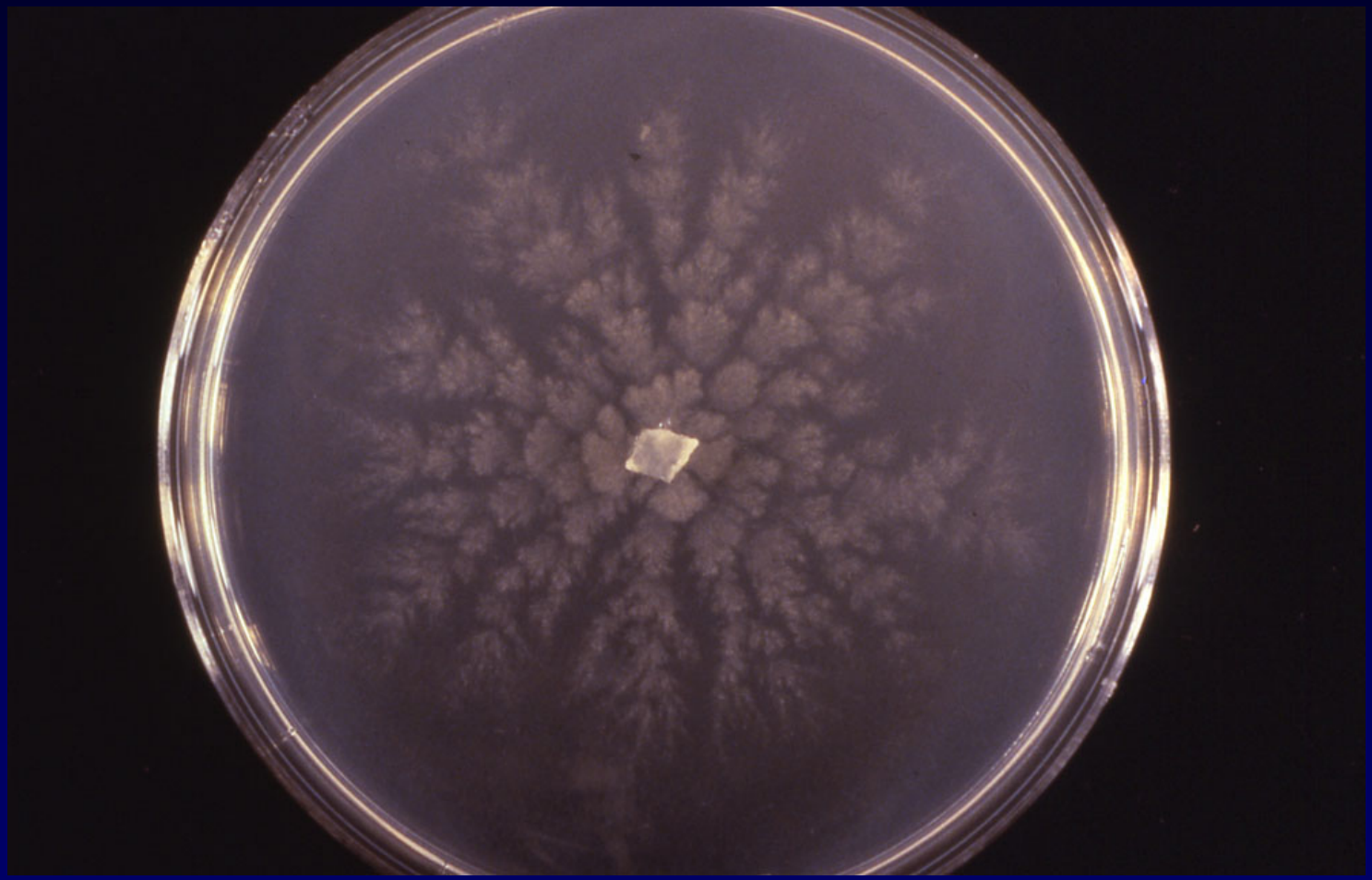
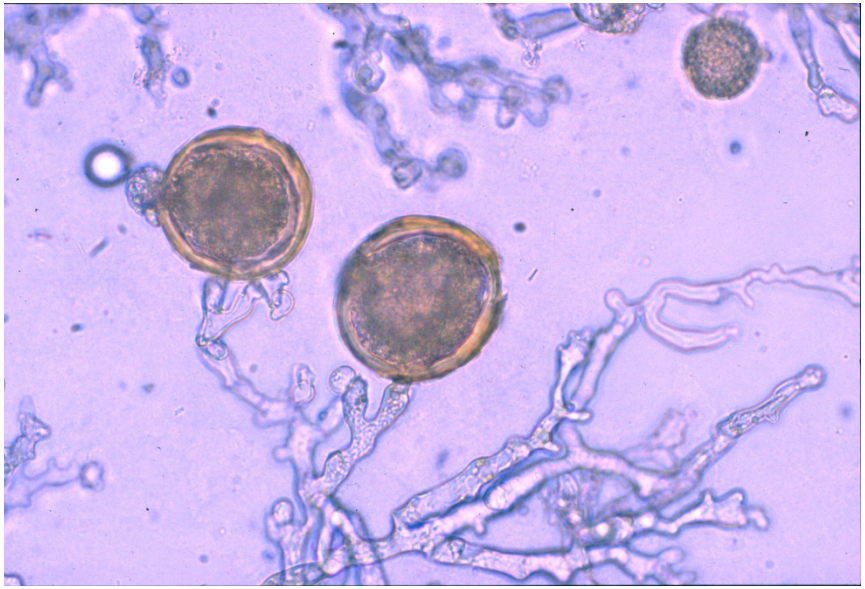
- We use the term lineage, to indicate clearly distinct (genetically and phenotypically) groups of strains within a species. How many lineages of *P. ramorum* are there in the US ornamental industry and how many are there in California?
- How do we explain the large distribution range of SOD in California
- What was the change in US and international policy brought on by *P. ramorum*
- Do you remember some of the ecological impacts caused by SOD

P. ramorum growing in a Petri dish (2000)



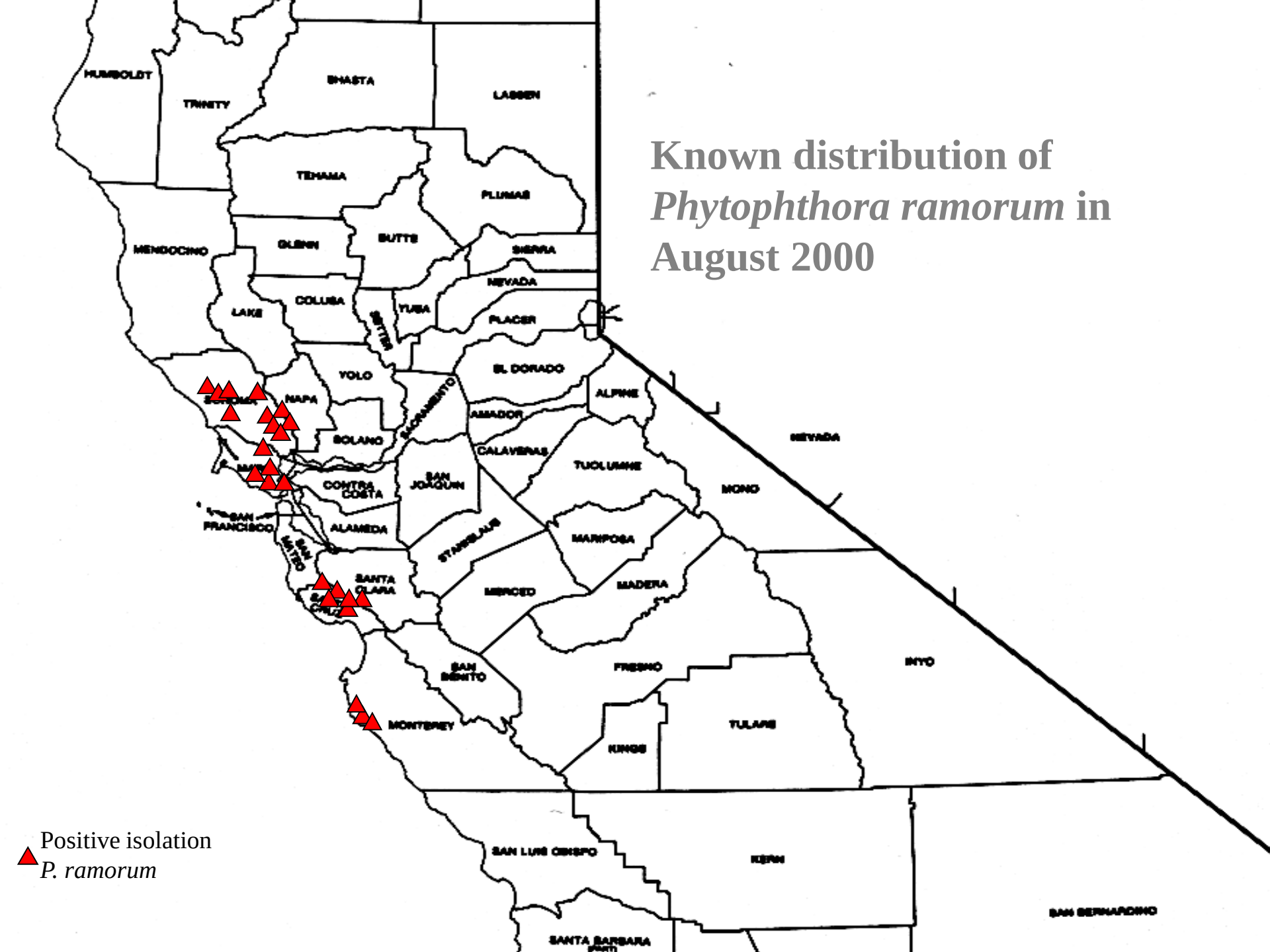
Phytophthora ramorum

Sporangia

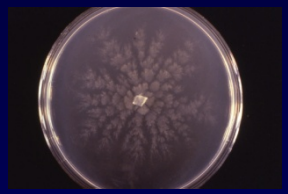


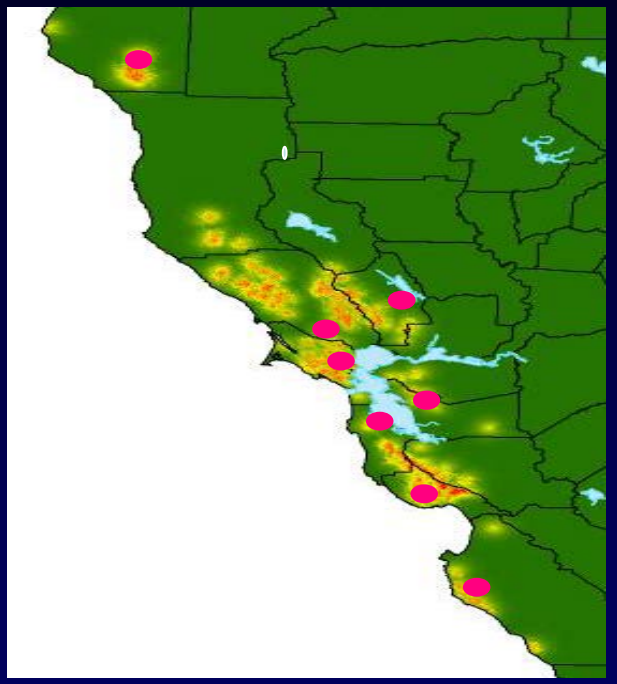
Chlamydospores

SOD pathogen called *Phytophthora ramorum* arrived to California in 80s on infected ornamental plants


Known distribution of *Phytophthora ramorum* in August 2000
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
GLENN
BUTTE
SIERRA
NEVADA
COLUSA
LAKE
YUBA
PLACER
SUTTER
YOLO
EL DORADO
NAPA
SACRAMENTO
ALPINE
AMADOR
SOLANO
CALAVERAS
NEVADA
TUOLUMNE
MONO
CONTRA COSTA
SAN JOAQUIN
SAN FRANCISCO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SAN BENITO
FRESNO
INYO
MONTEREY
TULARE
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
Positive isolation
P. ramorum

P. ramorum introduced at least 12 times in CA (Mascheretti et al. 2009). Multiple introductions and not ability to move far explain distribution of disease





Because pathogen is exotic, native flora has limited resistance to its attack and regular tree health maintenance simply will not suffice

Distribution of SOD in California wildlands

- Distribution is result of discrete introductions followed by natural spread but only in favorable habitats (redwood-tanoak and mixed evergreen)
- As a result, distribution is extremely patchy in 14 contiguous coastal counties from Northern Humboldt to Southern Monterey
- Presence is extremely marginal in San Francisco, Solano, and Lake counties

Bay/Oak association

Bay

Yearly

Coast Live Oak (no sporulation)

Canker margin in phloem

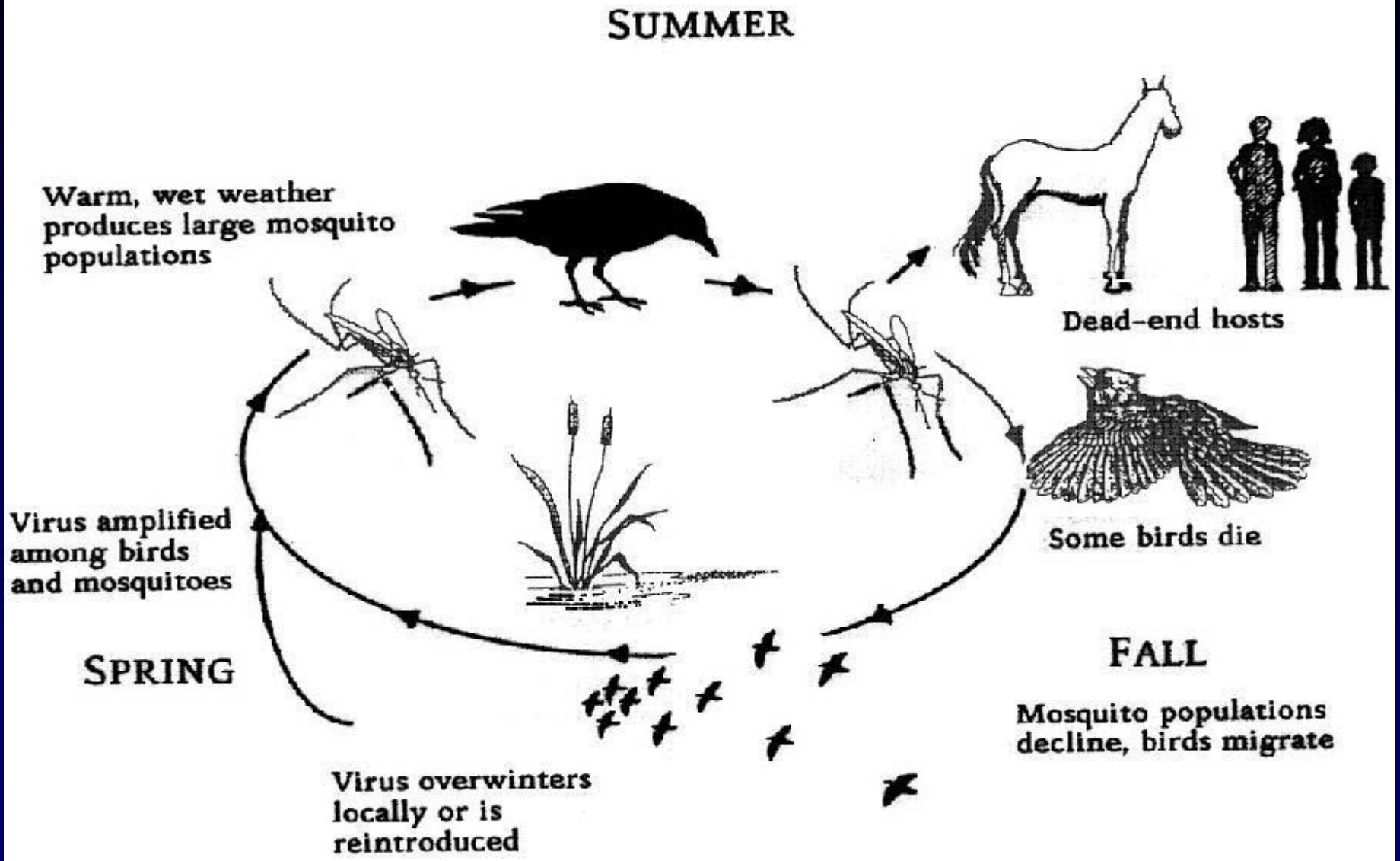
Sporangia

Wave years

Bleeding canker

Soil

Life Cycle of the West Nile Virus



Oaks

Coast live oak

Quercus agrifolia

Black oak

Q. kellogii

Shreve’s oak

Q. parvula var. *shrevei*

Canyon Live oak

Tanoak

Notholithocarpus densiflorus

Tanoak leaves also very infectious:
-tanoaks behave both as oaks and bay:

Tanoak infection does not require bay laurel

Hypoxylon (Anulohypoxylon) fruitbodies on the main stem are a sign that a tree is functionally dead

Only health compromised trees attract bark and ambrosia beetles: frass (sawdust) on the trunk is a sign of insect colonization

Tanoak vs. Oak mortality

- Tanoak – Big Sur
  - 70%
- Marin – predicted
  - 15 years for 90%

All size classes

Infection yearly if rain

Leaves infectious

Small number of sporangia necessary

- Oak- Big Sur
  - 40%
- Marin – predicted
  - 35 years for 90%

Small trees not affected

Infection only when Spring rainfall high

Not infectious

Confirmed Susceptible Species

Andrew's clintonia bead lily
Ardisia
Bearberry
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
Chinese guger tree
Coast live oak
Coast redwood
Dogwood species
Douglas fir
Eastern Joy Lotus Tree
European ash
European turkey oak
European yew
Evergreen huckleberry
Evergreen maple
False Solomon's seal
Formosa firethorn
Fetterbush
Goat willow
Grand fir
Griselinia
Holly
Holly olive
Holm oak
Horse chestnut
Hybrid witchhazel
Japanese evergreen oak
Laurustinus
Leucothoe species
Lilac
Loropetalum species
Madrone
Magnolia varities
Manzanita
Michelia
Mountain laurel
Myrtle-leafed Distylium
Northern red oak
Oleander
Oregon ash
Oregon grape
Osmanthus
Pacific yew
Persian ironwood
Pieris varieties
Planetree maple
Poison oak
Prunus species
Red fir
Red lotus tree
Red tip photinia
Redwood ivy
Rhododendron species
Roble beech
Rosa species & hybrids
Rugosa rose
Salal
Salmonberry
Scotch heather
Scribbly gum
Sessile oak
Sheep laurel
Shreve's oak
Southern red oak
Spicebush
Spike witch hazel
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

