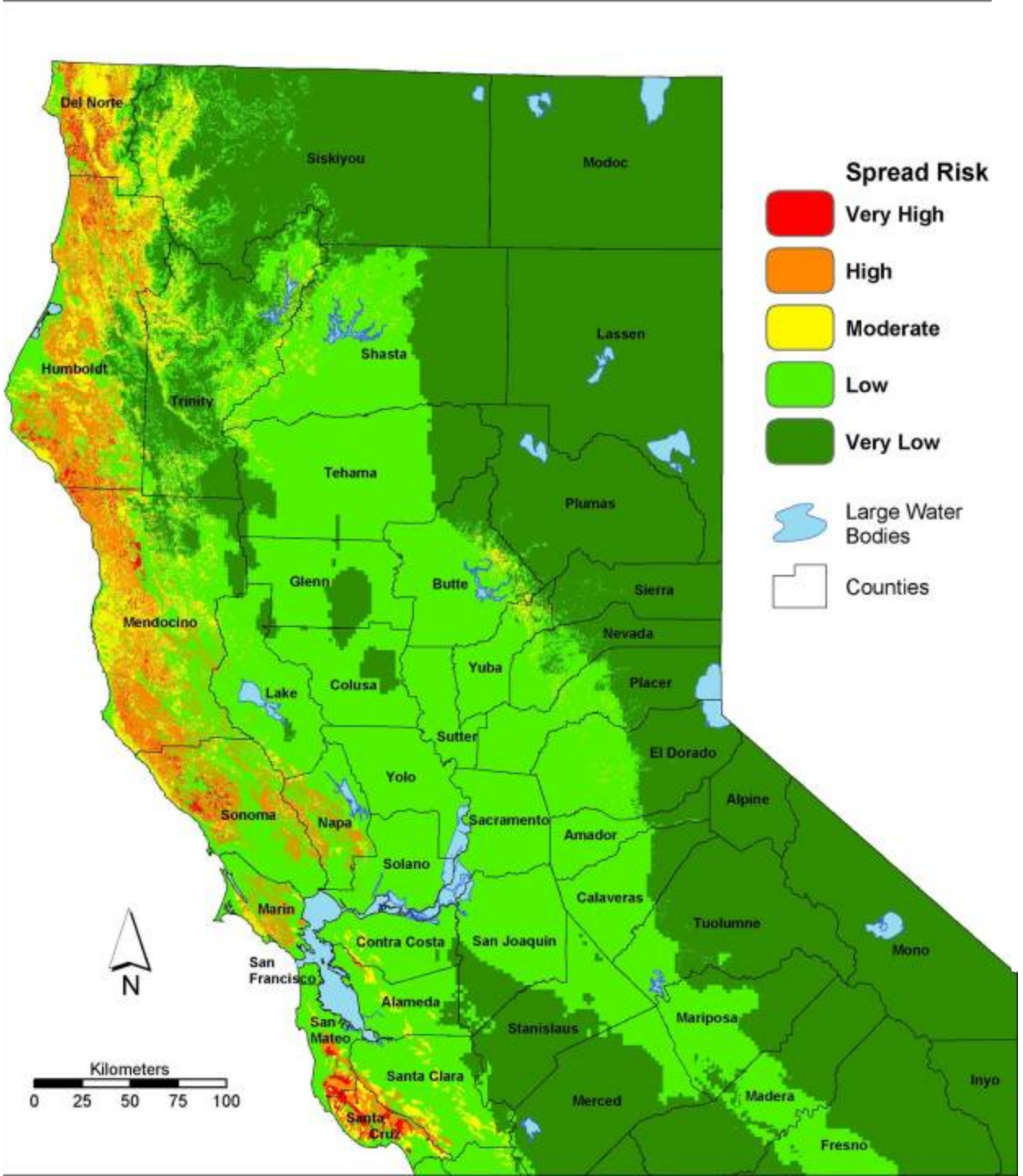
Symptoms relatively generic



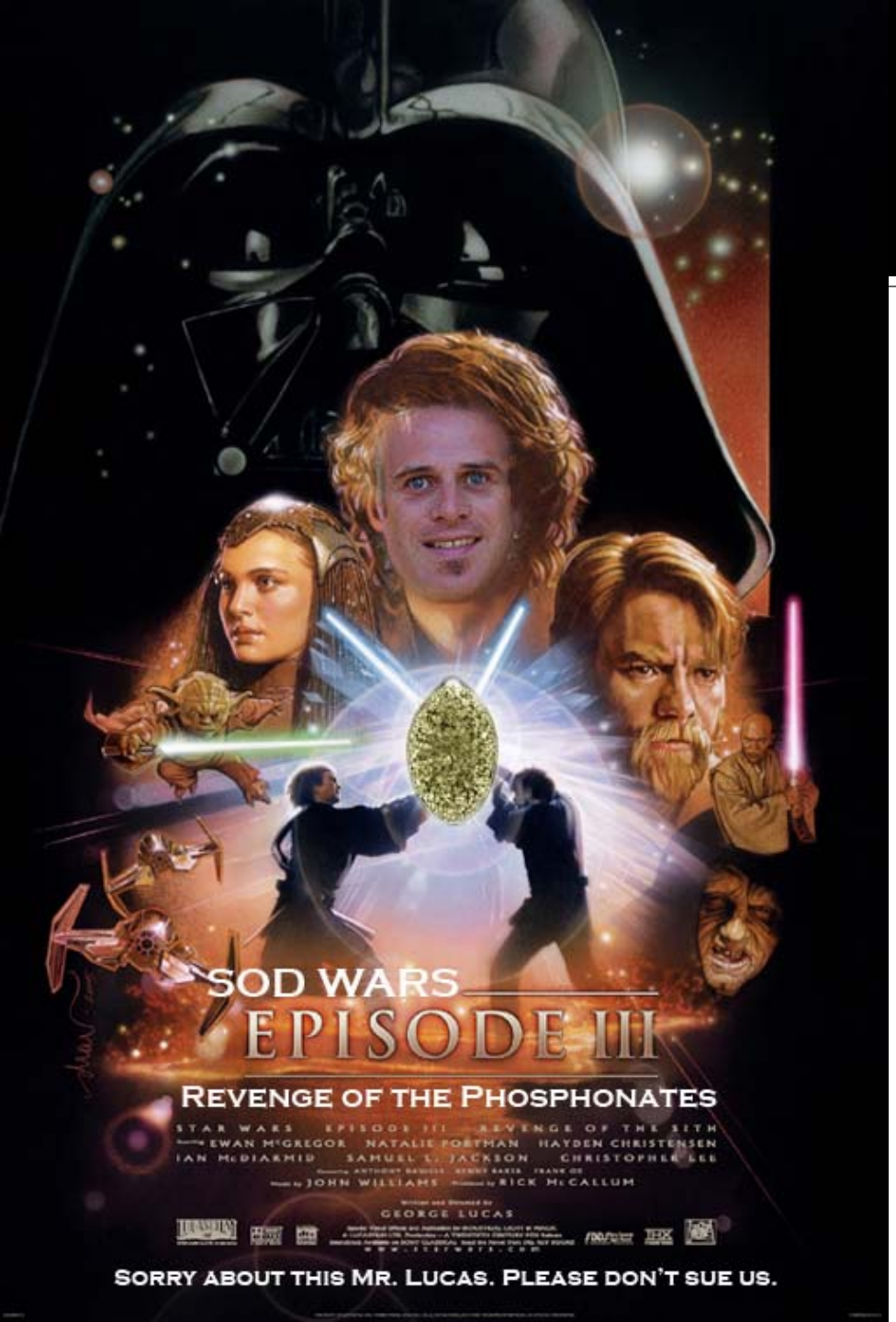
ERADICATION

Nothofagus fusca =dead end host

Fuchsia excorticata = super spreader



Meentemeyer et al., 2004



USDA Competitive Grant Program

Pacific Southwest US Forest Service

The Betty & Gordon Moore Foundation

NSF: Ecology of Infectious Diseases

Sudden Oak Death Update for Foresters and Landowners

Ukiah & Eureka, California

May 12-13, 2010