Confirmed Susceptible Species

Andrew's clintonia bead lily
Ardisia
Bearberry
Bigleaf maple
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California bay laurel
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Osmanthus
Pacific yew
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Tanoak
Toyon
Viburnum varieties
Victorian box
Vine maple
Western maidenhair fern
Western starflower
White fir
Winter's bark
Witch hazel
Wood rose
Yew

Symptoms on Buckeye leaves and petioles

Scorching of maple leaves caused by *P. ramorum*

Autumn

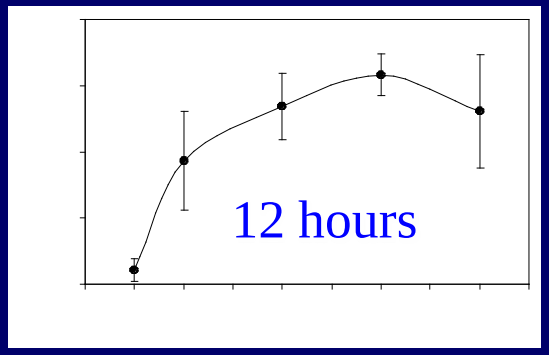
Spring

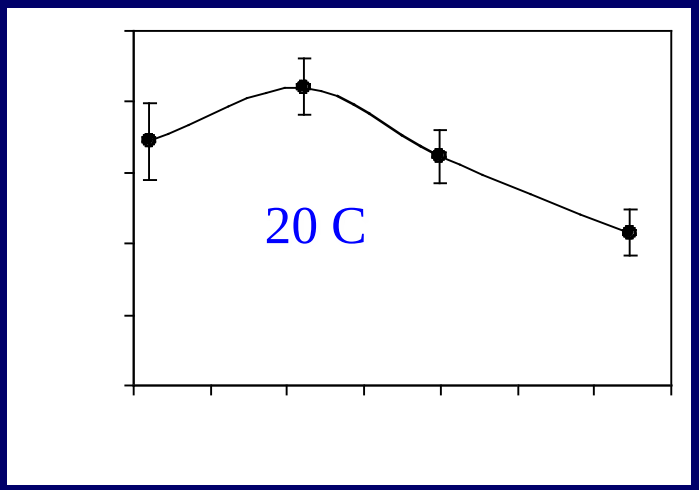
Primary cause of death is girdling of phloem, vessel blocking, while secondary organisms accelerate the process

Girdling occurs much faster than visible symptoms on crown. Girdled trees can survive apparently “green” 4 years + after being girdled

Girdled trees can fail even if “green” because of activity of secondary organisms

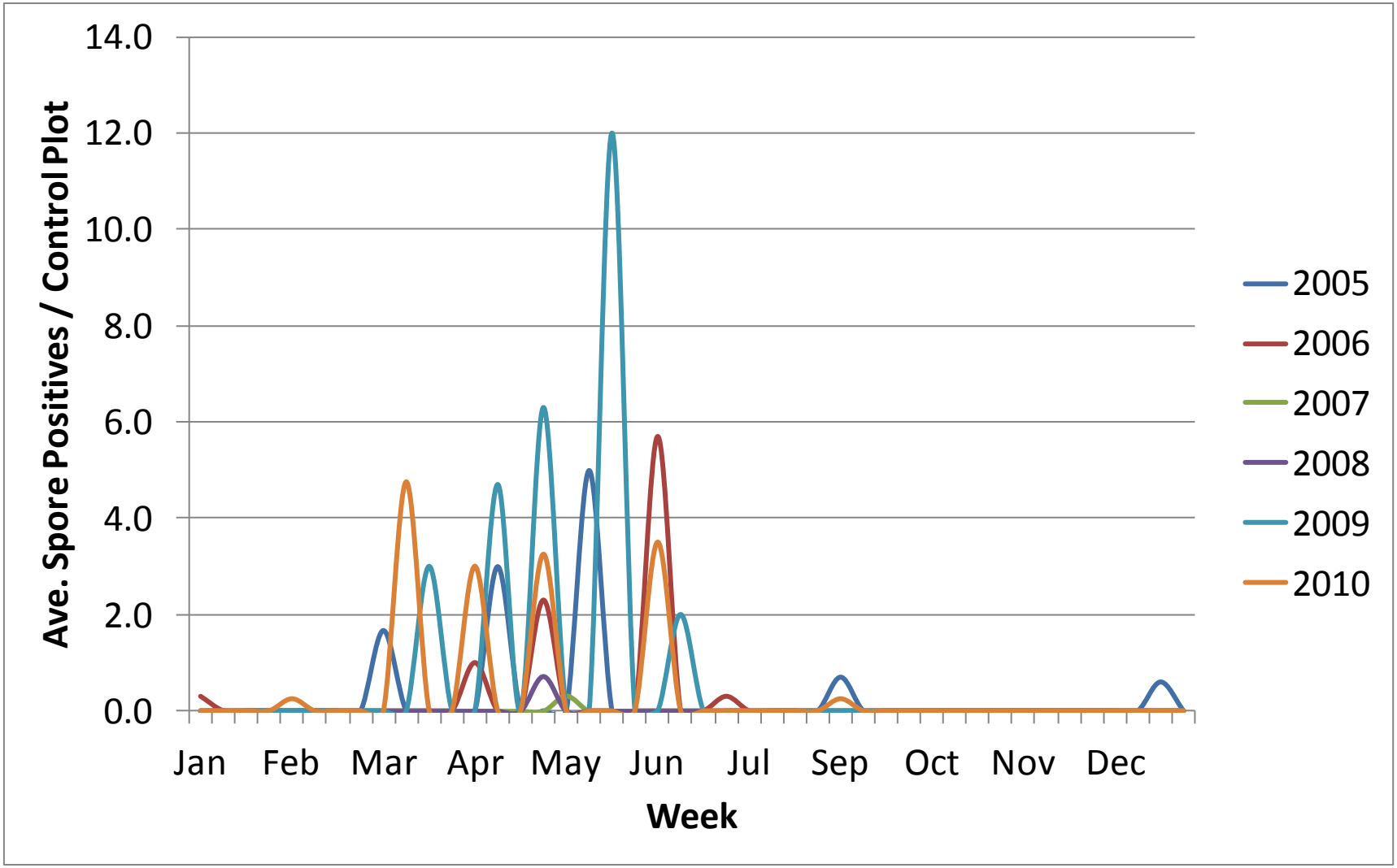
While insecticides may temporarily prolong the life of treated trees, beetle attacks are a good indicator of “hazard” trees





By inoculating with zoospores and without wounding, the ideal conditions for infection were figured out: these conditions are present in California especially when there are rainy late Springs: these conditions do not happen every year

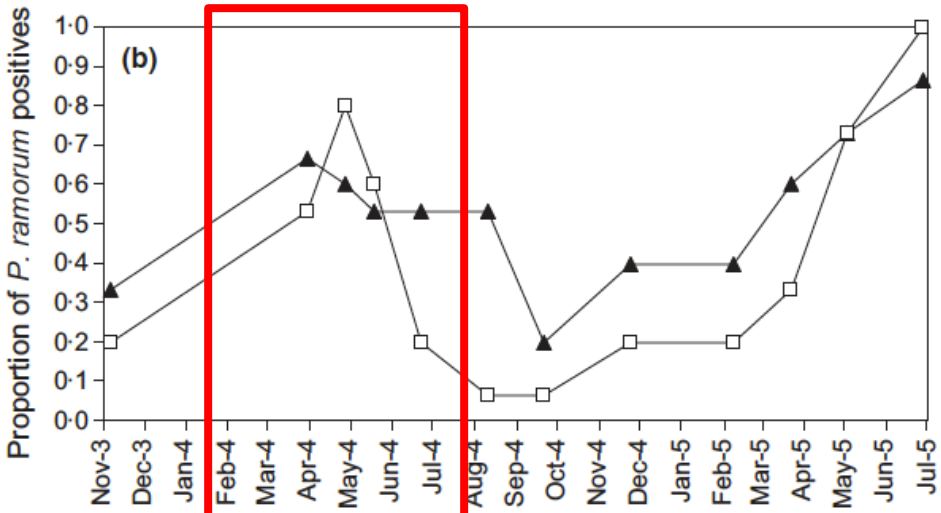
SOD spore catches in water: mid-April to mid-June is consistent



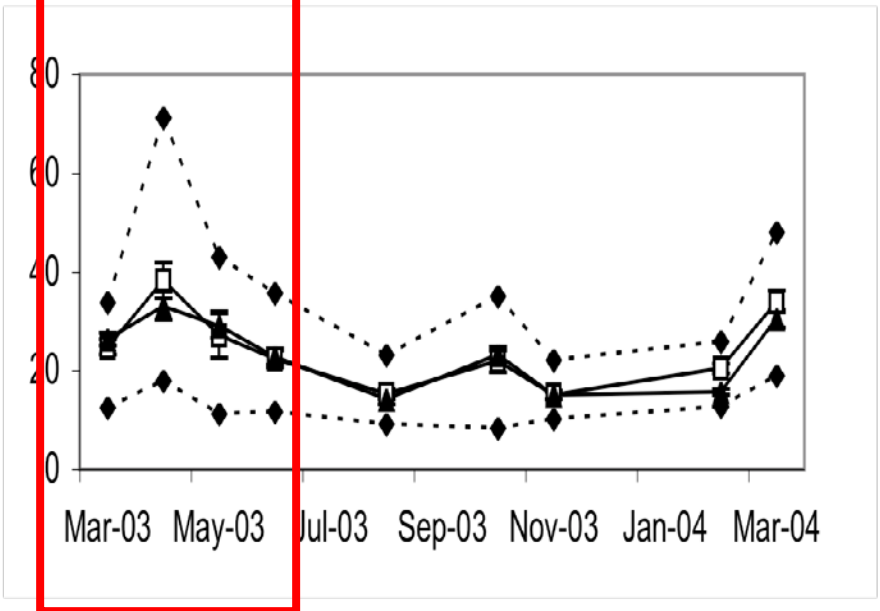
Synchrony pathogen-host:

Host susceptibility

Susceptibility of bay laurels
(lesion size in nature)



Susceptibility of oaks (lesion size in lab)



Pathogen

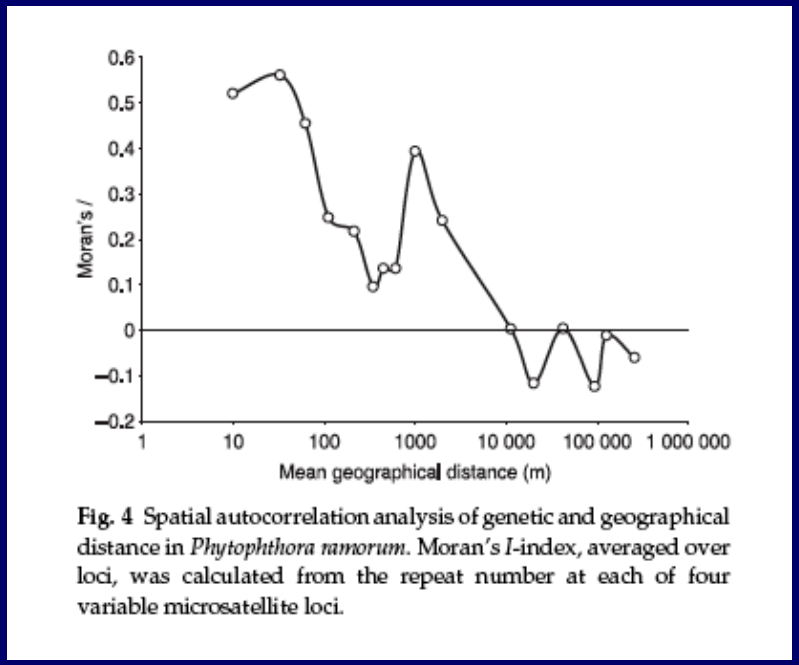


Fig. 4 Spatial autocorrelation analysis of genetic and geographical distance in *Phytophthora ramorum*. Moran's *I*-index, averaged over loci, was calculated from the repeat number at each of four variable microsatellite loci.

When multiple rain events occur sporangia are produced on leaves of infectious hosts such as bay laurel and tanoak and can be airborne

mostly up to 100 m but when winds are strong up to 2 miles

New infections occur almost exclusively during the rainy season in or near sites previously infested

Limit tree-care and forestry work during wet season

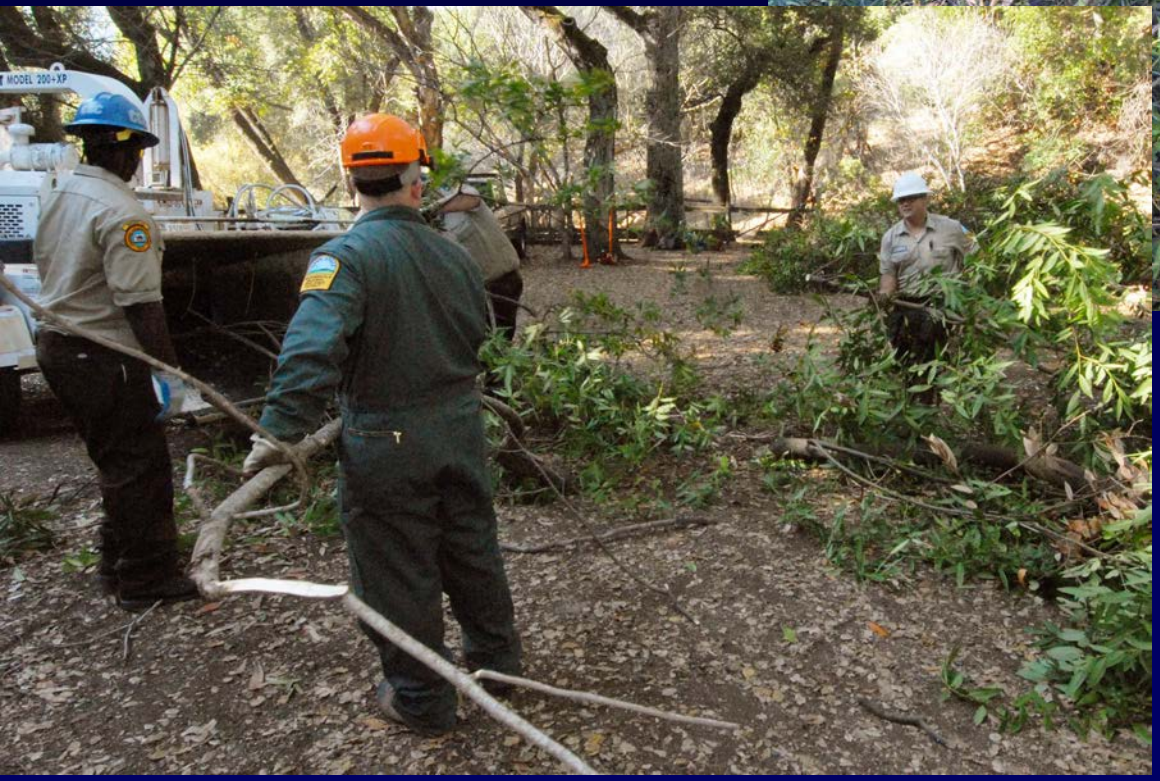
If necessary to work in wet season, schedule to work in uninfested sites before working in infested sites

P. ramorum has a short spread range, knowing its fine scale distribution is essential

Landscape level factors

- Presence of sporulating hosts (bay laurels and tanoaks) positively correlated with mortality
- Madrone negatively correlated with mortality
- High diversity of hosts slowing down the disease
- Forest patches under 50 m not favorable
- Connectivity between stands (forest corridors) favors disease
- Because of recent arrival predictions are imperfect (lack of equilibrium)

Bay Laurel Removal for SOD Control

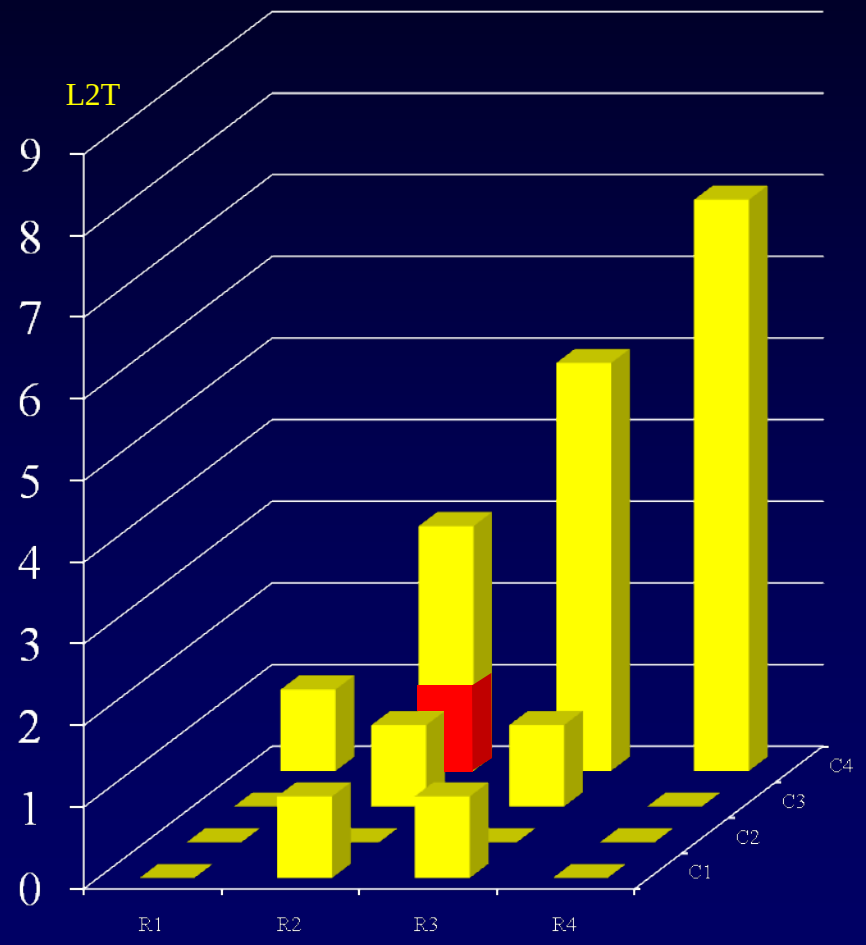


SOD Spore Monitoring at SDSF

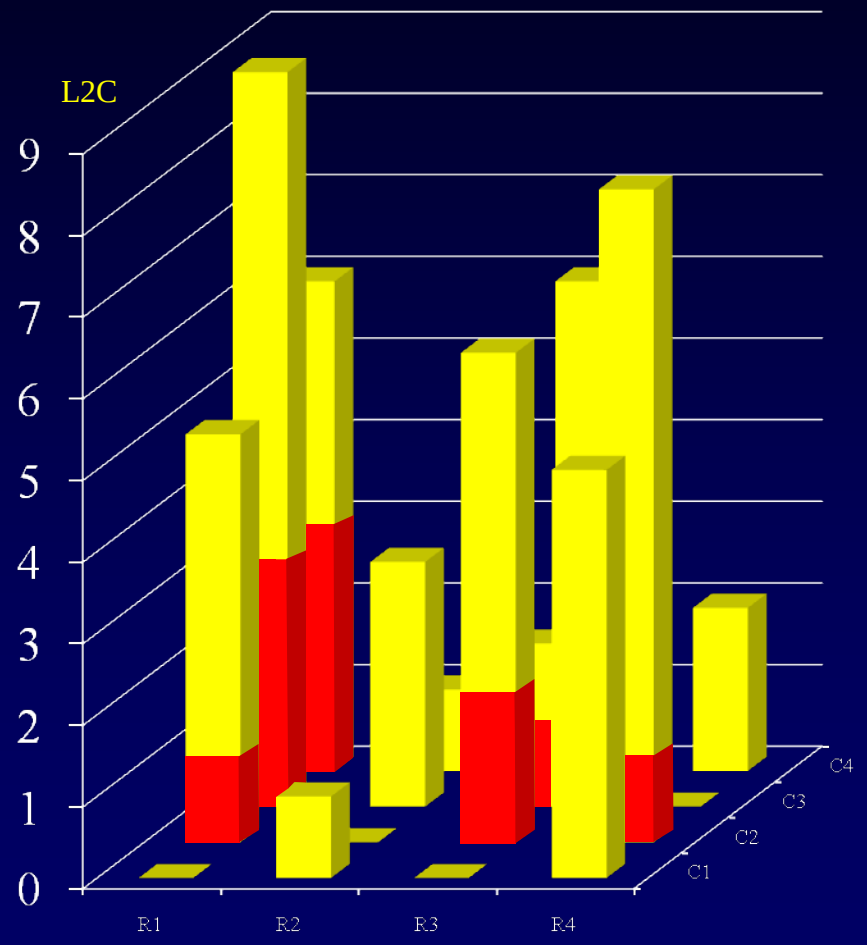
8 Experimental Field Sites
16 Buckets / Site
5 Leaves / Bucket
= 640 leaves sampled every 3 weeks February through June for 6 years

Effect of Bay Removal on SOD Spore Counts

Combined *P. ramorum*
Spore Counts 2005& 2006



Bay Laurels Removed



Untreated Control

Is reduction in spore loads caused by removal of bays in the 10-20 m range sufficient to prevent infection of oaks?

ONLY HIGH INOCULUM (RED) CAUSED OAK INFECTION

Conclusions:

1- Bay removal at moderate distance from oaks appears to sufficiently reduce inoculum level to prevent infection, even if it does not eliminate it Removal of bays 10 m around oaks recommended. For large specimens we recommend 20 m

Oak-centric

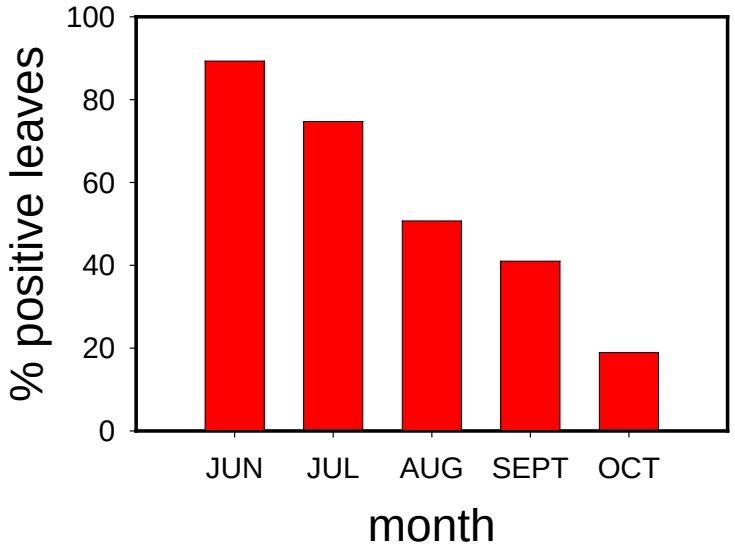
2- Bay removal at the stand level will reduce inoculum. Floristically more diversified forests show lower disease incidence.

Stand-wide

3- *P. ramorum* survives on bay leaves, but not everywhere. We have recently shown that only some sites allow survival during droughts. Elimination of bays in these sites will be very effective

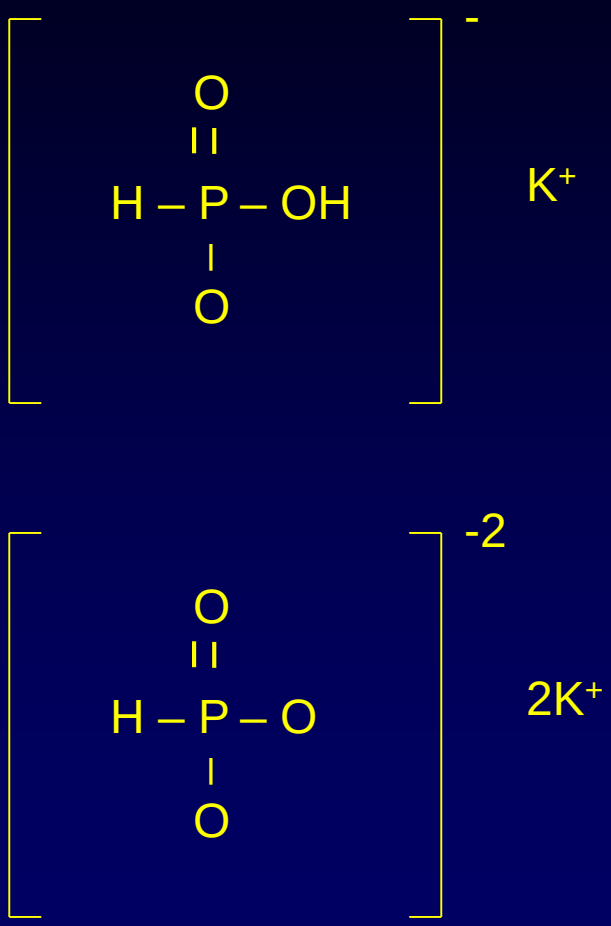
Ecology

Recovery of *P. ramorum* from attached bay leaves

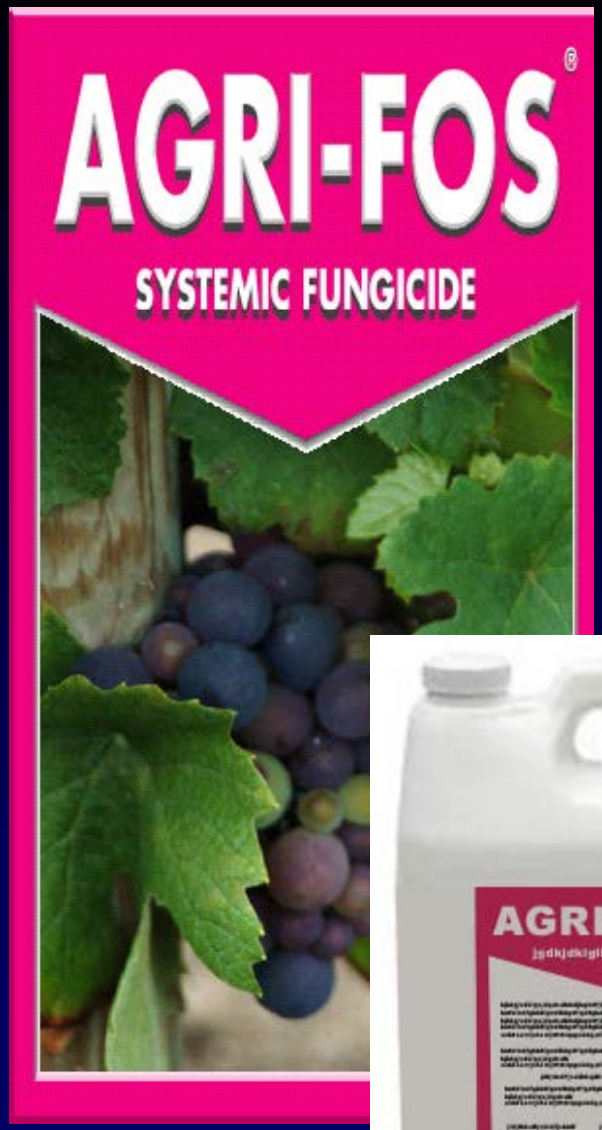


In a survey of 2000 trees observed and isolated from 3 times a year four four years we have determined less than 5% of bay laurels carry over infection after dry season. We believe these 5% are key in epidemiology

Phosphonate (aka Phosphite) Chemical Treatments



- Water soluble. Systemically absorbed and translocated by the xylem and phloem
- Inhibits fungal growth and activates the plant's own defensive response
- Preventative treatments are more effective than curative


AGRI-FOS
SYSTEMIC FUNGICIDE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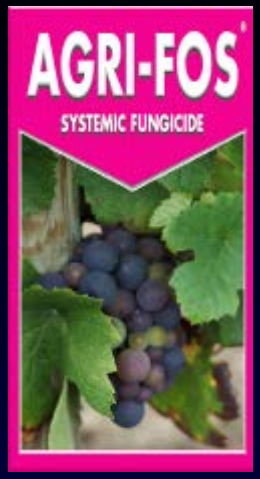
Injection Treatment



Plant Pathology (2008) Doi: 10.1111/j.1365-3059.2008.01894.x

Efficacy of phosphonic acid, metalaxyl-M and copper hydroxide against *Phytophthora ramorum in vitro* and *in planta*

M. Garbelotto*, T.Y.

Department of Environmental Si

Arboriculture & Urban Forestry 33(5): September 2007 309

ISA

Arboriculture & Urban Forestry 2007. 33(5):309–317.

ARBORICULTURE & URBAN FORESTRY

Phosphite Injections and Bark Application of Phosphite + Pentrabark™ Control Sudden Oak Death in Coast Live Oak

M. Garbelotto, D.J. Schmidt, and T.Y. Hamik

Preventive treatment that strengthens response of oaks: we developed an alternative to injection

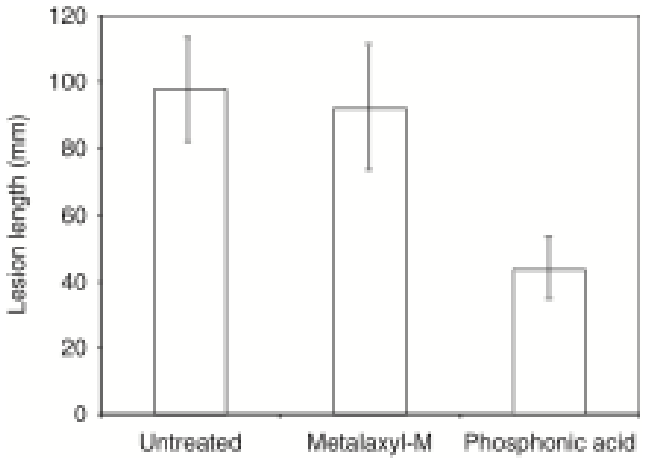


Figure 2 Lesion length (with bars showing standard deviation) caused by three *Phytophthora ramorum* isolates inoculated underbark in the phloem of potted coast live oak saplings, either untreated, treated with metalaxyl-M drench, or by phosphonic acid injection. Each treatment was performed on 15 saplings one week before inoculation; the experiment was terminated 6 weeks after inoculation.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SYSTEMIC FUNGICIDE


PENTRA-BARK
BARK PENETRATING SURFACTANT
PENTRA-BARK
CAUTION
Quest


Topical Treatment

Conclusions on treatments

- Treat with phosphites before infection occurs (infected bays but oaks healthy/ entire tanoak cluster healthy)
- Treat once a year but in Fall to give time for plant to respond. If first treatment in Spring, repeat in Fall the first year. Do not treat in summer or December-January as trees do not respond well
- Injection holes will seal in three years, do not inject in spring as drill holes could facilitate infection

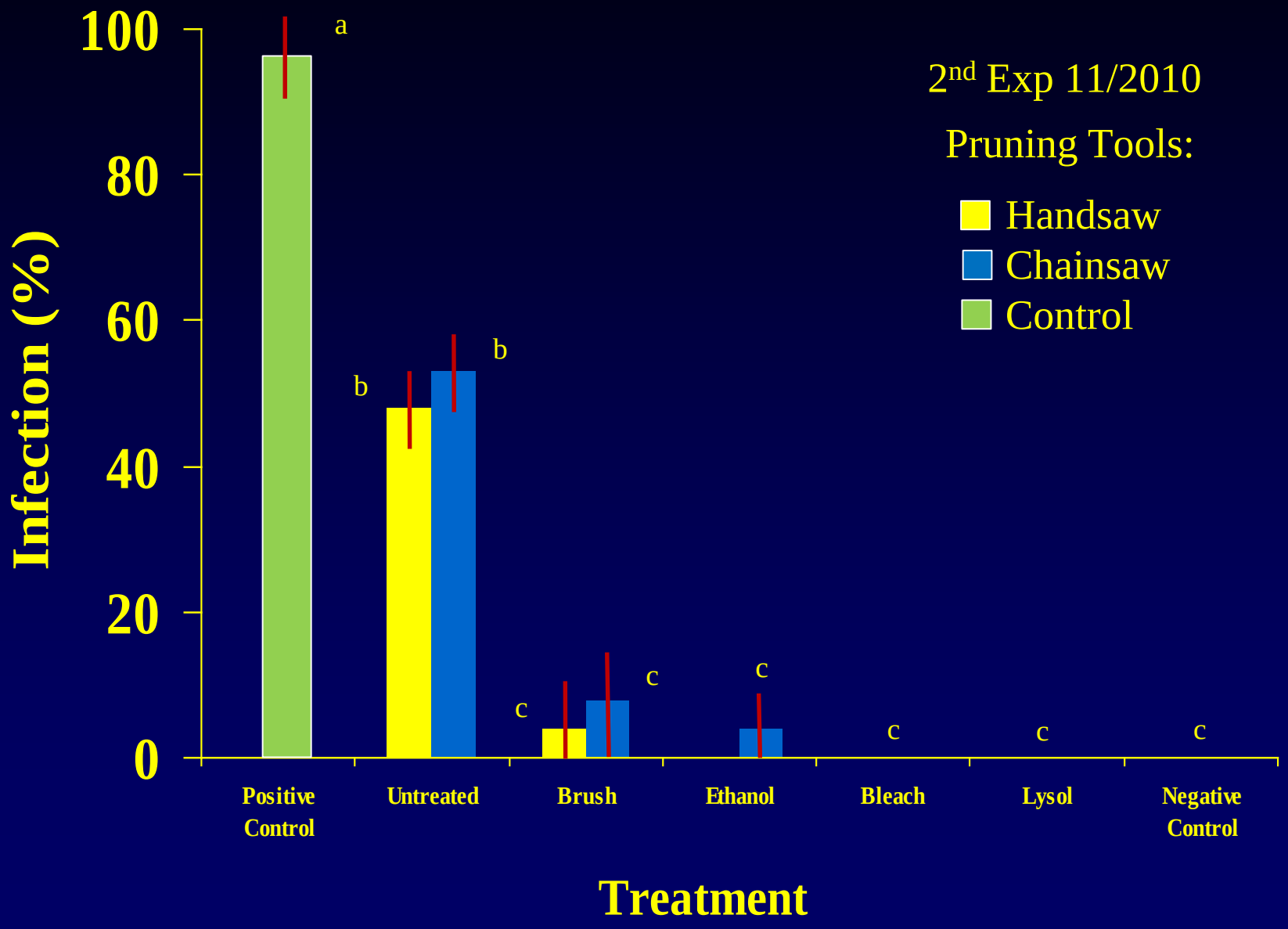
Four Treatments:

- Wire Brush
- 70% Ethanol + Brush
- 5% Bleach (Na Hypochlorite) + Brush
- 6.25% Lysol (ADBAC) + Brush

Cleaning Tools

Infected Tool Surface

Transmission of SOD Through Pruning Tools



Sanitation

Green waste more infectious than wood and soil

Drying infected material is best strategy to sanitize: small chips best, thin layers best, exposure to sunlight best, dry on site before removing if possible

For sanitation of equipment, tools, and vehicles: if it looks clean it is not infectious

The search for the Holy Grail of resistance:

There are significant differences in susceptibility among individuals within all species tested

Constitutive chemistry and/or phenology invoked to explain differences that are both inheritable (i.e. genetic)and determined by the environment

Resistance proper not found yet, but decreased susceptibility and/or tolerance may be extremely useful and more durable

The search for the Holy Grail of resistance:

- Ongoing screening for resistance in tanoak includes common garden tests both in lab and nature. With phenotypic traits studied by family (half sibs) including lesion size, survival in absence and presence of SOD and morphology


10 sites,
229 trees

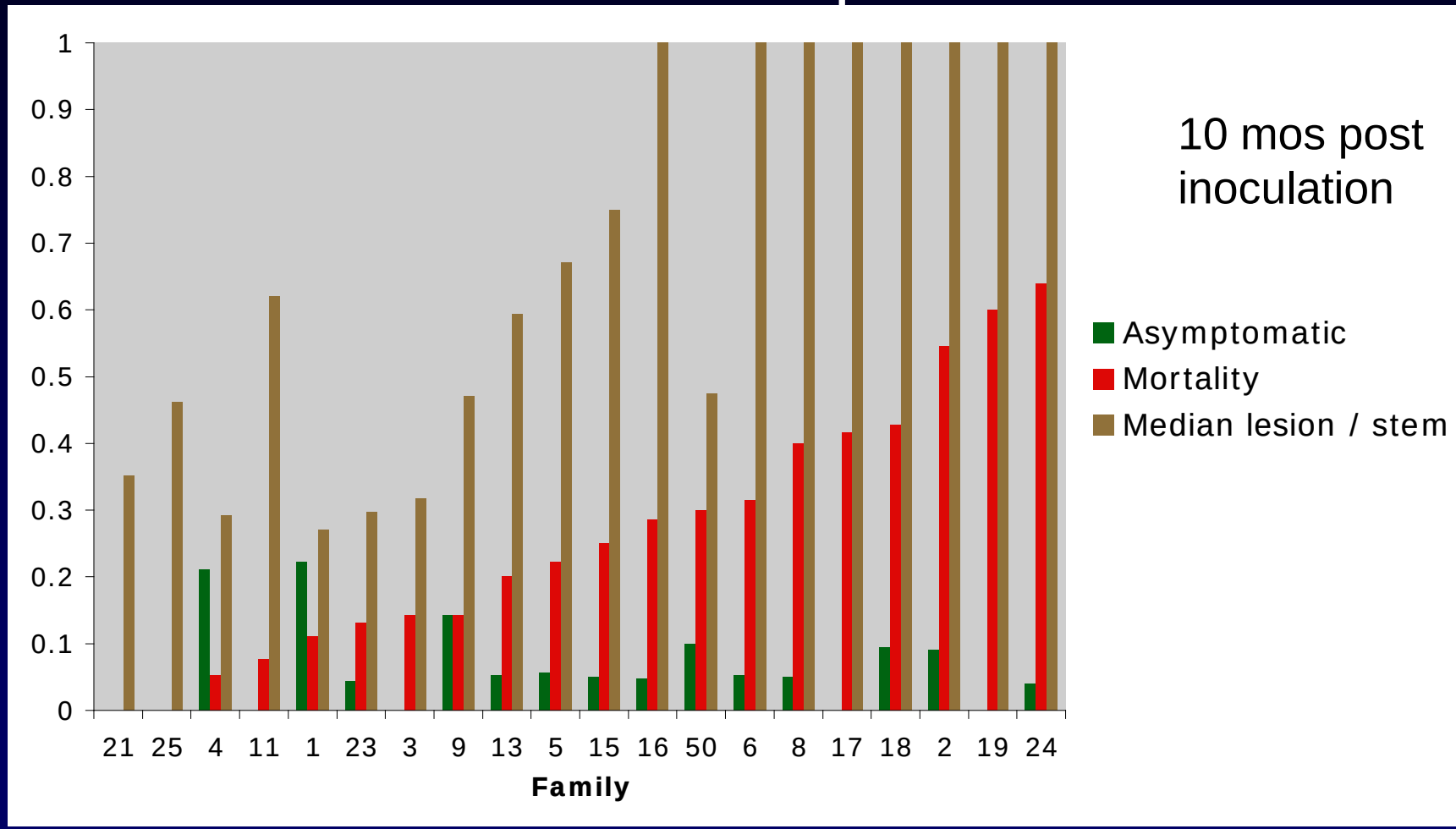

13,000


BL-5-221

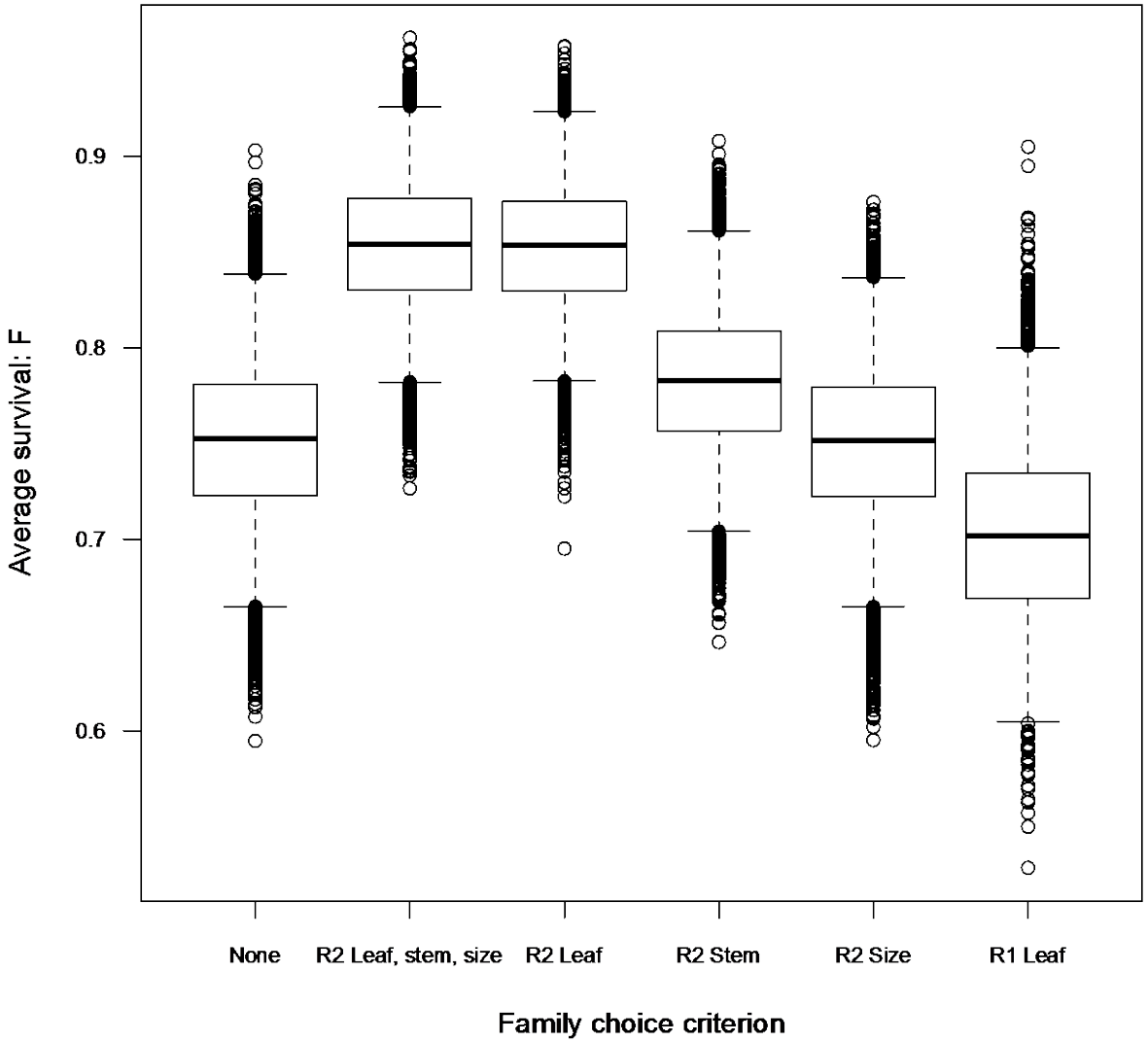

BL13-236


800

Common garden seedling tip assays of families indicates role of genetic variation within host species



Predicted survival of seedlings with and without selection based on resistance to *P. ramorum*



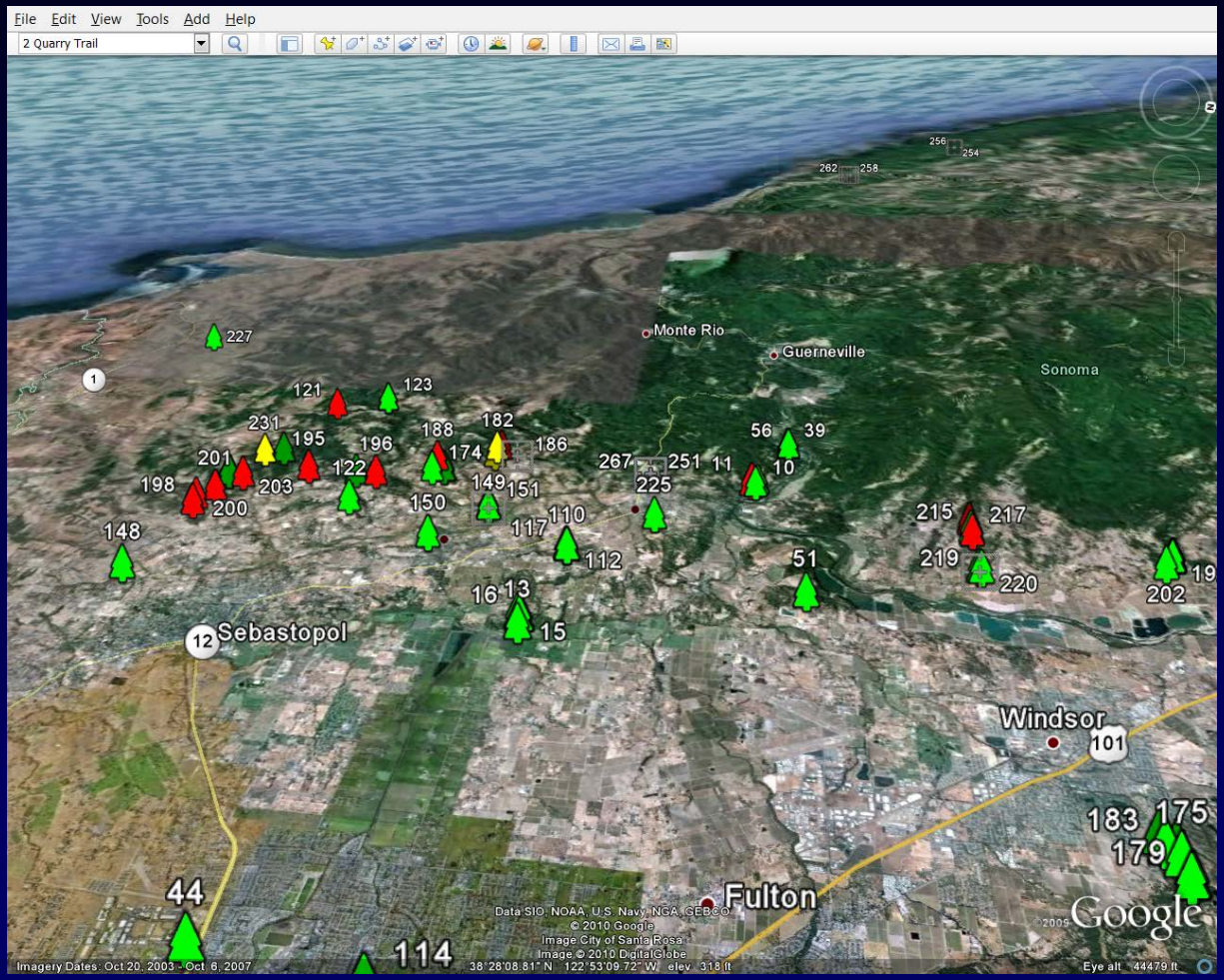
Why should we care about variation in susceptibility?

1- Less susceptible oaks/tanoaks in habitats less conducive to *P. ramorum*= survival

2- High susceptibility of bays can be used to predict sites with the highest risk of SOD outbreaks

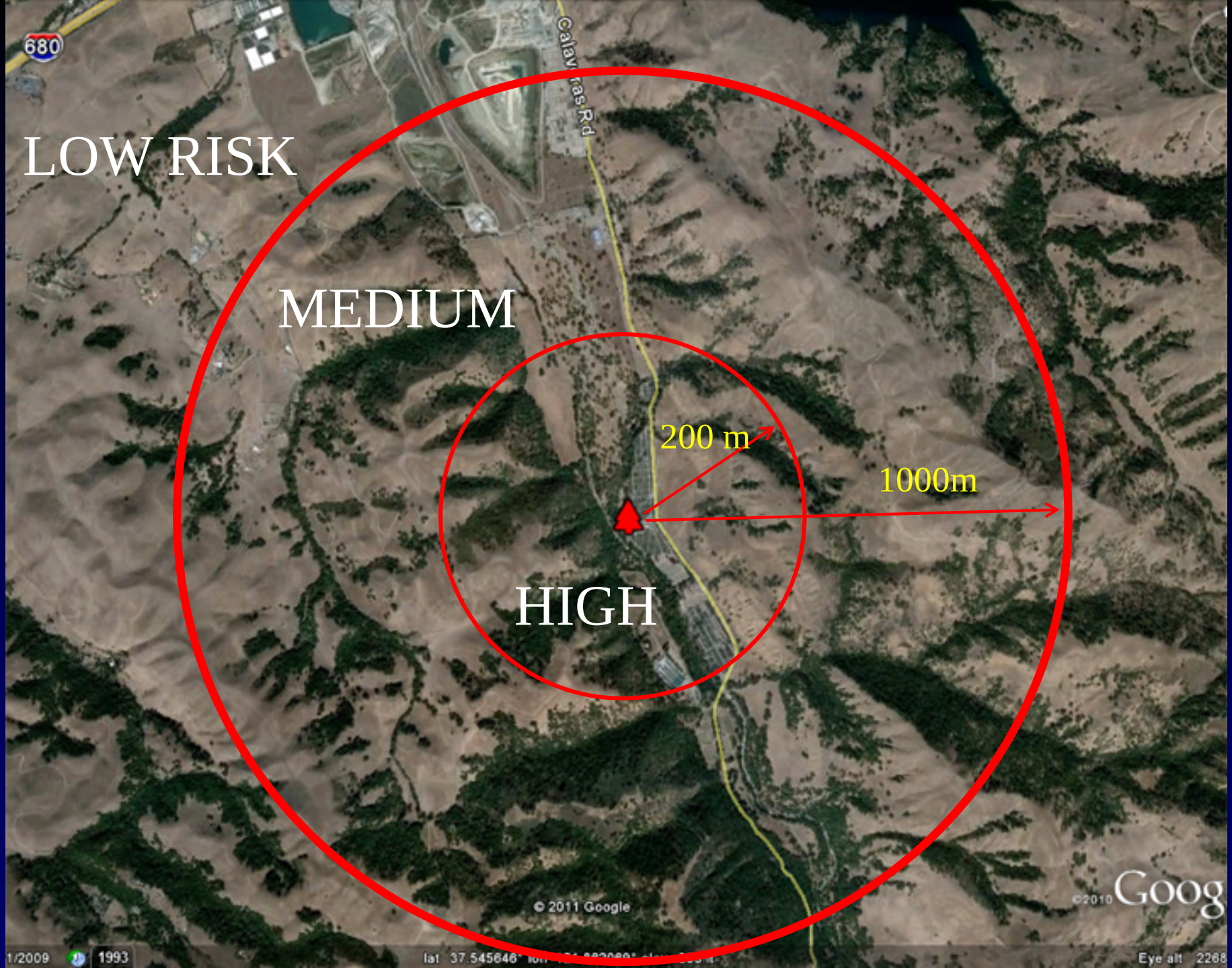
3- We have shown that reforestation efforts using families that show low susceptibility in the lab and good growth are going to be significantly more successful

SOD Blitzes and SODMAP (June 2012)
www.sodblitz.org



What have we learned from Blitzes

- Disease incidence triples during rainy year even in old infestations
- New infestations discovered
- In truly coastal areas, disease incidence remains high, while in more interior areas there are significant fluctuations (e.g. Western vs. Central Sonoma)
- Spread rate will change when disease changes climatic zone


LOW RISK
MEDIUM
HIGH
200 m
1000m
680
Calaveras Rd
© 2011 Google

What is the

SODMAP Project

- The SODMAP Project is a partnership of scientists and citizens, working together to create the most complete distribution map of a forest disease ever produced in the world.

- SODMAP incorporates laboratory confirmed collections of plant and water samples from 2005 to the present.

Sodmap.org

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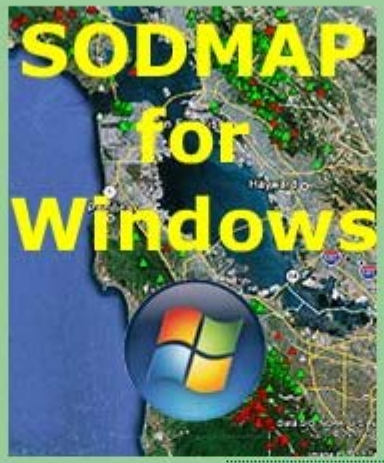
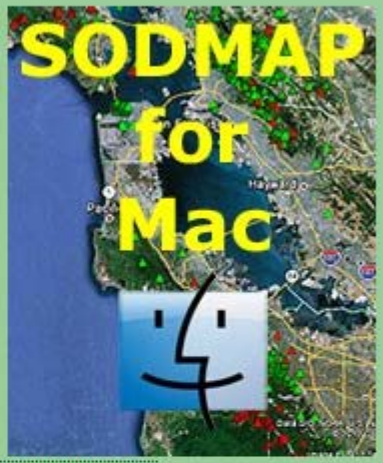
publications
diagnosis
treatment
links
contact us
ucb courses

Featured
This Month

SODMAP Project

This project made possible thanks to funding from:
USDA Forest Service, State and Private Forestry
The Gordon and Betty Moore Foundation



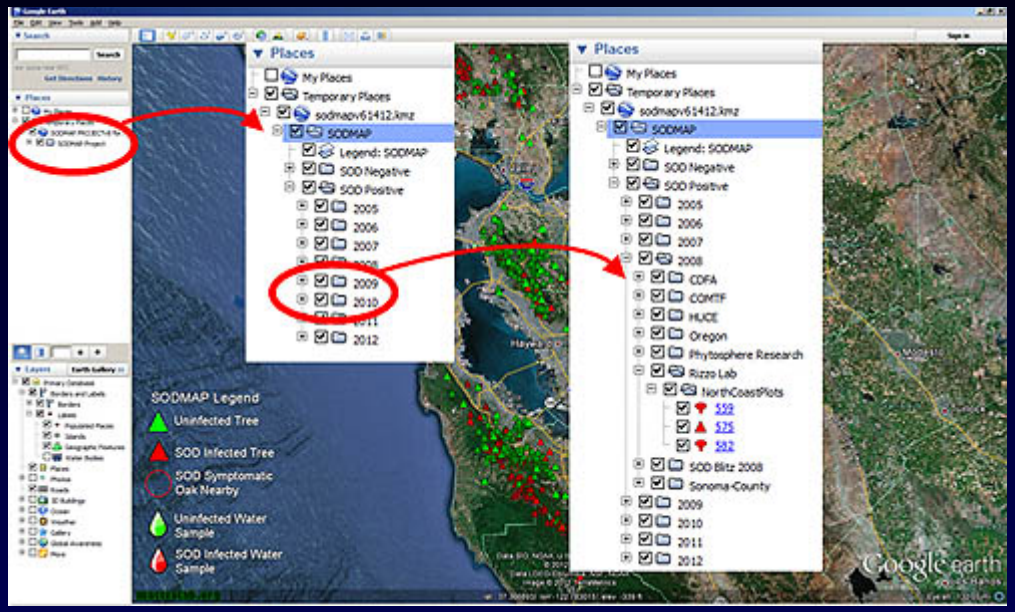


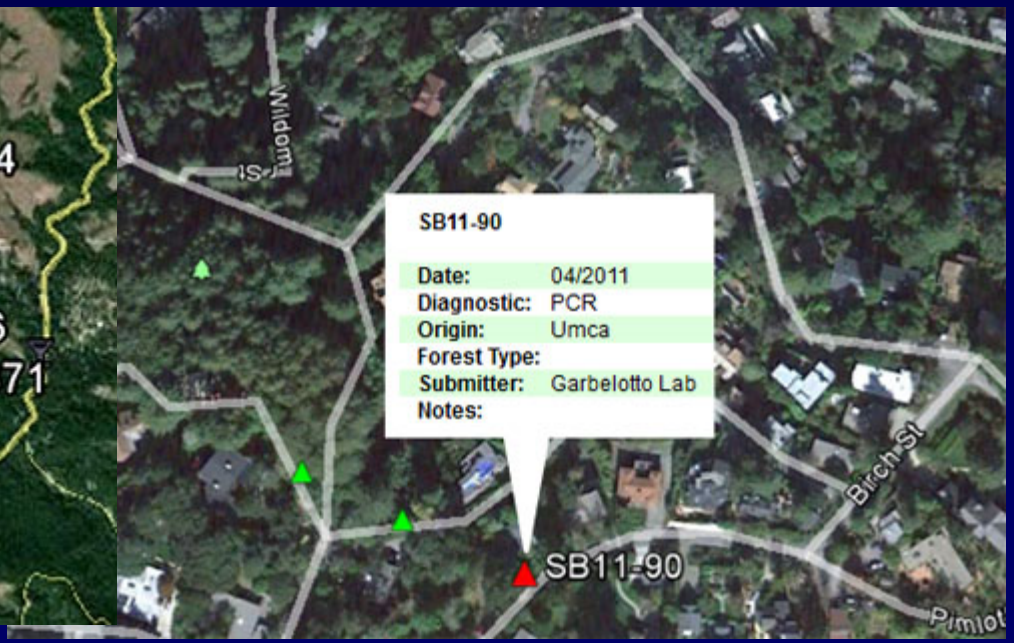
SODMAP Guide and Instructions

The SODMAP Project is a partnership of scientists and citizens, working together to create the most complete distribution map of a forest disease ever produced in North America. SODMAP incorporates laboratory confirmed collections of plant and water samples from 2005 to the present. It includes both SOD-positive, as well as, SOD-negative specimens to better illustrate the range and distribution of the disease.

SODMAP is the result of a collaboration between hundreds of citizen scientists participating each year in the SOD Blitzes organized by the U.C. Berkeley Forest Pathology and Mycology Laboratory, other research organizations, and government facilities. Contributors to the 2012 SODMAP include: M. Garbelotto, UC Berkeley; D.M. Rizzo, U.C. Davis; Ross Meetenmeyer; UNC Charlotte, Ted Swiecki, Phytosphere Research; Don Owen, Cal Fire; Jack Marshall, Cal Fire; Cheryl Blomquist, CDFA; Lisa Bell, UCCE; Yana Valachovic. UCCE.

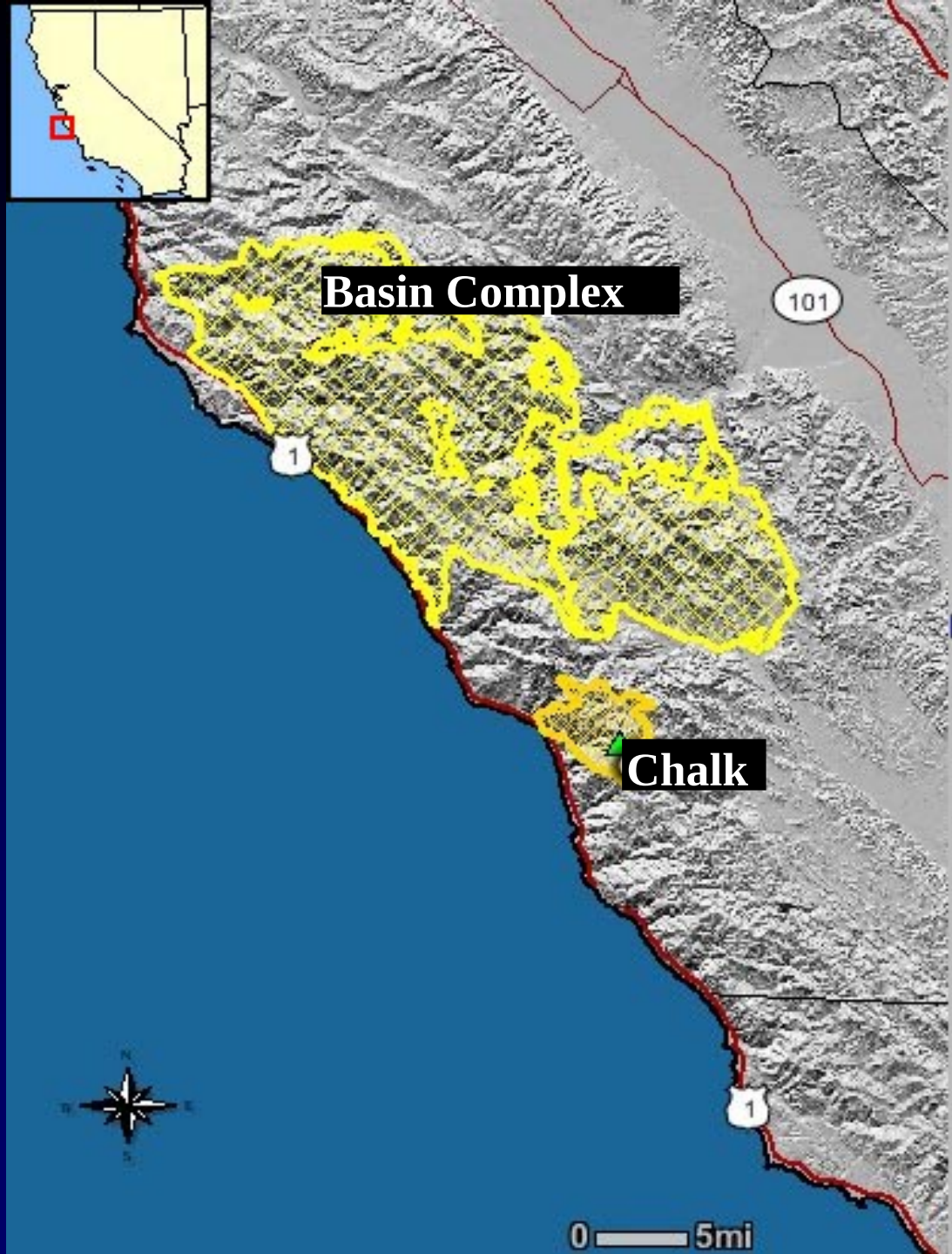
Using SODMAP





Big Sur fires 2008

Image: K. Frangioso

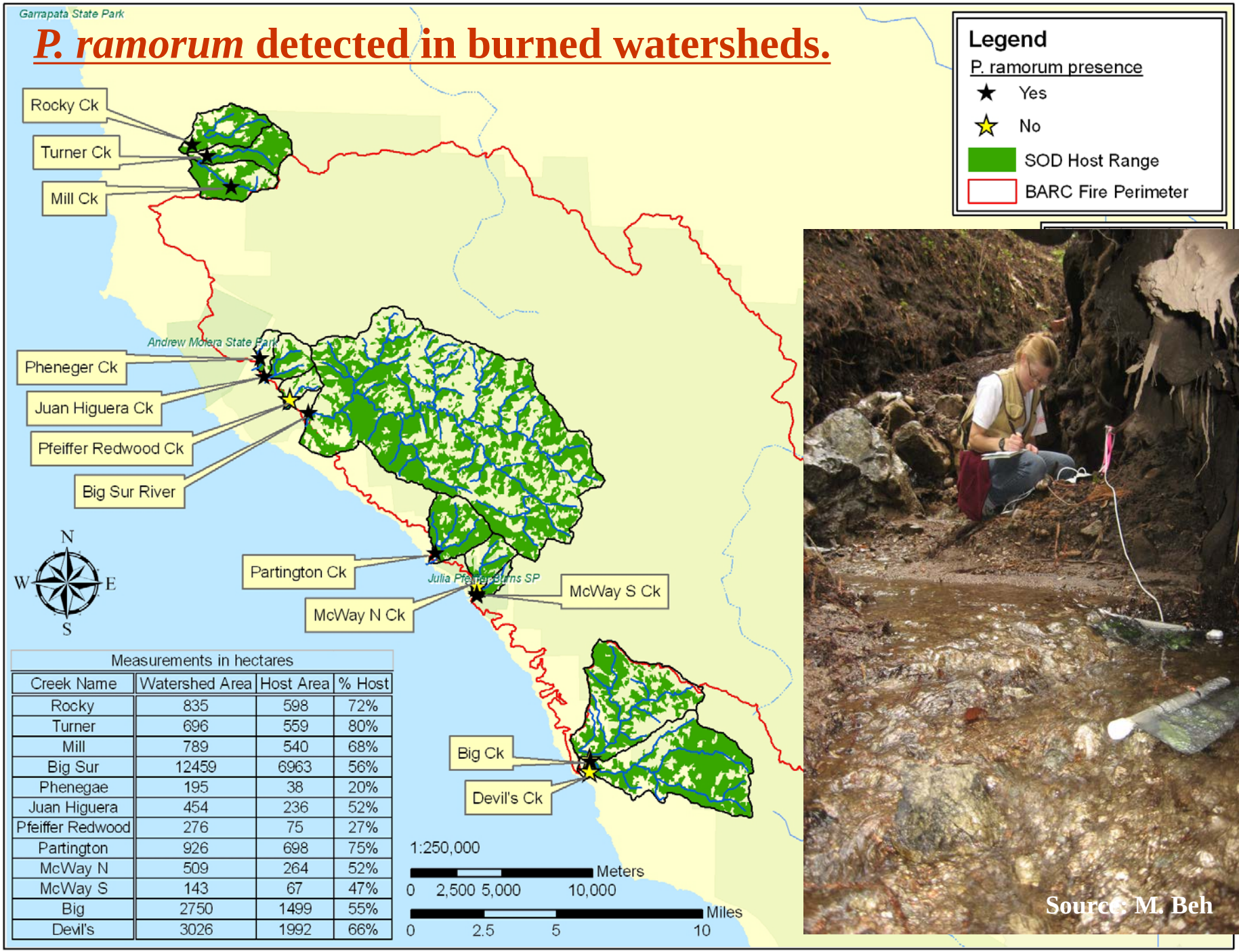


SOD make fires worse?

Early stage → canopy scorching.

Late stage → soil damage.

P. ramorum detected in burned watersheds.



Measurements in hectares

Creek Name	Watershed Area	Host Area	% Host
Rocky	835	598	72%
Turner	696	559	80%
Mill	789	540	68%
Big Sur	12459	6963	56%
Phenegae	195	38	20%
Juan Higuera	454	236	52%
Pfeiffer Redwood	276	75	27%
Partington	926	698	75%
McWay N	509	264	52%
McWay S	143	67	47%
Big	2750	1499	55%
Devil's	3026	1992	66%

Photo: Heather Mehl

P. ramorum recovered from heavily burned forest:

from Soil

& Basal Sprouts of

Tanoak & Bay Laurel

(all previously infested sites)

Combined effect of fire and SOD

- Mortality of medium sized redwoods

Effect of drought is significant reduction in populations of the pathogen on bay laurels (bay is reservoir of inoculum). Approximately only 5% carry infection: weak point in epidemiology

Final remarks

- SOD is an example of an environmental disaster due to poor regulation of a specific trade that is unrelated to forests

- In ornamental nurseries there are three distinct lineages of *P. ramorum*: with significant differences. Only 1 lineage is present in forests: it is essential to prevent further introductions in California

- Despite the limited dispersal ability the pathogen is solidly established mostly for two reasons: high infectivity and huge reproductive potential

- The pathogen is constrained by ecological factors: such as UV light , temperature and even related species that occupy the same niche (e.g bay laurel leaves)

- As of 2012, only 15% of the habitat favorable to *P. ramorum* has been occupied: we are only at the beginning of the epidemic. The example of Sudden Larch Death in the UK and Ireland shows the potential for unexpected outcomes

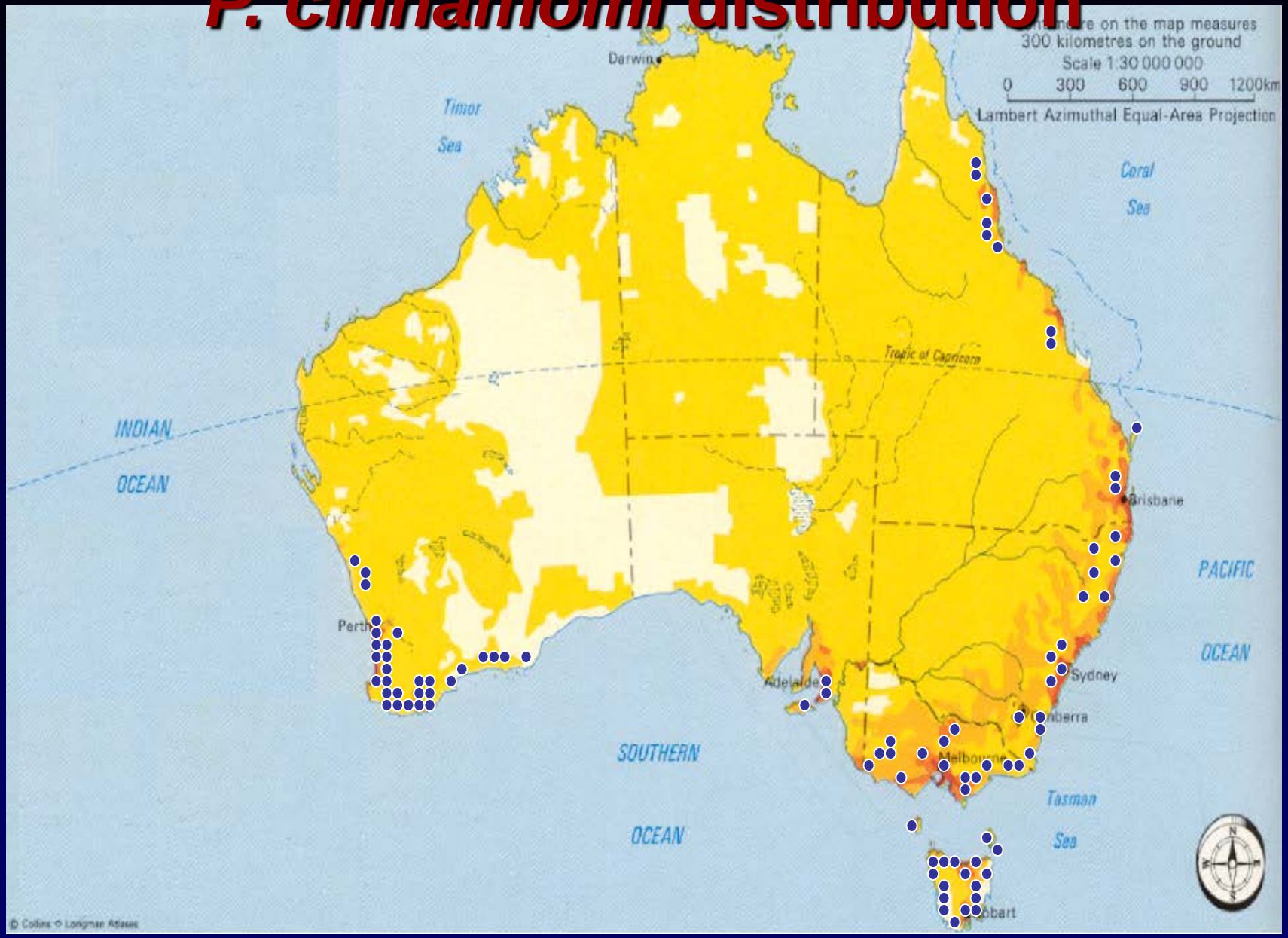
P. cinnamomi in Western Australia

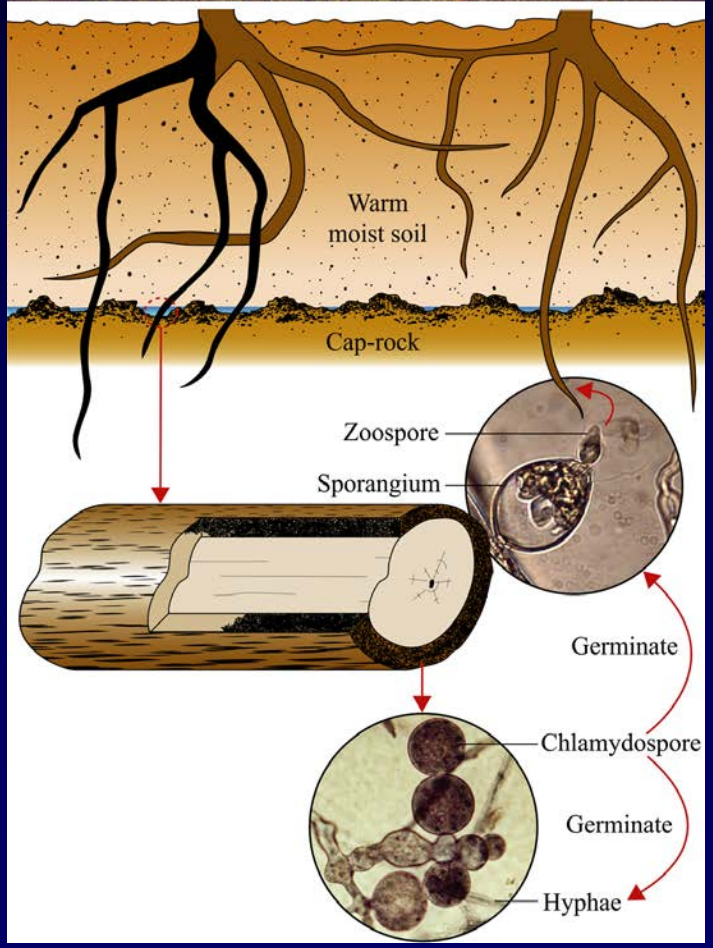
- Causes disease sometimes referred to as “jarrah dieback”
- 1921 first jarrah deaths; 1964 deaths shown to be caused by *P. cinnamomi*.
- Predominantly A2 mating type
- Three clonal lineages
- No sexual reproduction occurs

Impact Natural Ecosystems

- Between 8-9,000 plant species in south-west of Western Australia
- Approximately 2000 species are susceptible to *Phytophthora cinnamomi*
- Indirect effects of *P. cinnamomi* on plant and animal communities is unknown

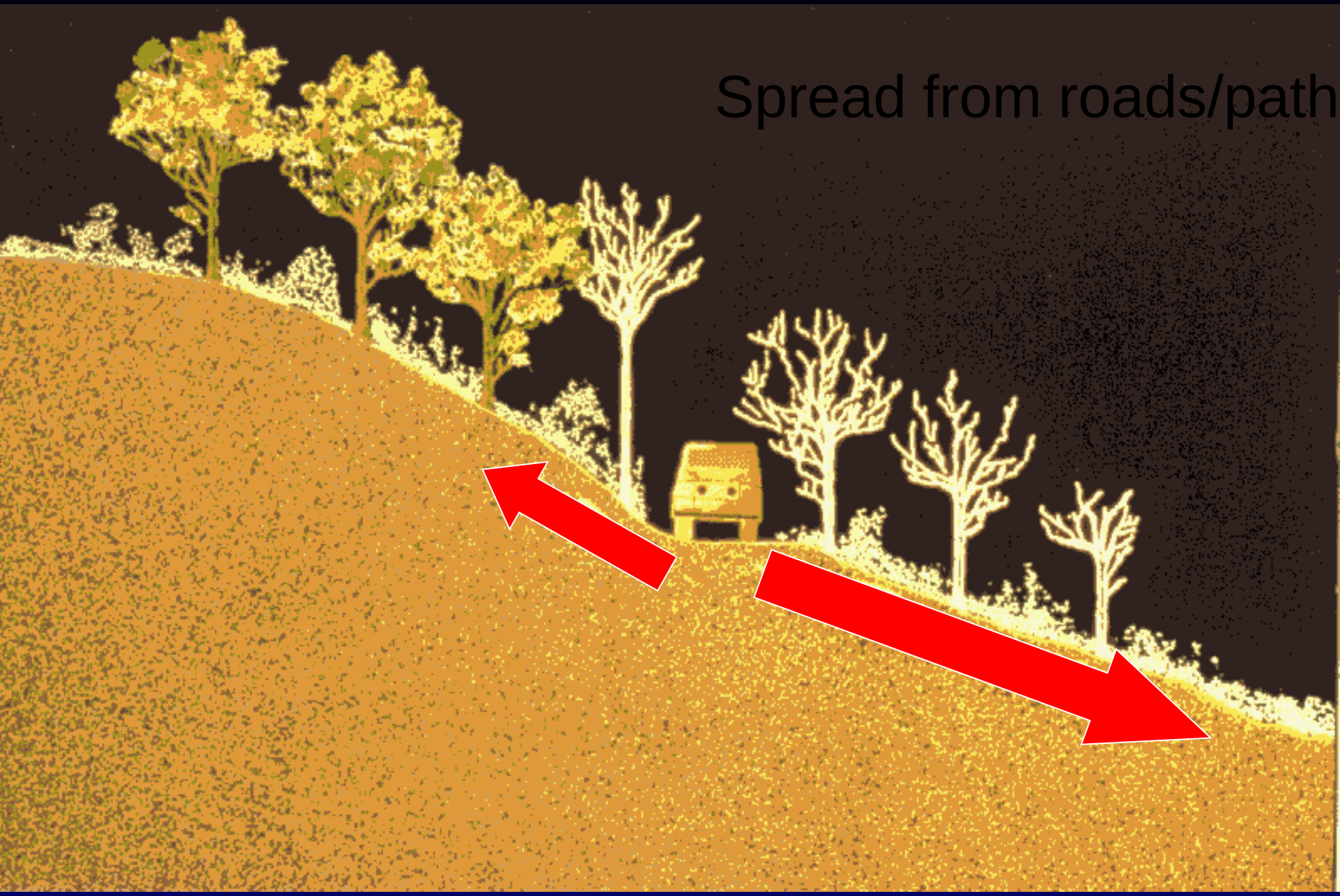
P. cinnamomi distribution




Warm
moist soil
Cap-rock
Zoospore
Sporangium
Germinate
Chlamydospore
Germinate
Hyphae

How is it spread?

- Natural – root contact, free draining water (warm & moist; spring, summer & early autumn)
- Artificial – transport of infested soil (tyres, road making)
  – hikers (boots, tent pegs & toilet trowels)
  – planting infected nursery stock

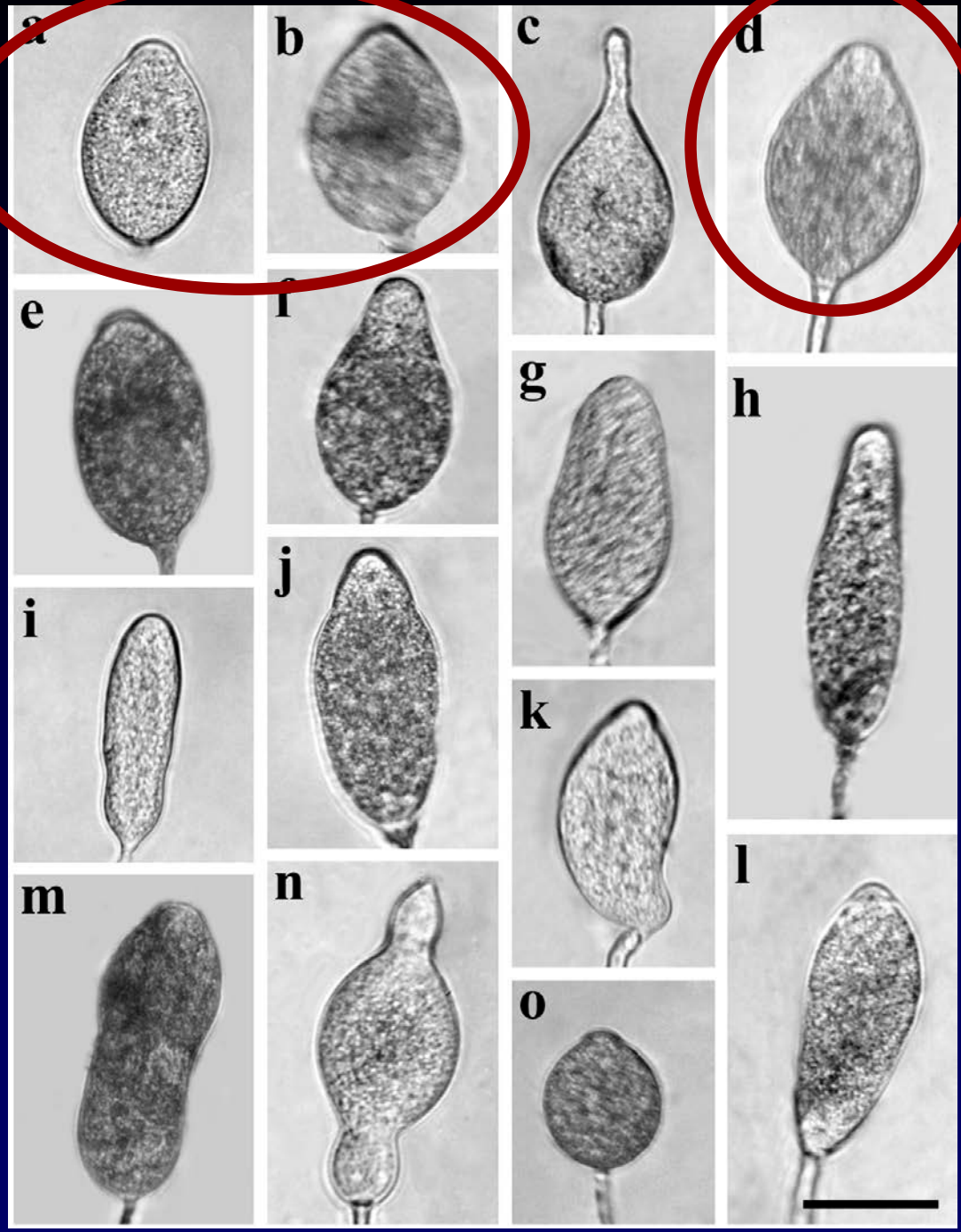

Spread from roads/path

Morphological phenotypes

- Sporangia
- Oospores
- Growth rates at different temperatures

- Significant differences even within a genotype

Typical
P. cinnamomi
sporangia



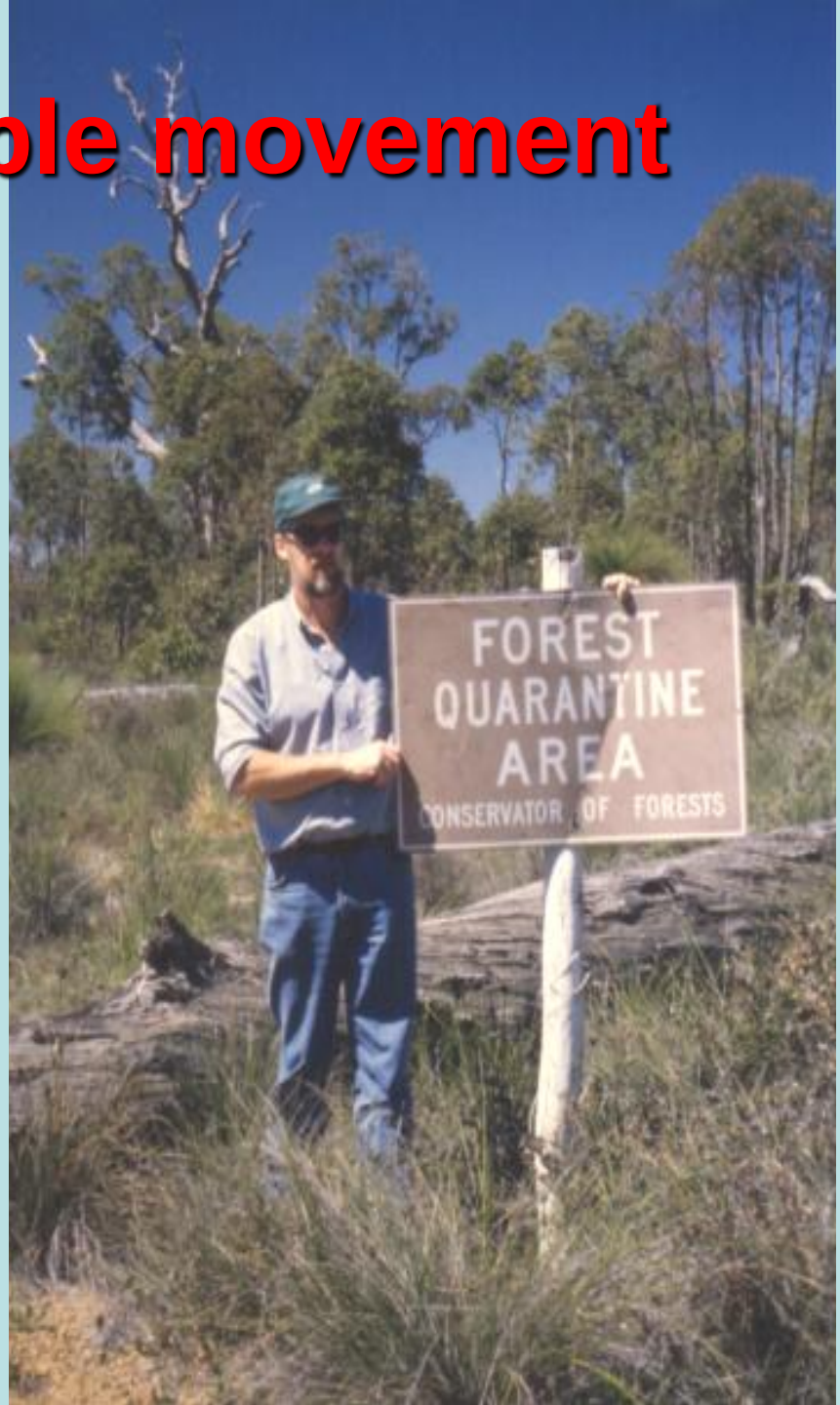
Within a *P. cinnamomi* lineage

There is substantial:

- Morphological diversity, and
- PATHOGENIC DIVERSITY

- We now may know why thanks to P. ramorum (have to come tomorrow)

2. people movement



3. Preventing water movement

4. Washing down vehicles & equipment

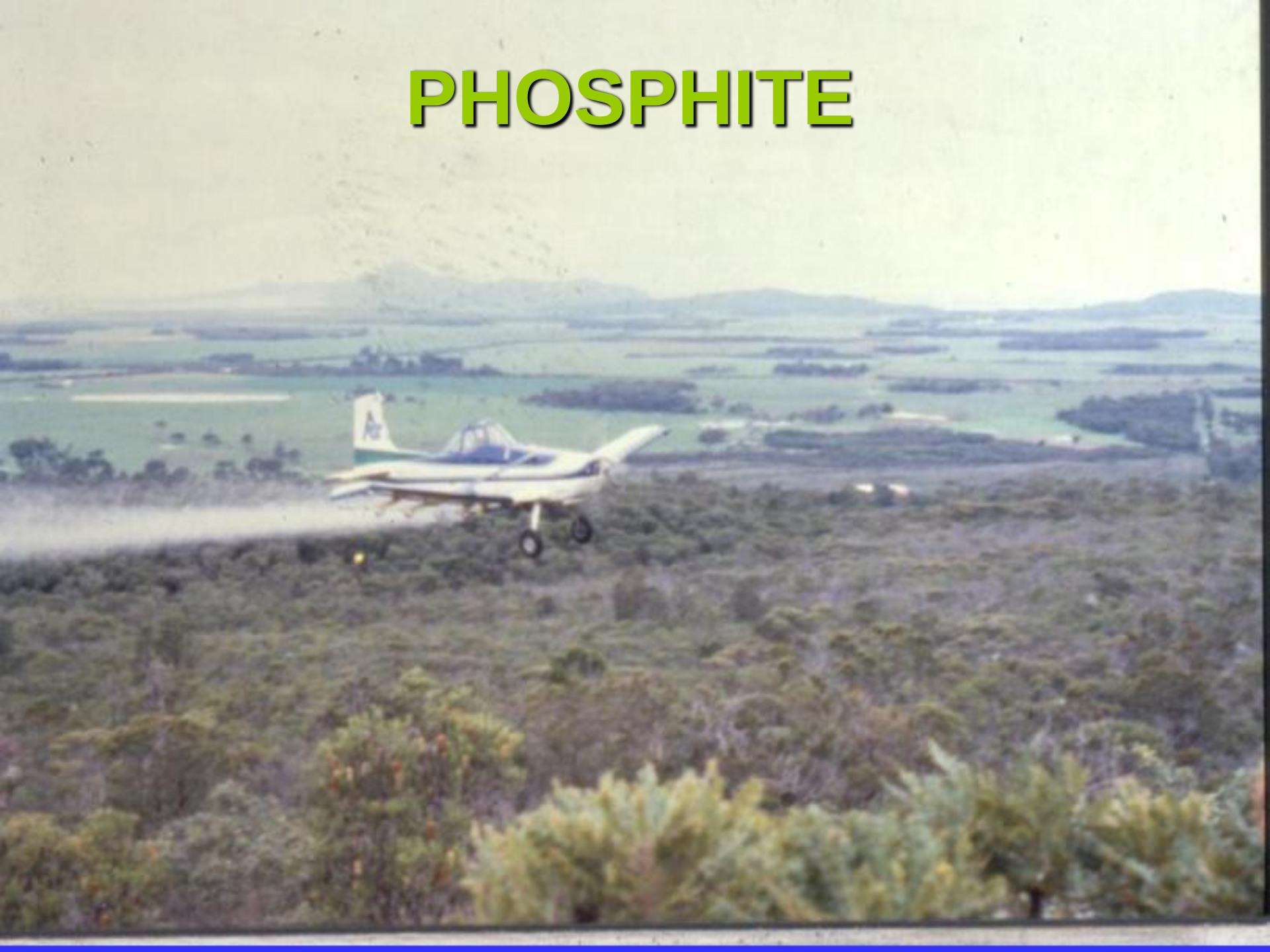
Importance of Hygiene/ Quarantine

- Isolates vary in capacity to cause disease
  - so do not want to move isolates in contaminated soil or infected plants between locations/regions/countries
    - WHY? To reduce chances of species mixing and opportunities for HYBRIDIZATION

Importance of Quarantine

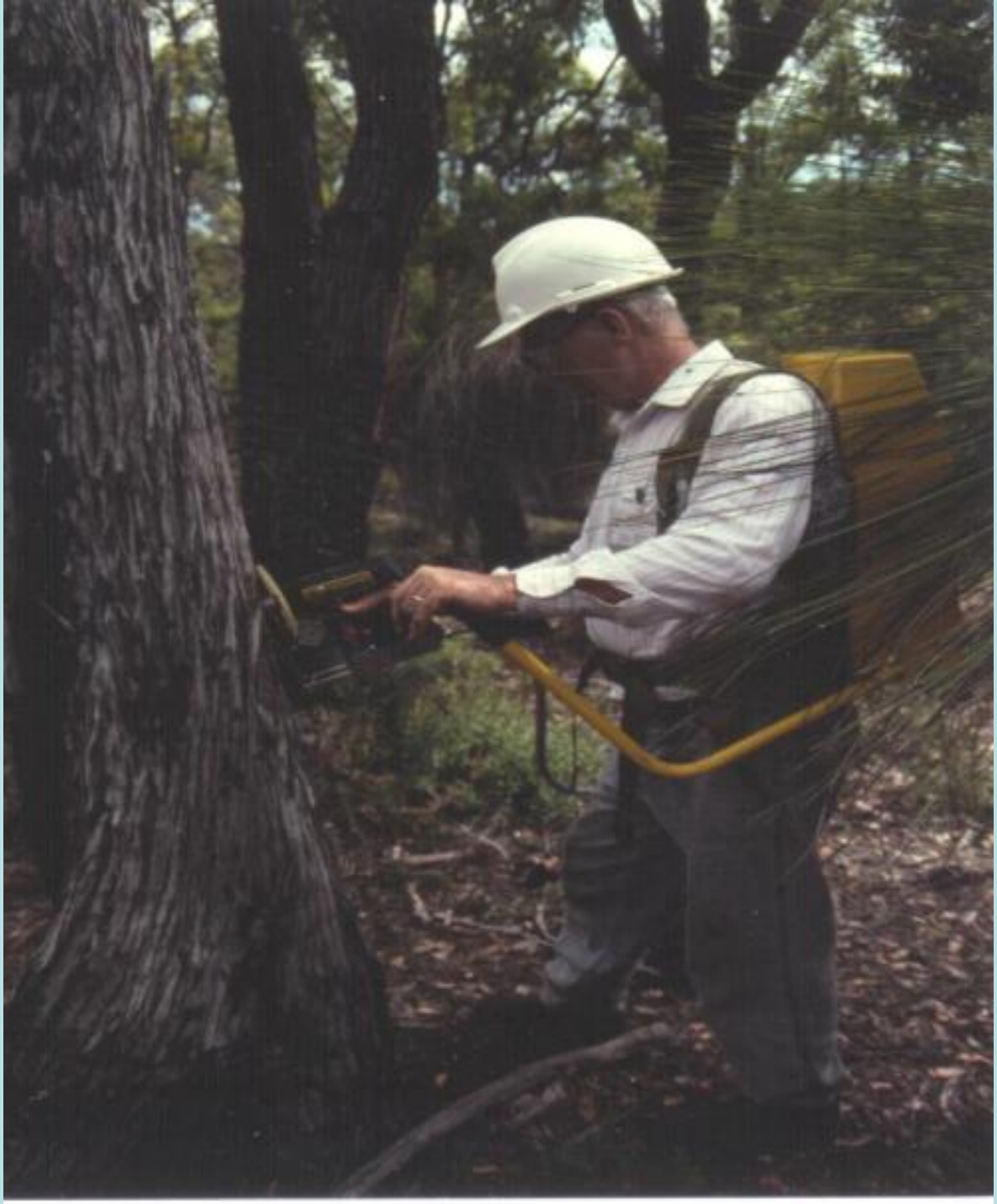
- What is disease-free material?
- False negatives using baiting and plating onto selective media
- Use of wetting and drying techniques can give recoveries in 2 of every 10 plants sampled

PHOSPHITE



Phosphite

- Unique fungicide as translocated in xylem and phloem
- Trunk injection, soil drench & foliar sprays
- Direct and indirect action *in planta*
- Controls many *Phytophthora* diseases



Effectiveness of Phosphite

- Phosphite contains, but does not stop colonization by *P. cinnamomi* in the majority of plant species (trunk injection can last for 6 years).
- It does not always stop sporulation and zoospore release from treated but infected plant material.

Potential adverse effects of phosphite

- Phytotoxicity
- Reduced plant reproductive capacity
- Production of phosphite tolerant strains of *P. cinnamomi* (?)

CONCLUSION

Disease control in natural plant communities must involve:-

- Quarantine and hygiene
- Phosphite

Oak root canker
(*Phytophthora cinnamomi*)

- **Species originally from PNG or Borneo, a common agricultural pathogen**
- **Soilborne, waterborne common in the wild in other parts of the US**
- **If host not extremely susceptible, predisposing factors needed for mortality to occur (e.g. oaks in Southern Europe)**
  - **Dry spell**
  - **Man-induced ecological alterations**

P. cinnamomi causes Littleleaf disease of pines on former-agricultural soils with hardpan in the Eastern US

Problem: Oak decline

Locations:

- Del Dios Area (Lake Hodges)
- County Parks
- Rural Areas

Oak Tree Survey at Del Dios

Results:

Of 474 *Quercus agrifolia* trees,
27% had bleeding cankers on the trunk.

Of 86 *Quercus engelmannii* trees,
none showed bleeding.

Pathogenicity Tests

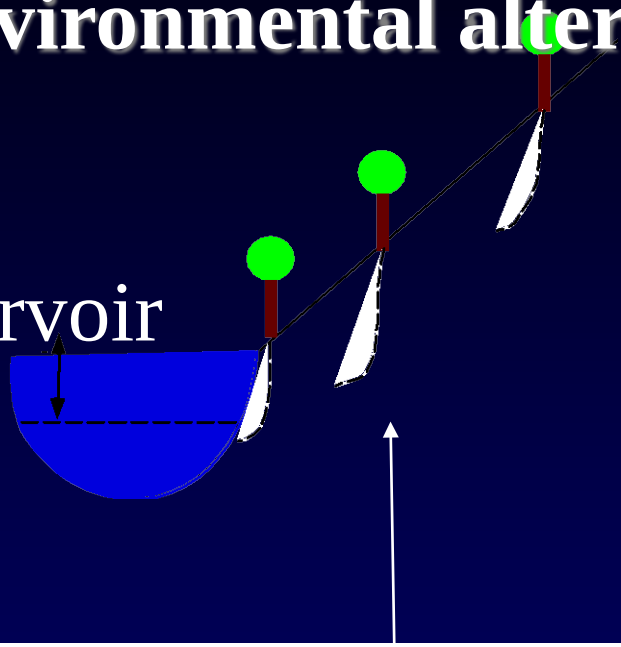
September Results:

Q. agrifolia	135 mm lesions
Q. engelmannii	49 mm lesions
Control	no lesions

Temperature: 21, 24, 18° C

Example of man-induced environmental alteration

Phytophthora cinnamomi
Introduced on
Coast Live Oak
San Diego Co.



Oaks at mid-slope experience fluctuations in the water table level: if infected by *P. cinnamomi* become extremely weak and attractive to insects

Ione manzanita: endangered species

Ione
Extremely harsh ecosystems, serpentine soild (very acidic, rich in Fe++), mining operations

Two major components of plant cover are manzanitas:

A. viscida (white manzanita)

A. myrtifolia (ione manzanita)

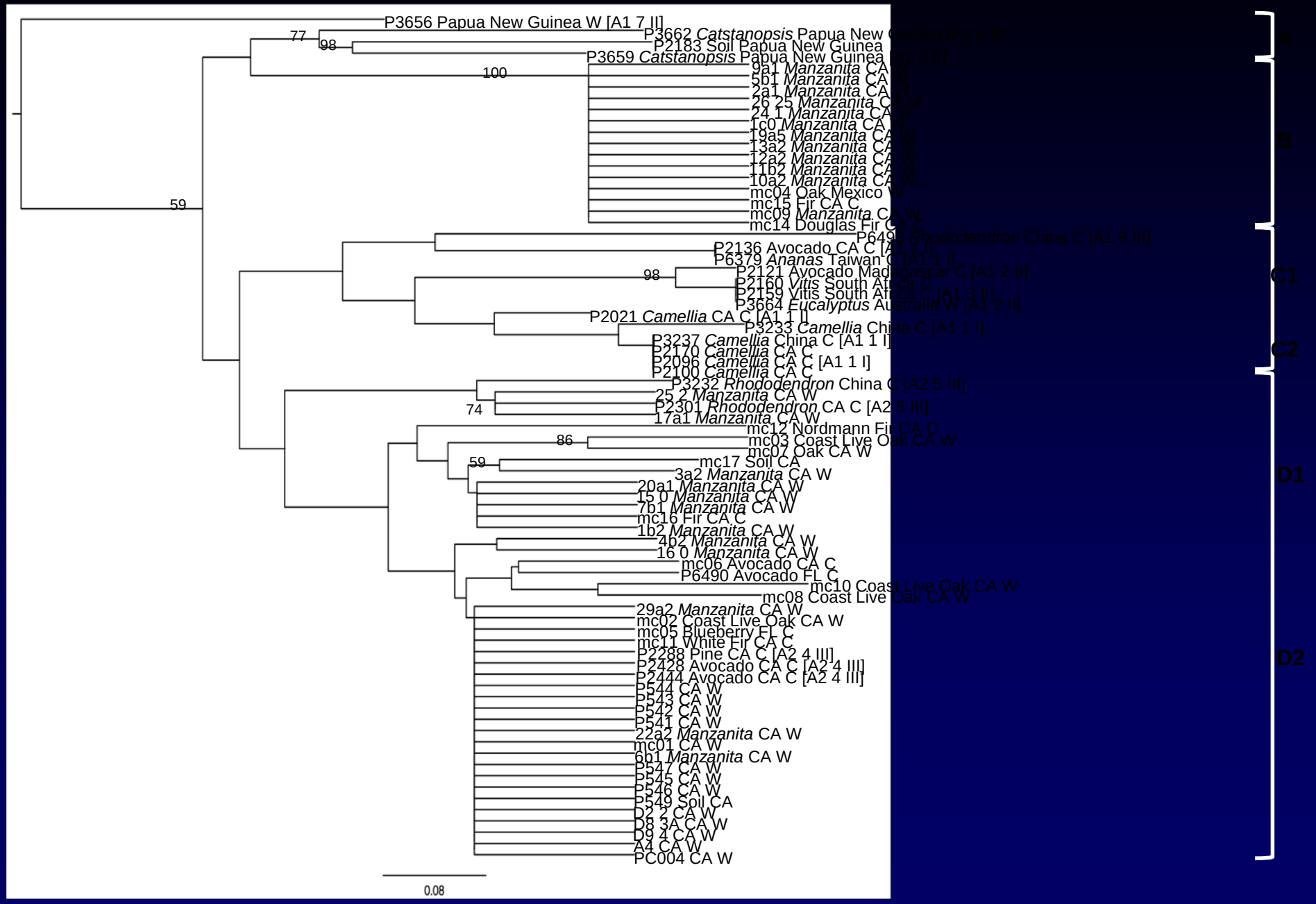
Ione manzanita is a rare endemic species of the Ione area, one that has well adapted to the local conditions, but it

Because of almost total susceptibility to soilborne *P. cinnamomi*

Genetic diversity of Pc in Ione is staggering, it includes all of the diversity present in California natural ecosystems

How can we explain this diversity?

- At least four introductions of four distinct strains
- Populations large enough that additional diversity generated locally (soil environment favorable to pathogen)
- One dominant strain is also present in Ca Christmas tree farms also matching a strain from a severe outbreak of oak mortality in Colima. This strain is novel


P3656 Papua New Guinea W [A1 7 II]
77
98
P3662 Catstanopsis Papua New Guinea [A1 6 II]
P2183 Soil Papua New Guinea
P3659 Catstanopsis Papua New Guinea [A1 6 II]
100
9a1 Manzanita CA W
5b1 Manzanita CA W
2a1 Manzanita CA W
26 25 Manzanita CA W
24 1 Manzanita CA W
1c0 Manzanita CA W
19a5 Manzanita CA W
13a2 Manzanita CA W
12a2 Manzanita CA W
11b2 Manzanita CA W
10a2 Manzanita CA W
mc04 Oak Mexico W
mc15 Fir CA C
mc09 Manzanita CA W
mc14 Douglas Fir CA C
59
P6498 Rhododendron China C [A1 8 III]
P2136 Avocado CA C [A1 1 I]
P6379 Ananas Taiwan C [A1 1 I]
98
P2121 Avocado Madagascar C [A1 2 II]
P2160 Vitis South Africa C
P2159 Vitis South Africa C [A1 3 III]
P3664 Eucalyptus Australia W [A1 2 II]
P2021 Camellia CA C [A1 1 I]
P3233 Camellia China C [A1 1 I]
P3237 Camellia China C [A1 1 I]
P2170 Camellia CA C
P2096 Camellia CA C [A1 1 I]
P2100 Camellia CA C
P3232 Rhododendron China C [A2 5 III]
25 2 Manzanita CA W
74
P2301 Rhododendron CA C [A2 5 III]
17a1 Manzanita CA W
mc12 Nordmann Fir CA C
86
mc03 Coast Live Oak CA W
mc07 Oak CA W
59
mc17 Soil CA
3a2 Manzanita CA W
20a1 Manzanita CA W
15 0 Manzanita CA W
7b1 Manzanita CA W
mc16 Fir CA C
1b2 Manzanita CA W
4b2 Manzanita CA W
16 0 Manzanita CA W
mc06 Avocado CA C
P6490 Avocado FL C
mc10 Coast Live Oak CA W
mc08 Coast Live Oak CA W
29a2 Manzanita CA W
mc02 Coast Live Oak CA W
mc05 Blueberry FL C
mc11 White Fir CA C
P2288 Pine CA C [A2 4 III]
P2428 Avocado CA C [A2 4 III]
P2444 Avocado CA C [A2 4 III]
P544 CA W
P543 CA W
P542 CA W
P541 CA W
22a2 Manzanita CA W
mc01 CA W
6b1 Manzanita CA W
P547 CA W
P545 CA W
P546 CA W
P549 Soil CA
D2 2 CA W
D8 3A CA W
D9 4 CA W
A4 CA W
PC004 CA W
0.08
A
B
C1
C2
D1
D2

Genetic structure of *P. cinnamomi* tells us

- Same genotypes found in distant part of the world but on same crop. Evidence of efficient long distance movement
- Genotypes in the wild match genotypes in different trades, suggesting different trades/industry responsible for the infestation of different areas
- One new genotype is extremely aggressive; should regulation be imposed for new strains?


PLANT DISEASE AREA
THE VEGETATION BEHIND THIS SIGN MAY CONTAIN
A PLANT DISEASE THAT IS EASILY SPREAD
THIS AREA CLOSED
TO ALL PUBLIC USE
FOR FURTHER INFORMATION CALL BLM: (916) 985-4474

Predisposing conditions

- Serpentine soils, with limited microbial activity (hence outbreaks often in mining areas)
- Alternation of wet and dry periods i.e. Mediterranean climates: infection occurs in wet periods but disease advances during dry months
- Hard pan with underground water table

And in the greater SF Bay Area

- *P. cinnamomi* associated with root infections and tree decline of California Bay laurels and Pacific madrones. Also threatening another manzanita, the pallid manzanita

- Normally in association with human disturbance (roads, landscaping, urban development etc) including estates with lush gardens

- Interesting genetic homogeneity of strains, mostly linked to ornamental plant industry

Where does *P. cinnamomi* come from?

- Avocado orchards once surrounded oak woodlands infected by *P. cinnamomi*
- Christmas tree farms are above the Ione manzanita range

Ornamental plants are everywhere

Hidden costs of activities on natural ecosystems

Once introduced, these organisms are almost impo
eradicate

Management options

- Avoid soil movement or movement of infected plants
- Eradicate most infectious hosts
- Use of composts: effect is both direct on pathogen, but more importantly indirect with plant roots
- Soil Fumigation and Solarization
- Phosphonates

Thousand canker disease of walnuts

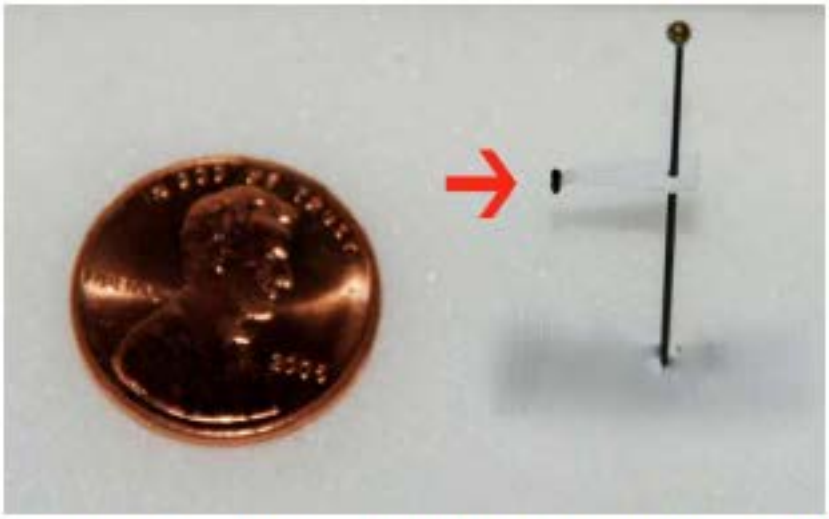
Geosmithia morbida: fungus

Pityophthorus juglandis: insect vector

Some facts about TCD

- Insect is native
- Fungus apparently is not native
- Association between insect and fungus happened in the Southwest (1990s?)
- Disease started in Southwest, moved to California, from California elsewhere in the USA
- Insect of the genus *Pityophthorus* normally attack small sized portions of trees, not this one
- Mortality is due to coalescence of large numbers of cankers, and not to spread of a single lesion
- Black walnuts are the only hosts: *J. californica*, *J. hindsii*, and their hybrids with *J. nigra (*are all susceptible

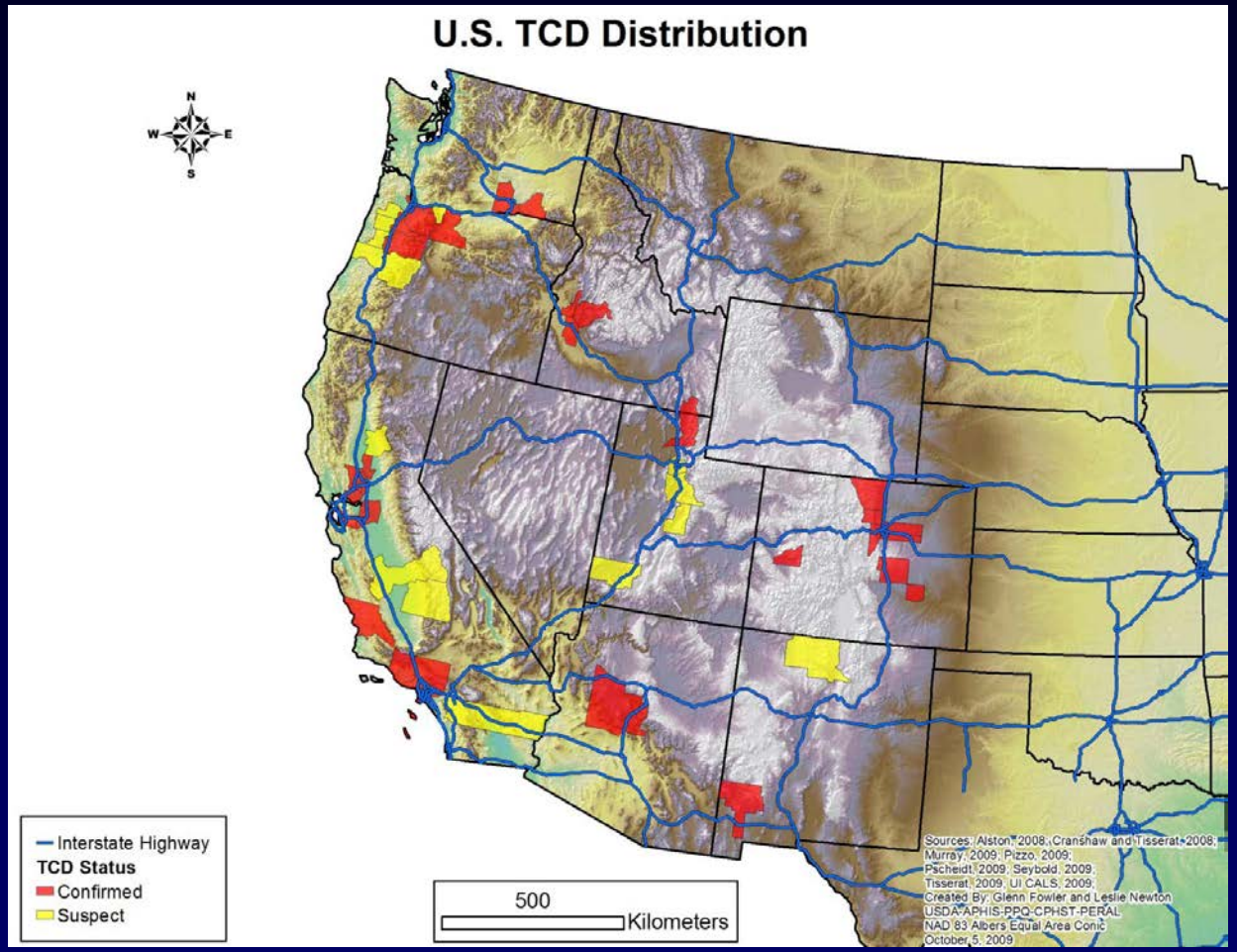
Walnut twig beetle



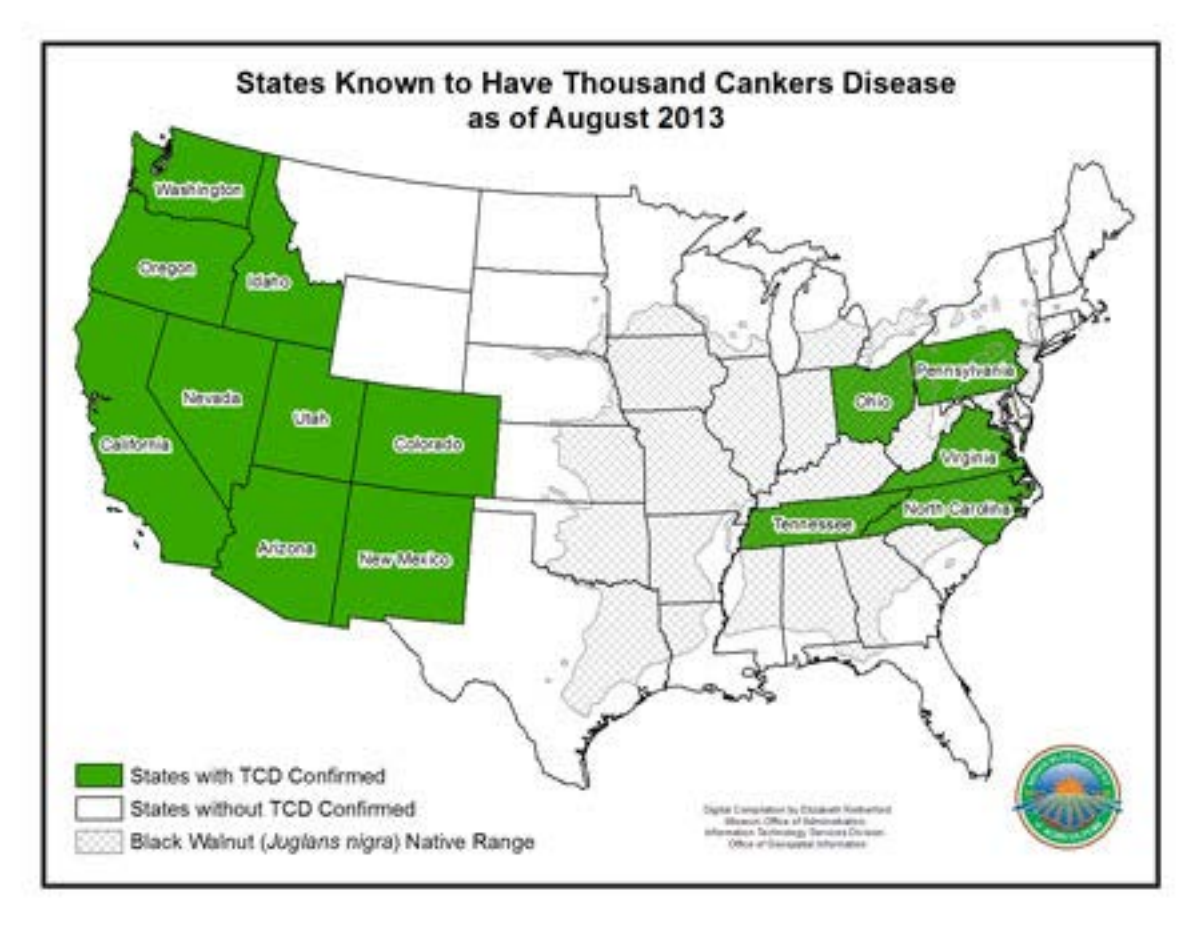
Small size of walnut twig beetle, Pityophthorus juglandis (photo by Eric Day).

The walnut twig beetle, Pityophthorus juglandis (*photo by Eric Day).*

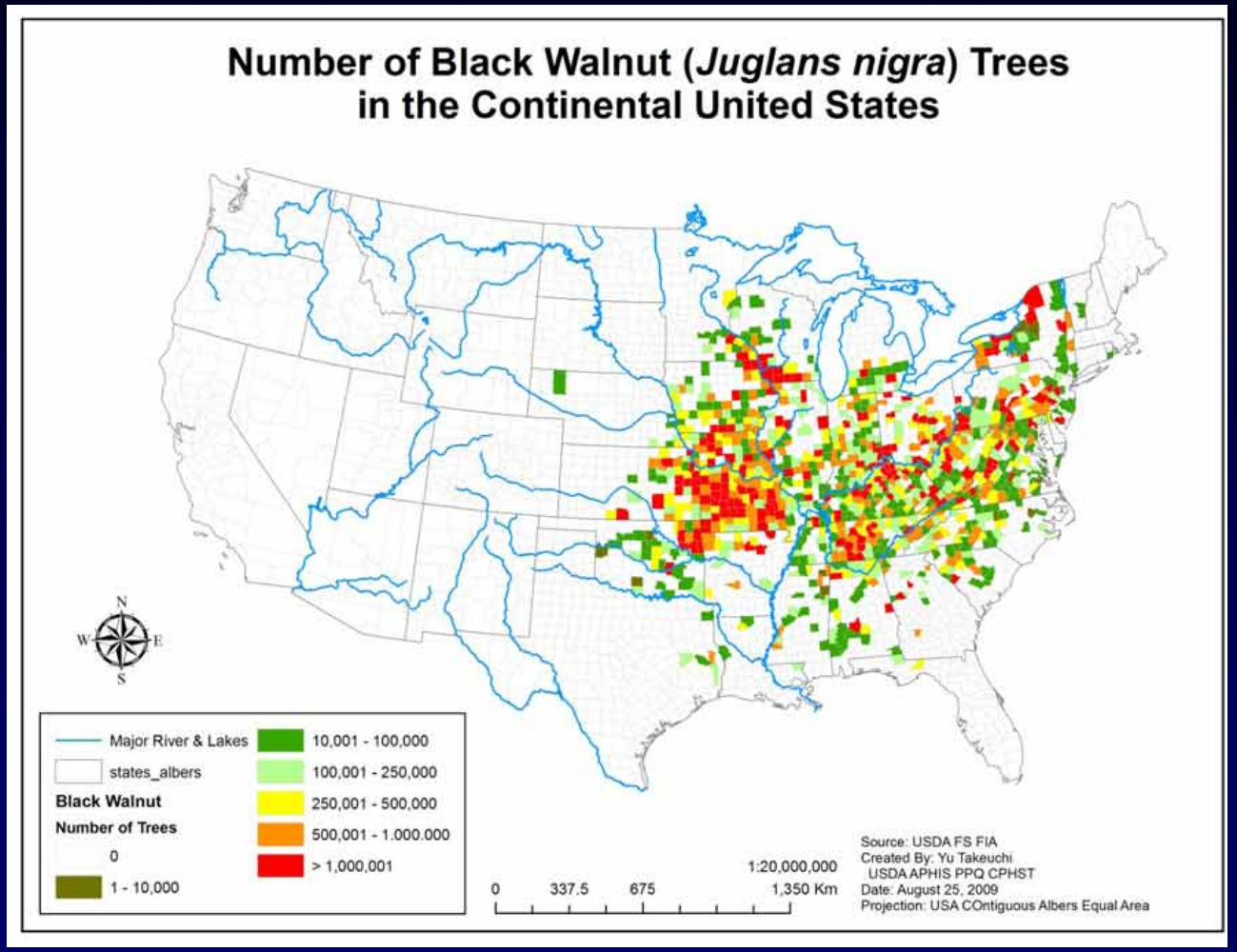
Distribution of TCD as of 2009



Distribution of TCD as of 2013



Distribution of Jn in Eastern US



Hypotheses on spread

- The most likely pathway for movement is raw wood (logs, burls, stumps, firewood, wood packaging material(WPM)). Other potential pathways include nursery stock, scion wood for grafting, and natural spread. The beetle/pathogen complex is likely to enter the east with each entrance event, as follows:

- Movement of untreated walnut (logs, burls, stumps, firewood) across the country from the west into eastern states appears limited but it does occur and it is rarely documented. Low grade walnut maybe utilized if bark is attached this could be an important pathway. Raw wood is the most critical pathway.

- Campsites and sawmills in the Great Plains states may facilitate the eastern movement of Thousand Canker Disease.

- To date there have been no reports of infected trees in walnut production nurseries; however, if nurseries do become infected, this could become an important pathway.

- Natural spread along riparian corridors is likely to occur.

Symptoms from a distance

- Early=flagging
  Late=dead canopy with

Close-up symptoms

Pinhead sized entry hole of beetle

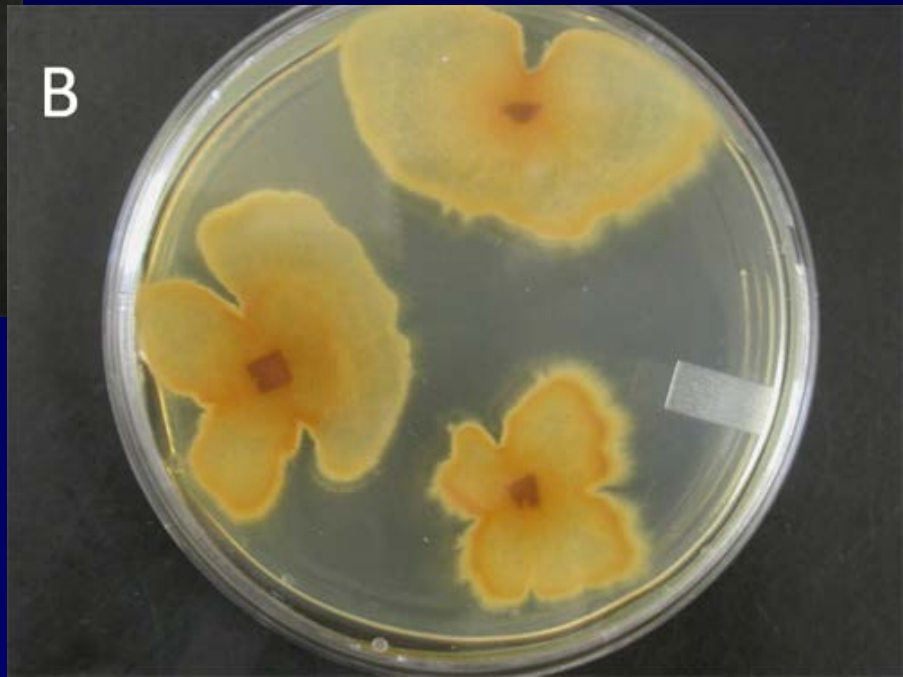
Close-up symptoms

Larvae tunnels produced along the grain, and so do the lesions

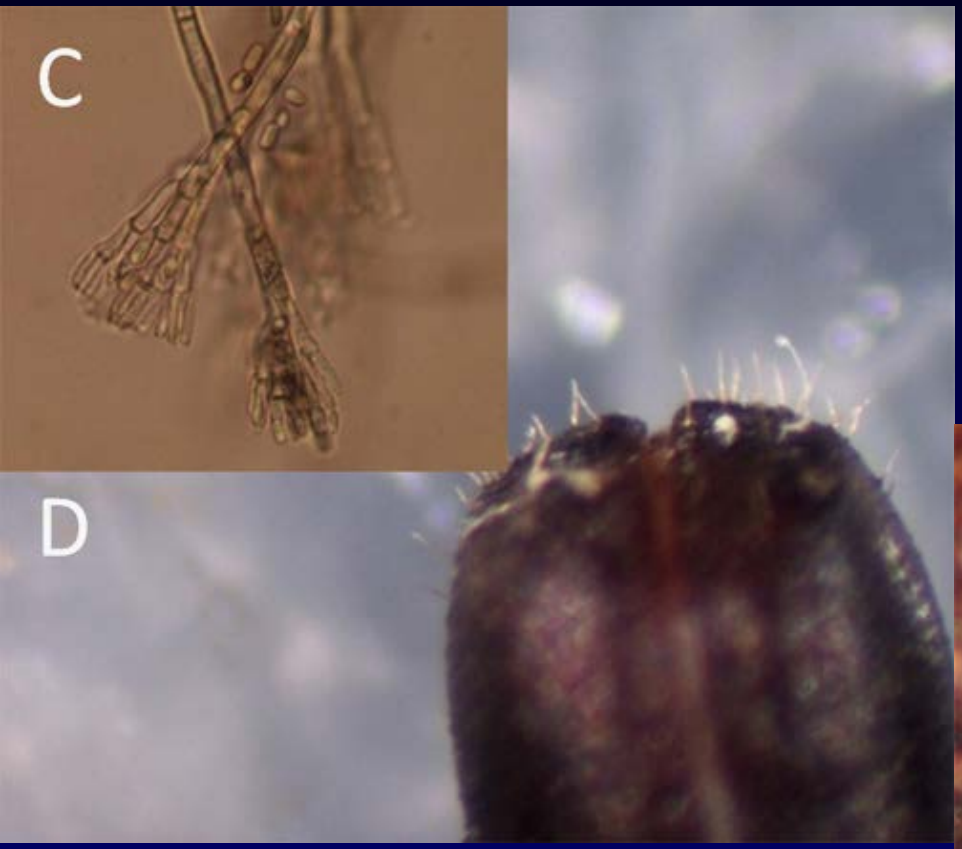
Close-up symptoms

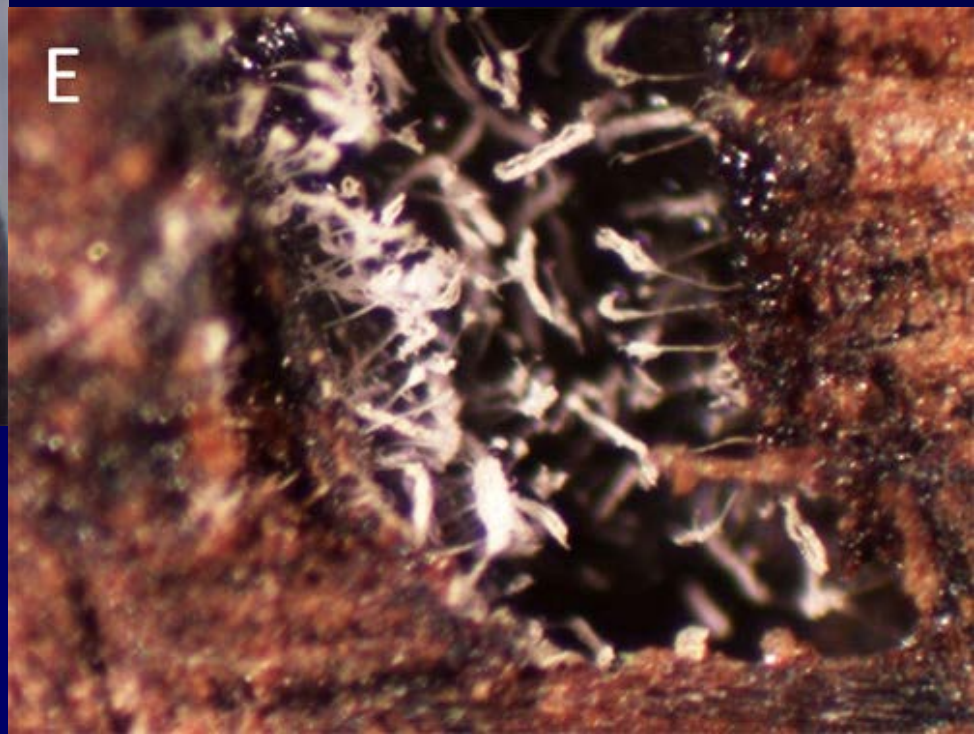
Mortality caused by coalescence of multiple cankers

Colonies of Gm on both sides



Fungus sporulating on beetle and in beetle gallery





WTB is believed to have 2 to 3 generations a year in California. Adults emerge for an initial flight period in April and May followed by a longer second generation flight period in mid-July to mid-September. After flying, male beetles initiate brood galleries on branches often near leaf scars or lenticels.

Males produce a pheromone and attract 2 to 3 females, which attract additional beetles to the tree. Females deposit eggs in galleries (tunnels) that are directed against the grain and constructed in the phloem and xylem (wood) surfaces. The gallery imprint is left on the wood surface. Small white C-shaped larvae hatch and create feeding mines that extend from the egg galleries. These mines are contained in the phloem and filled with dark brown to black-colored boring dust.

Larvae complete development in the mines and subsequently pupate within a single pupal cell. Adults emerge and either remain at the original tree or fly to other trees to mate and reproduce. WTB does not appear to be attracted to stressed or injured branches or trees.

Beetles are believed to inoculate the *Geosmithia* sp. fungus into the phloem during construction of feeding or reproductive galleries. The fungal pathogen colonizes and kills the phloem. Dead tissue is limited to the phloem and cambium and the fungus does not penetrate woody tissues. Secondary saprophytic fungi may opportunistically colonize the wood beneath cankers

Control?

- Bark application and drenches with insecticides apparently not effective
- Prevention is the best option
- Some efficacy reported with injections of insecticides, fungicides, and fertilizers

- What are the differences between aerial and soil-borne *Phytophthora* species?
- Reconstructing the genetic relationship of different strains of P. cinnamomi has helped us learn at least two important things. What are they?
- What are the three cases of *P. cinnamomi* outbreaks in California?
- How does 1000 canker disease spread and how can one control it?